Relationship Between Cardiovascular Health Metrics and Risk Profile, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters

JARON RAS

Student Number: 3405618

A thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy (Sport and Exercise Science)

At the

Department of Sport, Recreation and Exercise Science

Faculty of Community and Health Sciences

Supervisor:	Professor Lloyd Leach
Co-supervisors:	Professor Andre P. Kengne
	Professor Denise L. Smith
	Professor Elpidoforos S. Soteriades

1 September 2023

http://etd.uwc.ac.za/

Relationship Between Cardiovascular Health Metrics and Risk Profile, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters

THESIS FOR DOCTORAL DEGREE (PhD)

By

Jaron Ras

Principle Supervisor

Professor Lloyd Leach

University of the Western Cape

Department of Sport, Recreation and Exercise Science

Co-supervisors

Professor Andre P. Kengne

South African Medical Research Council

Non-communicable Diseases Research Unit

Professor Denise L. Smith

Skidmore College

Health and Human Physiological Sciences

Professor Elpidoforos S. Soteriades

Open University of Cyprus

Healthcare Management Program

School of Economics and Management

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

ABSTRACT

Introduction: Firefighting is a hazardous occupation that involves firefighters risking their lives in life-threatening situations, where they are exposed to severe temperatures, hazardous chemicals and fumes, placing tremendous strain on the cardiovascular and musculoskeletal systems. These working conditions necessitate that firefighters remain in optimal physical condition to maintain adequate cardiovascular and musculoskeletal health in order to manage these stressors. Moreover, physical fitness, cardiovascular and musculoskeletal health were significantly related to occupational performance in firefighters. However, this relationship has not been extensively investigated, particularly in South Africa.

Aim: The aim of the study was to assess the relationship between cardiovascular health metrics and risk profile, musculoskeletal health, physical fitness, and occupational performance in firefighters.

Methods: This study was conducted in two phases. In ***Phase I***, a thorough narrative literature review and two systematic reviews, with meta-analyses, were conducted to determine the effect of cardiovascular and musculoskeletal health and physical fitness on occupational performance in firefighters. In ***Phase II***, which took place at a standardized fire station located in the City of Cape Town Metropolitan area. Physical measurements were taken to obtain data on firefighters' cardiovascular disease risk factors, cardiovascular health metrics, physical fitness and physical ability test. Two previously validated questionnaires were used to obtain data on firefighters' lifestyle habits, such as physical activity, diet, cigarette smoking and musculoskeletal health.

Results: The literature reviews revealed the following (i) firefighters who were aged, obese, physically inactive, cigarette smokers and unfit, with musculoskeletal discomfort were at the

http://etd.uwc.ac.za/

highest risk of cardiovascular and musculoskeletal health disorders, and unsatisfactory occupational performance; (ii) Age had a moderate effect on occupational performance ($Z = 5.15$, $p<0.001$), whereas gender had a large effect size on occupational performance ($Z=4.24$, $p<0.001$). (iii) A moderate negative correlation was found between cardiorespiratory fitness and occupational performance ($r = -0.584$, $p<0.001$). Significant low negative correlations were found between upper body endurance ($r = -0.344$, $p < 0.001$), abdominal endurance ($r = -0.308$, $p<0.001$), grip strength ($r = -0.421$, $p<0.001$), upper body strength ($r = -0.318$, $p<0.001$), and lower body strength ($r = -0.216$, $p = 0.020$) and OP; (iv) A moderate effect for cardiorespiratory fitness level on systolic blood pressure ($Z = 5.94$, $p<0.001$), diastolic blood pressure ($Z = 2.45$, $p<0.001$), total cholesterol ($Z = 3.80$, $p<0.001$), low-density lipoprotein cholesterol ($Z = 4.44$, $p<0.001$), triglycerides ($Z = 3.76$, $p<0.001$) and blood glucose concentration ($Z = 4.78$, $p<0.001$).

The results from the cross-sectional study indicated that age, body mass index, body fat percentage, diastolic blood pressure, total cholesterol and Framingham cardiovascular risk score increased the odds of reporting musculoskeletal injuries (MSIs) ($p<0.05$). Musculoskeletal discomfort was associated with total cholesterol and low-density lipoprotein ($p<0.05$). The results indicated that cardiorespiratory fitness, muscular strength and muscular endurance were significantly associated with a better overall cardiovascular health profile ($p<0.01$). Higher levels of physical fitness were associated with lower musculoskeletal injuries, however, increased the feeling of musculoskeletal discomfort in firefighters ($p<0.05$). Age, lean body mass, body fat percentage, absolute oxygen consumption (ab$\dot{V}O_{2max}$), grip strength, leg strength, push-ups and sit-ups capacity, weekly metabolic equivalent minutes and heart rate variability were associated with physical ability test completion times ($p<0.01$).

Conclusion: Adverse cardiovascular disease risk profile was associated with musculoskeletal injuries and musculoskeletal discomfort, while cardiorespiratory fitness, muscular strength and

http://etd.uwc.ac.za/

muscular endurance were significantly associated with a better overall cardiovascular health (CVH) profile. In addition, higher physical fitness was associated with lower MSIs and MSD. Younger, non-obese, fitter and stronger firefighters, with a better CVH status, performed significantly better and were most likely to pass the physical ability test. It is recommended that firefighters should maintain high levels of physical fitness and a good level of cardiovascular health and musculoskeletal health to ensure a satisfactory level of occupational performance and overall personal well-being.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

DECLARATION

I, **Jaron Ras**, hereby declare that ***"Relationship Between Cardiovascular Health Metrics and Risk Profile, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters"*** is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full name: **Jaron Ras** Date: **1 September 2023**

Signature:

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

DEDICATION

This thesis is dedicated to my fiancé Tammy Hartel, thank you for your continuous support, sacrifices and for always motivating me to give one hundred percent towards my studies. To my parents, Jerome Christian Ras and Verena Michelle Ras and all my family members, thank you for your unconditional love and support.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

KEYWORDS

Africa

City of Cape Town

Body Composition

Cardiovascular Disease Risk Factors

Cardiorespiratory Fitness

Cardiovascular Health

Firefighting

Flexibility

Meta-analysis

Musculoskeletal Discomfort

Musculoskeletal Health

Musculoskeletal Injury

Muscular strength and endurance

Narrative Review

Physical Ability Test

Physical Fitness

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Occupational Health

Occupational Performance

Systematic Review

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

LIST OF ABBREVIATION AND ACRONYMS

AHA	=	American heart association
ASCVD	=	atherosclerotic cardiovascular disease
BA	=	breathing apparatus
BMI	=	body mass index
CoCTFRS	=	City of Cape Town Fire and Rescue Service
CAD	=	coronary artery disease
CVD	=	cardiovascular disease
CVH	=	cardiovascular health
CVHI	=	cardiovascular health index
DBP	=	diastolic blood pressure
HC	=	hip circumference
HF	=	high frequency
HDL-C	=	high-density lipoproteins cholesterol
HRV	=	heart rate variability
IPAQ	=	international physical activity questionnaire
LBM	=	lean body mass
LDL-C	=	low-density lipoproteins cholesterol
LF	=	low frequency
LoBMSD	=	lower back musculoskeletal discomfort
LoBMSI	=	lower back musculoskeletal injury
LF/HF	=	low frequency/high frequency ratio
MET	=	metabolic equivalent

UNIVERSITY of the
WESTERN CAPE
http://etd.uwc.ac.za/

MSD	=	musculoskeletal discomfort
MSH	=	musculoskeletal health
MSI	=	musculoskeletal injury
NFBG	=	non-fasting blood glucose
PAT	=	physical ability test
PPE	=	personal protective equipment
SBP	=	systolic blood pressure
SCD	=	sudden cardiac death
SDNN	=	standard deviation of normal-to-normal heartbeats
RMSSD	=	root mean square of successive differences between normal heartbeats
TC	=	total cholesterol
UBMSD	=	upper body musculoskeletal discomfort
UBMSI	=	upper body musculoskeletal injury
$\dot{V}O_2$	=	volume of oxygen consumed per minute
$\dot{V}O_{2max}$	=	maximal volume of oxygen consumed per minute
WC	=	waist circumference
WHR	=	waist-to-hip ratio

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

UNITS OF MEASUREMENT

BF%	=	body fat percentage
cm	=	centimetres
kg	=	kilogram
kgf	=	kilogram force
$kg \bullet m^{-2}$	=	kilograms per square metre
$L \bullet min^{-1}$	=	liters per minute
m	=	metre
min	=	minutes
$mL \bullet kg^{-1} \bullet min^{-1}$	=	milliliters per kilogram per minute
mm	=	millimetres
$mmol \bullet L^{-1}$	=	millimoles per litre
mm Hg	=	millimetres of mercury
rpm	=	repetitions per minute

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

STATISTICAL SYMBOLS AND ABBREVIATIONS

%	=	percentage
ANOVA	=	analysis of variance
ANCOVA	=	analysis of covariance
B	=	unstandardized beta coefficient
β	=	standardized beta coefficient
CI	=	confidence interval
H	=	Kruskal-Wallis H
I^2	=	I squared value
MD	=	mean difference
MANCOVA	=	multivariate analysis of covariance
OR	=	odds ratio
p	=	probability
$p25^{th}$	=	25^{th} percentile
$p75^{th}$	=	75^{th} percentile
r	=	correlation coefficient
R^2	=	correlation coefficient squared
SD	=	standard deviation
SMD	=	standardized mean difference
SE	=	standard error
U	=	Mann-Whitney U
VIF	=	variance inflation factor
ω^2	=	Wald test statistic

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

$\bar{x}$	=	mean
$\tilde{X}$	=	median
χ^2	=	Chi-Square
Z	=	Z score

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

ACKNOWLEDGEMENTS

To the Almighty. Thank you for always being there for me, always guiding me, never leaving me and always loving me.

I would like to express my sincere appreciation to my supervisors, Professor Lloyd Leach, Professor Andre Pascal Kengne, Professor Denise Smith and Professor Elpidoforos Soteriades for their incredible supervision, mentorship, encouragement and constructive criticims during this PhD journey. Thank you for always pushing me to my full potential and for always encouraging me and believing in me. I will treasure everything you have taught me.

To the City of Cape Town for allowing me to conduct my study, and to Mr Ian Bell for supporting the study from the start to the end.

To each District Head and Station Commander who allowed me to do my testing, and to every firefighter who voluntarily participated in the study.

To the National Research Foundation, thank you for supporting me financially in order to study further and to follow my dreams. And to the Ryoichi Sasakawa Young Leaders Fellowship Fund (SYLFF), thank you for awarding me the fellowship and believing in my abilities as a researcher and young leader.

To the department of Sport, Recreation and Exercise Science, University of the Western Cape, thank you for making my PhD experience a pleasant one and a great learning experience.

To the Honours students and research team who assisted me with data collection, data capturing and data cleaning.

http://etd.uwc.ac.za/

TABLE OF CONTENTS

http://etd.uwc.ac.za/

http://etd.uwc.ac.za/

http://etd.uwc.ac.za/

http://etd.uwc.ac.za/

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

LIST OF APPENDICES

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

LIST OF TABLES

http://etd.uwc.ac.za/

http://etd.uwc.ac.za/

CHAPTER NINE

CHAPTER TEN

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

CHAPTER ELEVEN

CHAPTER TWELVE

http://etd.uwc.ac.za/

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

LIST OF FIGURES

http://etd.uwc.ac.za/

CHAPTER SIX

CHAPTER THIRTEEN:

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

PREFACE

This thesis is written in publication format. The roles of the PhD candidate in the study is outlined below:

Phase I

This was considered the literature review phase. In this phase, a narrative review, a systematic review protocol, two systematic reviews and a book chapter was compiled and published in peer-reviewed journals. The candidate designed the studies, developed the protocol, conducted the literature searchers, performed the data collection and curation, data analysis and interpretation of the results. In addition, the candidate was the first author in each of the publications from chapters two to six.

Phase II

This involved the collection of physical ability test (PAT) data, physical fitness data, cardiovascular health data and musculoskeletal health data. The candidate conceptualized this phase of the study, collected the research data, collated, curated, cleaned and coded the data, conducted the literature searches, performed the data analysis and interpretation of the results. In addition, the candidate was the first author in the publications in chapters seven to thirteen.

Examiners notes: Each manuscript is written and formatted according to the journal guidelines, language preferences, abbreviations and formula requirements. **Chapter Six** was a original research article published during the PhD canditure from a previous project that provided preliminary data informing the current study.

http://etd.uwc.ac.za/

LIST OF PAPERS PUBLISHED DURING PHD CANDIDATURE

1. **Ras J**, Smith DL, Kengne AP, Soteriades E, Leach L. Cardiovascular Disease Risk Factors, Musculoskeletal Health, Physical Fitness, and Occupational Performance in Firefighters: A Narrative Review. Journal of Environmental and Public Health.2022. https://doi.org/10.1155/2022/7346408
2. **Ras J**, Kengne AP, Smith D, Soteriades ES, Leach L. Effects of cardiovascular health, musculoskeletal health and physical fitness on occupational performance of firefighters: protocol for a systematic review and meta-analysis. BMJ open. 2022 Jul 1;12(7):e061435. http://dx.doi.org/10.1136/bmjopen-2022-061435
3. **Ras J**, Kengne AP, Smith DL, Soteriades ES, November RV, Leach L. Effects of Cardiovascular Disease Risk Factors, Musculoskeletal Health, and Physical Fitness on Occupational Performance in Firefighters—A Systematic Review and Meta-Analysis. International Journal of Environmental Research and Public Health. 2022 Sep 21;19(19):11946. https://doi.org/10.3390/ijerph191911946
4. **Ras J**, Kengne AP, Smith DL, Soteriades ES, Leach L. Association between Cardiovascular Disease Risk Factors and Cardiorespiratory Fitness in Firefighters: A Systematic Review and Meta-Analysis. International Journal of Environmental Research and Public Health. 2023 Feb 5;20(4):2816. https://doi.org/10.3390/ijerph20042816
5. **Ras, J**. and Leach, L. (2022). Relationship Between Physical Activity, Coronary Artery Disease Risk Factors and Musculoskeletal Injuries in the City of Cape Town Fire and

http://etd.uwc.ac.za/

Rescue Service. *INQUIRY: The Journal of Health Care Organization, Provision, and Financing*, *59*, 00469580221084485. https://doi.org/10.1177/00469580221084485

6. **Ras J**, Smith DL, Soteriades ES, Kengne AP, Leach L. A Pilot Study on the Relationship Between Cardiovascular Health, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters. European Journal of Investigation in Health, Psychology and Education. 2022 Nov;12(11):1703-18. https://doi.org/10.3390/ejihpe12110120
7. **Ras, J.**, Soteriades, E. S., Smith, D. L., Kengne, A. P., & Leach, L. (2023). Association between Cardiovascular and Musculoskeletal Health in Firefighters. *Journal of Occupational and Environmental Medicine*, 10-1097. 10.1097/JOM.0000000000002872. https://journals.lww.com/joem/toc/2023/07000
8. **Ras, J.**; Smith, D.L.; Soteriades, E.S.; Kengne, A.P.; Leach, L. Association between Physical Fitness and Cardiovascular Health in Firefighters. *Int. J. Environ. Res. Public Health* **2023**, *20*, 5930. https://doi.org/10.3390/ijerph20115930
9. **Ras, J.**, Soteriades, E. S., Smith, D. L., Kengne, A. P., & Leach, L. Association between Physical Fitness and Musculoskeletal Health in Firefighters. *Frontiers in Physiology*, *14*, 1210107. doi: 10.3389/fphys.2023.1210107
10. **Ras, J.**; Smith, D.L.; Soteriades, E.S.; Kengne, A.P.; Leach, L. (2023). Physical Fitness, Cardiovascular and Musculoskeletal Health in Firefighters. *Frontiers in Public Health*. 11:1241250. https://doi.org/10.3389/fpubh.2023.1241250
11. **Ras, J.**, Soteriades, E. S., Smith, D. L., Kengne, A. P., & Leach, L. (2023). Physical Fitness, Cardiovascular and Musculoskeletal Health and Task Performance in Firefighters. *BMC Public Health*. Accepted for Publication.

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

12. **Ras J**, Leach L. Use of Mobile Technology in Assessing Occupational Performance and Stress in Firefighters. Handbook of Research on New Media, Training, and Skill Development for the Modern Workforce 2022 (pp. 150-186). IGI Global.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

LIST OF ADDITIONAL PAPERS PUBLISHED DURING PHD CANDIDATURE

1. **Ras J**, Leach L. Prevalence of Coronary Artery Disease Risk Factors in Firefighters in the City of Cape Town Fire and Rescue Service – A Descriptive Study. Journal of Public Health Research. 2021;10(1). https://doi.org/10.4081/jphr.2021.2000
2. **Ras, J.**, & Leach, L. (2021). Relationship Between Various Coronary Artery Disease Risk Factors in Firefighters. *Journal of Occupational and Environmental Medicine*, *63*(7), e433-e439. https://doi.org/10.1097/JOM.0000000000002679
3. **Ras J** and Leach L. Predicting coronary artery disease risk in firefighters – a cross-sectional study [version 1; peer review: 1 approved with reservations]. *F1000Research* 2021, **10**:701 (https://doi.org/10.12688/f1000research.54219.1)
4. **Ras, J.**, & Leach, L. (2021). Association Between Major Coronary Artery Disease Risk Factors in The City of Cape Town Firefighter and Rescue Service. *The Open Public Health Journal*, *14*(1). http://dx.doi.org/10.2174/1874944502114010360
5. **Ras, J.**, & Leach, L. (2022). Alcohol Consumption, Physical Activity, and CAD Risk Factors in Firefighters. *The Open Public Health Journal*, *15*(1). http://dx.doi.org/10.2174/18749445-v15-e221026-2022-73
6. **Ras J**, Mosie D, Strauss M, Leach L. Knowledge of and Attitudes toward Health and Cardiovascular Disease Risk Factors among Firefighters in Cape Town, South Africa. Journal of Public Health Research. 2022;11(1). https://doi.org/10.4081/jphr.2021.2307
7. **Ras, J.**, & Leach, L. (2022). Firefighters' Health Knowledge, Cardiovascular Disease Risk Factors, and Sociodemographic Characteristics as Predictors of Firefighters

http://etd.uwc.ac.za/

Attitudes Toward Health. *Journal of Occupational and Environmental Medicine*, *64*(11), e705-e713. https://journals.lww.com/joem/toc/2021/07000

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

DEFINITIONS OF TERMS

Cardiovascular disease (CVD) risk factors are a group of characteristics or behavirous that contribute to the development of atherosclerotic heart disease, and include among others aging, obesity, hypertension, high cholesterol (hypercholesterolemia), a family history of CVD, physical inactivity and impaired blood glucose [1].

Health metrics are a group of seven specific cardiovascular health behaviours and factors, which include smoking, diet, physical activity, body mass index, blood pressure, total cholesterol, and fasting blood glucose that reduce cardiovascular disease morbidity and mortality [2].

Heart rate variability is the variation in the time intervals between heartbeats, measured in milliseconds (ms) [3,4].

Musculoskeletal disorders are injuries and/or disorders that affect the human body's movement or musculoskeletal system [22].

Musculoskeletal health encompasses the health of the muscles, joints and bones within the body and how they interact together without pain [6]. Good musculoskeletal health allows individuals the perform activities of daily living with ease and without discomfort [6].

Occupational performance is the ability to perceive, desire, recall, plan and carry out roles, routines, tasks and sub-tasks for the purpose of self-maintenance, productivity, leisure and rest

http://etd.uwc.ac.za/

in response to demands of the internal and/or external environment [7].

Physical fitness is defined as the ability to perform muscular work satisfactorily and includes cardiovascular endurance, body composition, muscular strength, muscular endurance and flexibility [8].

Risk profile provides information or a risk score based on the number or group of risk factors which places an individual at risk for CVD [1].

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

CHAPTER ONE

Introduction to the Study

1. Introduction

1.1. Background of the Study

Firefighting is a hazardous occupation that involves firefighters risking their lives in life-threatening situations, where they are exposed to severe temperatures, hazardous chemicals, and fumes [9,10]. These severe conditions necessitate that firefighters wear protective clothing and rescue equipment that is heavy and insulated, placing tremendous strain on the cardiovascular and musculoskeletal systems [11–13]. These types of strenuous working conditions cause tremendous cardiovascular and physical strain, predisposing firefighters to sudden cardiac events and musculoskeletal disorders [5,9]. These working conditions necessitate firefighters remain in satisfactory physical condition to maintain adequate cardiovascular and musculoskeletal health in order to manage these stressors [14–16].

UNIVERSITY of the
WESTERN CAPE

1.1.1. Cardiovascular Health

Current research indicates that among the emergency services, firefighters have the highest percentage of mortality (45%), due to sudden cardiac death (SCD), with the majority of causes related to underlying cardiovascular disease (CVD) risk factors [9,10]. Cardiovascular disease risk factors include modifiable risk factors, such as cigarette smoking, physical inactivity, obesity, hypertension, dyslipidemia and diabetes, and non-modifiable risk factors such as age, family history of heart disease [1]. Numerous studies have investigated the CVD risk profile of

http://etd.uwc.ac.za/

firefighters and reported adverse modifiable CVD risk profile, especially: obesity (63%), hypertension (42%), diabetes (15%), cigarette smoking (21%) and physical inactivity (49%); which all reduce aerobic capacity and lead to premature fatigue in firefighters [17–21]. In the City of Cape Town Fire and Rescue Service (CoCTFRS), the prevalence of dyslipidemia, cigarette smoking, obesity, hypertension, age, family history, physical inactivity and diabetes were 40.3%, 39.5%, 37.1%, 33.1%, 23.4%, 20.9%, 13.7% and 8.9%, respectively [22]. Cardiovascular disease risk significantly increases as firefighters aged and is usually lower in female firefighters, and significantly correlated with heart rate variability (HRV) [23,24]. Increased CVD risk is known to negatively affect firefighters' fitness and increased muscular fatiguability, which negatively affects firefighter occupational performance [18,19,25]. Yu et al. [26] reported that smokers and ex-smokers had a significantly lower maximal heart rate during the maximal running test, as well as a significantly higher average heart rate during the sewage rescue simulation scenario, and a body mass index (BMI) that was negatively associated with cardiopulmonary fitness levels. Jahnke et al. [27] reported that injuries were significantly related to cigarette smoking in firefighters. Seyedmehdi et al. [25] reported that age, BMI, low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C) and blood pressure were significantly associated with reduced fitness levels in firefighters. Similarly, Baur et al. [19], Durand et al. [18] and Nowak et al. [28] reported that age and BMI was significantly associated with decreased cardiorespiratory fitness in firefighters. Cigarette smoking and alcohol consumption were also significantly associated with reduced aerobic fitness in firefighters [29]. Smith et al. [30] reported that, while performing a complex emergency simulation, increased workloads (stair trials), increased age and BMI were significantly associated with higher HR during the simulation stair trial simulation. It is apparent that age, BMI and hypertension were associated with reduced cardiorespiratory capacity in firefighters.

http://etd.uwc.ac.za/

However, more research is needed in this area. Heart rate variability is a significant parameter in the cardiovascular health metrics and CVD risk profile paradigm, since it was significantly reduced by the modifiable CVD risk factors, and became a significant factor of CVD risk as firefighters aged [9,31,32]. Reduced HRV is generally indicative of autonomic dysfunction, and sympathetic nervous system over-stimulation, which negatively affected cardiovascular and anaerobic performance, and caused a decrease in occupational performance [9,32,33]. Resting heart rate (RHR) and HRV were significantly related to CVD, diabetes, and premature mortality in firefighters [17]. In addition, RHR and HRV were significant predictors of high blood pressure, hyperglycemia, and diabetes [34]. In previous studies, HRV was significantly related to aerobic performance, and was a marker of the body's stress-recovery status, as well as a predictor of musculoskeletal disorders [35–37]. However, further research is needed on the relationship between cardiovascular health and HRV, particularly in firefighters, as this may be used as an indicator highlighting at risk firefighters, possibly predisposed to sudden caric events while on duty.

UNIVERSITY of the
WESTERN CAPE

Cardiovascular disease risk factors have been known to reduce physical fitness and, subsequently, occupational performance in firefighters [25,38]. These risk factors have also been shown to predispose individuals to musculoskeletal injuries [39,40]. Deteriorating musculoskeletal health and musculoskeletal disorders are common among firefighters, with the shoulder, knee and lower back being the commonly affected areas [12,13,41]. These musculoskeletal health concerns limit firefighters' work performance [42]. Firefighters were reported to have the highest incidence of injuries among the emergency services [43].

http://etd.uwc.ac.za/

1.1.2. Musculoskeletal Health

Firefighter specific tasks, such as equipment carries, door breaches and hose drag place significant strain on the musculoskeletal system, causing firefighters to be at high risk of musculoskeletal disorders, particularly when their musculoskeletal health starts to deteriorate with age [5,38]. These occupational tasks, coupled with environmental factors, such as severe temperatures and breathing hazardous chemicals and fumes, caused increased fatigue, while performing emergency duties [2,37]. This further increased the likelihood of injury and, if any underlying cardiovascular or musculoskeletal disorder was present, could significantly limit occupational performance [38,39]. For this reason, firefighters need to be in good musculoskeletal health to prevent on-duty injuries and maintain optimal work performance [12,32]. Previous literature indicated that musculoskeletal disorders in firefighters were common, and increased with age and years of experience, and may also be related to firefighter physical activity habits outside of the job [39,40]. Previous literature indicated that low back (18 – 32%), ankle (15 – 77%), knee (17 – 19%) and shoulder (24 – 32%) injuries were the most prevalent in firefighters [5,6,38]. Negm et al. [40] reported that aged and more experienced firefighters reported more severe lower-limb disabilities, which were likely due to the combined effects of age-related decrements in soft tissue strength and chronic overuse related to firefighting [6,40]. This consequently increased the prevalence of injuries, and may be related to the decrease in cardiorespiratory fitness with increasing age in firefighters. Obesity was another key factor which played a significant role in influencing on-duty injuries and disability, as increased body weight placed more strain on all musculoskeletal structures, and predisposing firefighters to injury [32,37,38]. Obesity was also a significant predictor of on-duty musculoskeletal disorders and poor cardiorespiratory performance in firefighters [19,39]. Studies conducted by Poplin et al. [9,41] reported that reduced cardiorespiratory fitness was a

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

significant predictor of increased injury risk in firefighters. In contrast, Damrongsak et al. [42] reported that physical fitness did not reduce the incidence of back pain in firefighters. Similarly, Gordon and Lariviere [43] found that higher aerobic fitness was not significantly associated with injuries in firefighters. Musculoskeletal injuries, particularly those related to back and spinal pain were reported to be significant predictors of limitations in work and occupational performance in firefighters [36].

1.1.3. Physical Fitness

Physical fitness is considered an important aspect in firefighting that affected occupational performance and career longevity in firefighters, especially cardiorespiratory fitness, muscle strength and endurance [50,51]. Maintaining adequate physical fitness levels has the added benefit of supporting musculoskeletal health and reducing the development or progression of CVD risk factors [15]. Poor physical fitness, however, is associated with increased CVD risk and reduced musculoskeletal health [2,5,38]. The work of firefighting engages all aspects of physical fitness, and increased physical fitness has been reported to have a significant positive relationship with occupational performance in firefighting [17,25,28,42,63]. Nazari et al.[38] reported that age, sex, resting heart rate, and upper body and lower body strength were significant predictors of hose-drag and stair-climb completion times in firefighters. Michaelides et al. [55] reported that abdominal strength, power (step test), push-ups, resting heart rate, and body fat percentage contributed significantly to firefighters' performance in the physical ability tests. Similarly, Rhea et al. [52] reported that total fitness, bench press strength, hand grip strength, bent-over row endurance, bench press endurance, shoulder press endurance, biceps endurance, squat endurance, and 400 m sprint time correlated with job performance in firefighters.

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

1.1.4. Occupational Performance

To evaluate firefighter performance while on-duty, firefighter departments use simulated tasks that mimic the stressors placed on firefighters when on duty [14,56–58]. However, these assessments do not use the cardiovascular health metrics and risk profiles and musculoskeletal health in combination with physical fitness, when assessing occupational performance of firefighters. Mckune and Schmidt [59] reported that, in South Africa, firefighting assessments stressed all aspects of fitness, and significant correlations were found between physical fitness and task performance in firefighters. Occupational performance was an important consideration, when determining firefighter fitness for duty, as sub-standard occupational fitness significantly increased the likelihood of cardiovascular and musculoskeletal complications when on duty [11–13,15]. Cardiovascular health metrics, CVD risk profiles, musculoskeletal health and physical fitness were significantly related to occupational performance in firefighters [25,45,51]. However, this relationship has not been extensively investigated, particularly in South Africa. When substandard physical fitness and poor cardiovascular and musculoskeletal health occur concurrently, this placed tremendous strain on firefighters' bodies and, ultimately, negatively affected occupational performance [10,60]. When occurring together, increased CVD risk, reduced musculoskeletal health and poor physical fitness significantly and negatively affected firefighter occupational performance [50,51].

In summary, the effect of cardiovascular health metrics, CVD risk profiles, musculoskeletal disorders, and physical fitness on occupational performance in firefighters is important and needs further investigation, particularly, in a South African context. Therefore, the aim of this study was to assess the relationship between cardiovascular health metrics and risk profile, musculoskeletal health, physical fitness and occupational performance in firefighters.

http://etd.uwc.ac.za/

Furthermore, the study aimed to determine cardiovascular health metrics and risk profile, musculoskeletal health and physical fitness were significant predictors of occupational performance in firefighters. This study will also highlight key areas of focus when developing exercise/rehabilitation programmes to ensure that firefighters are ready for active duty.

1.2. Statement of the Problem

Historically, passing the cardiovascular fitness and occupational performance tests were considered sufficient parameters of fitness-for-duty in firefighters [26,52]. However, deteriorating cardiovascular and musculoskeletal health, and poor physical fitness have been associated with reduced occupational performance, which predispose firefighters to significant disability, while on duty [25,38,52]. In addition, most firefighters were not aware of their personal cardiovascular health and musculoskeletal health status, which is of significant concern [42,61–64]. The workloads that firefighters endure require them to be in optimal cardiovascular and physical condition in order to manage the work-related strain [38,52]. With the high prevalence of CVD risk factors, musculoskeletal disorders and low physical fitness among firefighters, the likelihood of sudden cardiac events and musculoskeletal injuries occurring, while on active duty, may increase significantly [10,11,13,65,66].

In South Africa it has been reported that firefighters have elevated stress levels compared to firefighters in other global regions, a high prevalence of CVD risk factors and musculoskeletal injuries, which negatively affect their job performance and overall health and well-being [22,67]. Currently, there is a significant gap in the existing literature that investigates the relationship between cardiovascular health metrics and risk profile, musculoskeletal health and

http://etd.uwc.ac.za/

physical fitness in firefighters, and how these parameters affect occupational performance, particularly in a South African context [22,59]. In developed and developing countries, poor cardiovascular health metrics and increased risk profile, together with underlying musculoskeletal health disorders and poor physical fitness, have been a quadrupled health burden [11,25,68]. Consequently, many firefighters on active duty are at increased CVD risk, compromised musculoskeletal health and low physical fitness [10,13,42,66,69]. Therefore, determining the relationship between cardiovascular and musculoskeletal health, physical fitness and occupational performance is of paramount importance. This study will highlight the need for strategic occupational and educational interventions regarding the health and wellness of firefighters in the CoCTFRS. In addition, there is need for advocating for suitable occupational health facilities with appropriate educational resources for firefighters.

Therefore, determining the relationship between cardiovascular and musculoskeletal health, physical fitness and occupational performance is of paramount importance. This study will highlight the need for strategic occupational and educational interventions regarding the health and wellness of firefighters in the CoCTFRS. In addition, there is need for advocating for suitable occupational health facilities with appropriate educational resources for firefighters.

UNIVERSITY of the
WESTERN CAPE

1.3. Research Question

The following research questions will be addressed in the study, namely:

1. What is the relationship between cardiovascular health metrics and risk profile, musculoskeletal health, physical fitness and occupational performance in firefighters?

http://etd.uwc.ac.za/

2. Are cardiovascular health metrics and risk profile, musculoskeletal health and physical fitness significant predictors of occupational performance in firefighters?

1.4. Aim of the Study

The aim of the study is to assess the relationship between cardiovascular health metrics and risk profile, musculoskeletal health, physical fitness and occupational performance in firefighters.

1.5. Objectives of the Study

The objectives of the study are to:

1. Assess the current literature on the relationship between cardiovascular heath metrics and risk profile, musculoskeletal health, physical fitness and occupational performance in firefighters by conducting a systemic review and meta-analysis.
2. Assess the relationship between cardiovascular health metrics and risk profile, musculoskeletal health, physical fitness and occupational performance in firefighters in the City of Cape Town Fire and Rescue Service.
3. Assess whether cardiovascular health metrics and risk profile, musculoskeletal health and physical fitness are significant predictors of occupational performance in firefighters in the City of Cape Town Fire and Rescue Service.

1.6. Hypotheses of the Study

The hypotheses of the study are the following:

H_0: There will be no significant relationship between cardiovascular health metrics and risk

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

profile, musculoskeletal health and occupational performance in firefighters.

H_1: There will be a significant relationship between cardiovascular health metrics and risk profile, musculoskeletal health, physical fitness and occupational performance in firefighters.

H_2: Cardiovascular health metrics and risk profile, musculoskeletal health and physical fitness will be significant predictors of occupational performance in firefighters.

1.7. Significance of the Study

Firefighting is a strenuous and hazardous occupation that places tremendous physical and mental strain on firefighters [11,25,30]. If firefighters are not in optimal cardiovascular and physical condition, this predisposes them to significant morbidity and mortality, while on duty [11]. Currently, there are few studies investigating the relationship between cardiovascular and musculoskeletal health, physical fitness and occupational performance [25,42,55]. Therefore, this study will aim to determine the relationship between cardiovascular health metrics and risk profile, musculoskeletal health, physical fitness and occupational performance in firefighters in the CoCTFR. Furthermore, the study will determine the predictors of occupational performance. The scarcity of research on CVD risk, musculoskeletal health, physical fitness and occupational performance is a concern, especially with regard to the early and premature retirement of firefighters [11,68,70].

Determining the extent to which CVD risk, musculoskeletal health, and physical fitness affect occupational performance will contribute to future studies, where guidelines, recommendations and models can be developed to aid in maintaining firefighter health and well-being throughout

http://etd.uwc.ac.za/

their careers. In addition, the early detection of firefighters with increased CVD risk, diminished musculoskeletal health and low physical fitness will assist in reducing the potential loss of life of firefighters and civilians, and decrease the possible damage to property [10,71]. This study will also highlight the need by the fire service to implement corrective intervention strategies, such as educational and lifestyle modification programmes, including physical training regimes designed to address the relatively high prevalence of CVD risk, musculoskeletal impairment, and poor physical fitness. Ultimately, the intention is to reduce the alarming morbidity and mortalities rates in the fire services in the CoCTFRS [11,13].

1.8. Overview of the Study Methodology

This section presents the various methodologies used to achieve the objectives of the study that encompass the study design and setting, participant sampling, data collection procedures and the reliability and validity of the study instruments. More specifically, the details of sample size and participant sampling, data collection procedures, research ethics and data analysis are described for each research paper in the subsequent chapters.

UNIVERSITY of the
WESTERN CAPE

1.8.1. Phase I: Systematic Review of Literature

1.8.1.1. Literature Review, Systematic Review and Meta-Analysis

The systematic review used a transparent and systematic process in order to define the research question, to search the literature, to assess the literary quality and to synthesize the findings, either qualitatively or quantitatively [74]. It involved formulating a search strategy that included all keywords and mesh terms to allow the search to run smoothly [74]. Once the articles were selected, they were thoroughly read and subjected to a data extraction process, as well as

http://etd.uwc.ac.za/

summarizing of results from the selected articles. The papers were then subjected to advanced analysis, known as a meta-analysis, and presented graphically in forest plots or as tables [75]. The full protocol and research methodology may be found in Chapters Three, Four and Five.

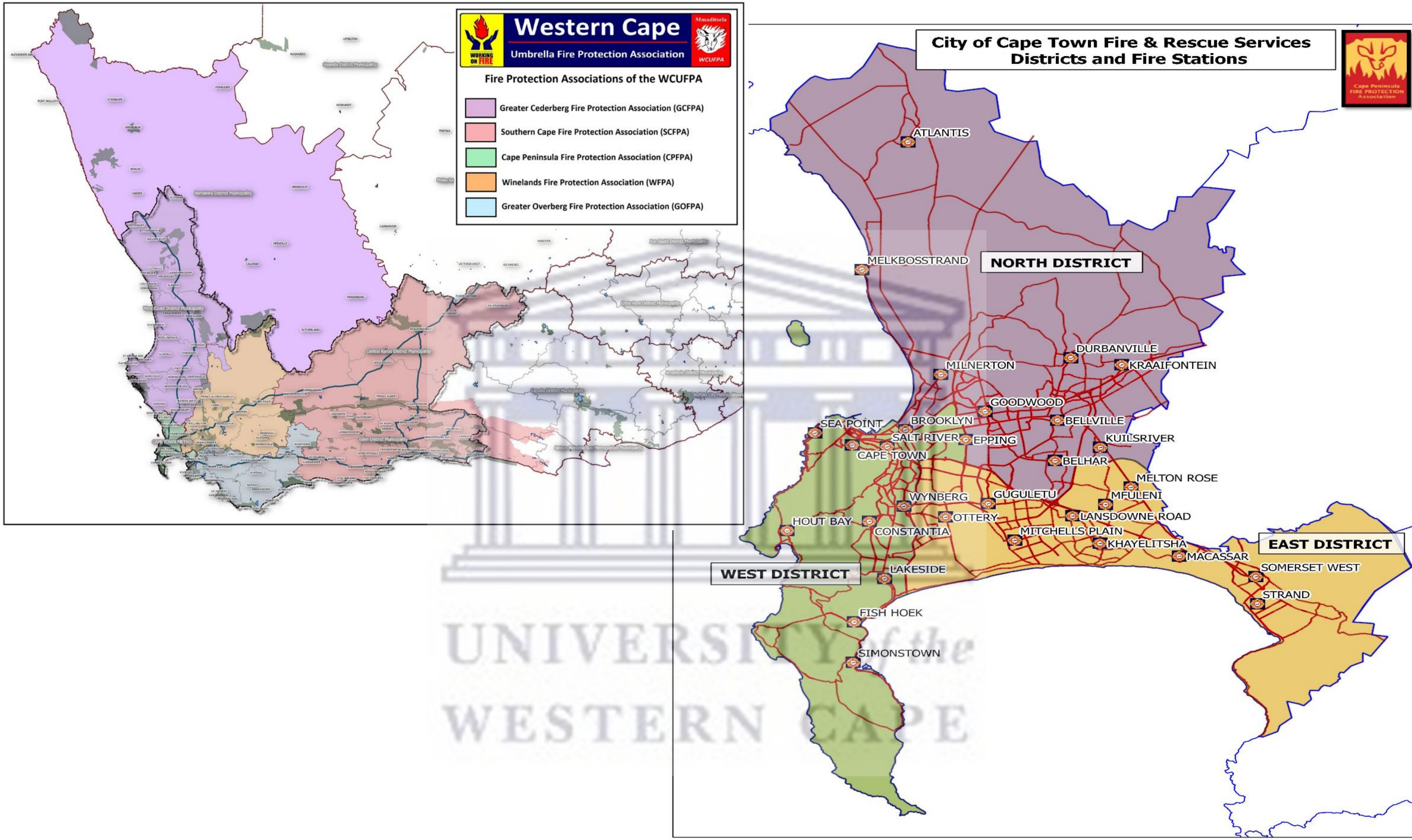
1.8.2. Phase II: Data Collection

1.8.2.1. Study Design and Setting

This study used a quantitative, non-experimental, cross-sectional, descriptive, and correlational research design. Data collection took place in the CoCT municipality district of the Westen Cape Umbrella Fire Protection Association (WCUFPA) (Figure 1.1). The CoCTFS district is further divided into North, West and East districts, consisting of a total of 32 fire stations in the three districts. Data collection took place at a single fire station in the CoCT municipal area. The data collection was divided into two stages, i.e., **Stage I** which encompassed all static measurements, such as height, weight, body fat percentage (BF%), lean body mass (LBM), blood pressure, blood glucose and cholesterol, and heart rate variability (HRV), as well as completing of the questionnaires (sociodemographic information, lifestyle information, and musculoskeletal health), and **Stage II** which encompassed all dynamic measurements, such as push-ups and sit-ups, grip strength, leg strength, flexibility and the physical ability test (PAT). Full details of the methodology used is found in Chapters Seven to Twelve.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/



UNIVERSITY of the
WESTERN CAPE

Figure 1.1: District map of the Western Cape Province Fire Protection Association and the City of Cape Town Fire and Rescue Service District.

Source: Cape Peninsula Fire Protection Agency https://cpfpa.org.za/maps/

http://etd.uwc.ac.za/

1.8.2.2. Sampling of Participants

There are approximately 1000 full-time firefighters from 96 platoons (32 fire stations) employed in the CoCTFRS. Using the finite sample size calculation, a minimum sample size of of 278 participants was required to participate in this study. In total, 309 full-time firefighters were recruited using the systematic sampling technique. Participant sampling took place during the annual physical fitness assessment for all firefighters in the CoCTFRS, where participants for the study were selected, using random systematic sampling.

1.8.3. Delimitations of the Study

1.8.3.1. Inclusion Criteria

The following inclusion criteria will be applied in the study, namely:

- Full-time firefighters permanently employed in the CoCTFRS.
- Male and female firefighters between the ages of 20 and 65 years.

1.8.3.2. Exclusion Criteria

The following exclusion criteria will be applied in the study, namely:

- Administrative staff who are not active firefighters.
- Volunteer firefighters or workers on short-time (i.e., contracted for the peak fire season only).
- Firefighters who have been hospitalized or on leave during the period of the study.

1.8.4. Instrument and Tester Reliability

Several steps were taken to ensure the reliability of the data collection in this study. Firstly, the research equipment used in the study were high-precision instruments that were calibrated prior

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

to use. Secondly, the researcher assistants were trained in various research techniques in order to ensure that tester technical error of measurement (TEM) was within acceptable research limits. Thirdly, each research assistant was given a specific test to perform for the duration of data collection in order to ensure consistency of the results. Fourthly, a test-retest reliability assessment was conducted by the principal investigator to ensure intra-tester and inter-tester reliability. The tester technical error of measurement (TEM) and the coefficient of variation of the technical error of measurement (CVTEM) was determined, and a minimum tester rating coefficient of 0.8 was required to ensure tester reliability, before the study commenced. Lastly, a pilot study was conducted to assess the reliability of the research instruments and the researcher assistants (Chapter Seven).

1.9. Outline of the Thesis

1.9.1. Chapter One: Introduction to the Study

In chapter one, a summary of the prevalence of cardiovascular health metrics and risk profile, and musculoskeletal health in firefighters is provided. The chapter provides the importance of physical fitness in firefighting. In addition, the chapter provides an overview on the relationship between cardiovascular health and risk profile, musculoskeletal health, physical fitness and occupational performance in firefighters.

1.9.2. Chapter Two: Publication One −A Narrative Literature Review

Title: Cardiovascular disease risk factors, musculoskeletal health, physical fitness, and occupational performance in firefighters: A narrative review

This review was aimed at investigating the relationship between CVD risk factors, musculoskeletal health, physical fitness and occupational performance. The results highlight that

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

aged, obese, physically inactive, cigarette smokers, and unfit were at the highest risk for cardiovascular and musculoskeletal health complications, and unsatisfactory occupational performance. Musculoskeletal health complications significantly affected occupational performance and work ability and were related to physical fitness of firefighters. Most cardiovascular risk factors were related to physical fitness, and all physical fitness parameters were related to occupational performance in firefighters.

1.9.3. Chapter Three: Publication Two − Systematic Review Protocol

Title: Effects of cardiovascular health, musculoskeletal health and physical fitness on occupational performance of firefighters: protocol for a systematic review and meta-analysis

This study is about the protocol for a systematic review aimed at determining the effect of cardiovascular health, musculoskeletal health, and physical fitness on the occupational performance of firefighters. The study highlighted the database search strategy that would be used, the databases that would be searched, the tools that would be used to retrieve information from each study, the critical appraisal tools that would be used and the data analysis techniques that would be used to perform the meta-analysis.

1.9.4. Chapter Four: Publication Three − Systematic Review One

Title: Effects of Cardiovascular Disease Risk Factors, Musculoskeletal Health, and Physical Fitness on Occupational Performance in Firefighters—A Systematic Review and Meta-Analysis

This study was conducted to determine the effects of CVD risk factors, musculoskeletal health, and physical fitness on the occupational performance of firefighters. In total, 30 studies were included in the systematic review and 25 studied included in the meta-analysis. The results

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

showed that aged firefighters with a poor body composition and lower levels of physical fitness performed worse on all occupational performance tasks. In addition, male firefighters performed significantly better on all occupational tasks. Moreover, all measures of physical fitness were related to better occupational performance, particularly cardiorespiratory fitness, muscle strength and endurance.

1.9.5. Chapter Five: Publication Four − Systematic Review Two

Title: Association between Cardiovascular Disease Risk Factors and Cardiorespiratory Fitness in Firefighters: A Systematic Review and Meta-Analysis

The limited number of papers on the cardiovascular health and physical fitness in firefighters highlighted the need to conduct this study. Therefore, the aim of the systematic review was to determine the association between cardiovascular disease risk factors and cardiorespiratory fitness in firefighters. The systematic review included 25 articles and for the meta-analysis, included 16 articles. The study found that aging and obesity reduced cardiorespiratory fitness in firefighters. And cardiorespiratory fitness had an inverse relationship with systolic blood pressure, diastolic blood pressure, total cholesterol, low-density lipoprotein cholesterol, triglycerides, and blood glucose concentrations.

UNIVERSITY of the
WESTERN CAPE

1.9.6. Chapter Six: Publication Five − Original Research Article One

Title: Relationship Between Physical Activity, Coronary Artery Disease Risk Factors and Musculoskeletal Injuries in the City of Cape Town Fire and Rescue Service

This study was conducted to investigate the relationship between physical activity, coronary artery disease risk factors and musculoskeletal injuries in firefighters. This study found that a high propotion (69.4%) of firefighters were physically inactive. Shoulder injuries were the most prevalent injury location (35.3%), followed by multiple injury sites and the back injuries.

http://etd.uwc.ac.za/

Firefighters that participated in more vigorous intensity exercise were more likely to report musculoskeletal injuries.

1.9.7. *Chapter Seven: Publication Six − Original Research Article Two*

Title: A Pilot Study on the Relationship Between Cardiovascular Health, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters

In this chapter, a pilot study was undertaken to investigate the feasibility of conducting a large-scale study on cardiovascular health metrics and risk profile, musculoskeletal health, physical fitness and occupational performance in firefighters. The study found that there was good reliability in terms of both the research instruments and research. Potential logistic and/or administrative challenges were also identified that could negatively impact the larger study. In conclusion, the pilot study supported the feasibility of conducting the main study.

1.9.8. *Chapter Eight: Publication Seven − Original Research Article Three*

Title: Association between Cardiovascular and Musculoskeletal Health in Firefighters

This chapter presents a study investigating the association between cardiovascular and musculoskeletal health in firefighters. The study reported that increasing age, BMI, BF%, DBP, TC, and the Framingham risk score increased the risk of reporting musculoskeletal injuries (MSIs). Obesity, hypertension and dyslipidaemia increased the risk of reporting MSIs, and musculoskeletal discomfort (MSDs) were associated with TC and low-density lipoprotein. For firefighters to develop and maintain overall health and wellbeing, they should establish good cardiovascular health profiles, especially as they aged.

1.9.9. *Chapter Nine: Publication Eight − Original Research Article Four*

Title: Association between Physical Fitness and Cardiovascular Health in Firefighters

http://etd.uwc.ac.za/

Firefighters perform strenuous work in dangerous and unpredictable environments, and they need to be in optimal physical condition. In this chapter, the study reported the association between physical fitness and cardiovascular health in firefighters. The study found that relative cardiorespiratory fitness was associated with systolic blood pressure (SBP), diastolic blood pressure (DBP), non-fasting blood glucose (NFBG) and total cholesterol (TC). Poor cardiovascular health index (CVHI) was negatively associated with rel$\dot{V}O_{2max}$ (scaled to body mass), leg strength and push-ups. Furthermore, age was inversely associated with absolute and relative $\dot{V}O_{2max}$, push-ups, sit-ups and sit-and-reach. Moreover, BF% was negatively associated with absolute $\dot{V}O_{2max}$, handgrip and leg strength, push-ups, sit-ups and LBM. LASSO regression showed relative cardiorespiratory fitness was the most significant indicator of good cardiovascular health. In conclusion, cardiorespiratory fitness, muscular strength and muscular endurance were significantly associated with a better cardiovascular health profile.

1.9.10. Chapter Ten: Publication Nine − Original Research Article Five

Title: Association between Physical Fitness and Musculoskeletal Health in Firefighters

Firefighters, often, sustain MSIs while on active duty, with many of them performing active duty with moderate-to-severe MSDs, which may negatively impact their occupational performance. This chapter presents a publication on the association between physical fitness and musculoskeletal health in firefighters. The study reported that higher levels of physical fitness reduced the odds of firefighters reporting MSIs. In addition, higher levels of physical fitness were associated with higher levels of MSDs. The maintenance of physical fitness was beneficial in reducing MSIs, however, increased the reporting of MSD in firefighters.

1.9.11. Chapter Eleven: Publication Ten − Original Research Article Six

Title: Physical Fitness, Cardiovascular and Musculoskeletal Health and Occupational

http://etd.uwc.ac.za/

Performance in Firefighters

This chapter investigated whether physical fitness, cardiovascular health and musculoskeletal health were significant predictors of occupational performance in firefighters. The results showed that absolute $\dot{V}O_{2max}$, handgrip strength, leg strength, push-ups, sit-ups, lean body mass, HRV were associated with PAT completion times. The results of the MANCOVA reported significant differences between the various of the PAT. In addition, 50.5% of the variance in occupational performance was explained by weekly MET minutes, BF%, ab$\dot{V}O_{2max}$, handgrip strength, leg strength and sit-ups. Firefighters should maintain high levels of physical fitness and good cardiovascular health to ensure satisfactory levels of occupational performance.

1.9.12. Chapter Twelve: Publication Eleven − Original Research Article Seven

Title: Evaluation of the Relationship between Occupational-Specific Task Performance and Measures of Physical Fitness, Cardiovascular and Musculoskeletal Health in Firefighters

This chapter presents a publication that investigated whether physical fitness, cardiovascular and musculoskeletal health were significant predictors of occupational-specific task performance in firefighters. The results found that certain physical fitness parameters, specifically, absolute $\dot{V}O_{2max}$, handgrip strength, leg strength, push-ups, sit-ups and lean body mass were associated with better completion times in all occupational tasks. Aging, obesity, and hypertension was negatively associated with task performance in firefighters. Firefighters with poorer musculoskeletal health performed poorer on tasks such as the step-up, charged hose drag and pull, and the rescue drag. In addition, key indicators of occupational task performance were absolute $\dot{V}O_{2max}$, handgrip strength, leg strength, sit-ups, lean body mass, BF% and weekly MET minutes.

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

1.9.13. Chapter Thirteen: Summary, Discussion, Conclusion and Recommendations

In this chapter, a summary of the results from the individual chapters are integrated and presented, i.e., the literature review, pilot study and original studies. The results are discussed in relation to the existing literature and the contribution of the current thesis to the literature on the research topic. In addition, the strengths and limitations of the study are outlined, and the implications of the study for firefighters, policy makers, and healthcare professionals are discussed.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

References

[1] Arnett DK, Blumenthal RS, Albert MA, Buroker AB, Goldberger ZD, Hahn EJ, et al. 2019 ACC/AHA Guideline on the Primary Prevention of Cardiovascular Disease: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Circulation.* 2019;140:e596–646. https://doi.org/10.1161/CIR.0000000000000678.

[2] Lloyd-Jones DM, Braun LT, Ndumele CE, Smith SC, Sperling LS, Virani SS, et al. Use of Risk Assessment Tools to Guide Decision-Making in the Primary Prevention of Atherosclerotic Cardiovascular Disease: A Special Report From the American Heart Association and American College of Cardiology. *Circulation.* 2019;139:e1162–77. https://doi.org/10.1161/CIR.0000000000000638.

[3] Dzikowicz DJ, Carey MG. Widened QRS-T angle may be a measure of poor ventricular stretch during exercise among on-duty firefighters. *Journal of Cardiovascular Nursing.* 2019;34:201–7. https://doi.org/10.1097/JCN.0000000000000554.

[4] Sydó N, Sydó T, Merkely B, Carta KG, Murphy JG, Lopez-Jimenez F, et al. Impaired Heart Rate Response to Exercise in Diabetes and Its Long-term Significance. *Mayo Clin Proc.* 2016;91:157–65. https://doi.org/10.1016/j.mayocp.2015.10.028.

[5] Nazari G, MacDermid J, Cramm H. Prevalence of musculoskeletal disorders among Canadian firefighters: A systematic review and meta-analysis. *J Mil Veteran Fam Health.* 2020;6:83–97. https://doi.org/10.3138/jmvfh-2019-0024.

[6] Vuori I. Exercise and Physical Health: Musculoskeletal Health and Functional Capabilities. *Res Q Exerc Sport.* 1995;66:276–85. https://doi.org/10.1080/02701367.1995.10607912.

http://etd.uwc.ac.za/

[7] Chapparo C, Ranka J. Occupational performance model (Australia): Definition of terms. Occupational Performance Model (Australia): *Monograph.* 1997;1:58–60.

[8] Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep.* 1985;100:126–31.

[9] Shin JH, Lee JY, Yang SH, Lee MY, Chung IS. Factors related to heart rate variability among firefighters. *Ann Occup Environ Med.* 2016;28:1–9. https://doi.org/10.1186/s40557-016-0111-6.

[10] Smith DL, Barr DA, Kales SN. Extreme sacrifice: Sudden cardiac death in the US Fire Service. *Extrem Physiol Med.* 2013;2:1–9. https://doi.org/10.1186/2046-7648-2-6.

[11] Smith DL, DeBlois JP, Kales SN, Horn GP. Cardiovascular strain of firefighting and the risk of sudden cardiac events. *Exerc Sport Sci Rev.* 2016;44:90–7. https://doi.org/10.1249/JES.0000000000000081.

[12] Hong O, Phelps S, Feld J, Vogel S. Occupational Injuries, Duty Status, and Factors Associated with Injuries among Firefighters. *Workplace Health Saf.* 2012;60:517–23. https://doi.org/10.1177/216507991206001203.

[13] Frost DM, Beach TAC, Crosby I, McGill SM. Firefighter injuries are not just a fireground problem. *Work.* 2015;52:835–42. https://doi.org/10.3233/WOR-152111.

[14] Ensari I, Motl RW, Klaren RE, Fernhall B, Smith DL, Horn GP. Firefighter exercise protocols conducted in an environmental chamber: developing a laboratory-based simulated firefighting protocol. *Ergonomics.* 2017;60:657–68. https://doi.org/10.1080/00140139.2016.1198496.

http://etd.uwc.ac.za/

[15] Nowak AM, Molik B, Wójcik A, Rutkowska I, Nowacka-Dobosz S, Kowalczyk M, et al. Physical activity and injuries relating to physical fitness of professional firefighters. *Advances in Rehabilitation.* 2018;32:13–22. https://doi.org/10.5114/AREH.2018.77933.

[16] Poplin GS, Roe DJ, Peate W, Harris RB, Burgess JL. The Association of Aerobic Fitness With Injuries in the Fire Service. *American Journal of Epidemiology*. 2013. https://doi.org/10.1093/aje/kwt213.

[17] Choi B, Ko S, Kojaku S. Resting heart rate, heart rate reserve, and metabolic syndrome in professional firefighters: A cross-sectional study. *Am J Ind Med.* 2017;60:900–10. https://doi.org/https://doi.org/10.1002/ajim.22752.

[18] Durand G, Tsismenakis AJ, Jahnke SA, Baur DM, Christophi CA, Kales SN. Firefighters' physical activity: relation to fitness and cardiovascular disease risk. *Med Sci Sports Exerc.* 2011;43:1752–9. https://doi.org/10.1249/MSS.0b013e318215cf25.

[19] Baur DM, Christophi CA, Cook EF, Kales SN. Age-related decline in cardiorespiratory fitness among career firefighters: Modification by physical activity and adiposity. *J Obes.* 2012;2012. https://doi.org/10.1155/2012/710903.

[20] Yang J, Teehan D, Farioli A, Baur DM, Smith D, Kales SN. Sudden cardiac death among firefighters ≤45 years of age in the United States. *American Journal of Cardiology.* 2013;112:1962–7. https://doi.org/10.1016/j.amjcard.2013.08.029.

[21] Soteriades ES, Smith DL, Tsismenakis AJ, Baur DM, Kales SN. Cardiovascular disease in US firefighters: A systematic review. *Cardiol Rev.* 2011;19:202–15. https://doi.org/10.1097/CRD.0b013e318215c105.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

[22] Ras J, Leach L. Prevalence of coronary artery disease risk factors in firefighters in the city of Cape Town fire and rescue service – A descriptive study. *J Public Health Res.* 2021;10. https://doi.org/10.4081/jphr.2021.2000.

[23] Wolkow A, Netto K, Langridge P, Green J, Nichols D, Sergeant M, et al. Coronary heart disease risk in volunteer firefighters in Victoria, Australia. *Arch Environ Occup Health.* 2014;69:112–20. https://doi.org/10.1080/19338244.2012.750588.

[24] Byczek L, Walton SM, Conrad KM, Reichelt PA, Samo DG. Implications for Occupational Health Nurse Practice. *Aaohn.* 2004;52:66–77.

[25] Seyedmehdi SM, Attarchi M, Cherati AS, Hajsadeghi S, Tofighi R, Jamaati H. Relationship of aerobic fitness with cardiovascular risk factors in firefighters. *Work.* 2016;55:155–61. https://doi.org/10.3233/WOR-162375.

[26] Yu CCW, Au CT, Lee FYF, So RCH, Wong JPS, Mak GYK, et al. Association between leisure time physical activity, cardiopulmonary fitness, cardiovascular risk factors, and cardiovascular workload at work in firefighters. *Saf Health Work.* 2015;6:192–9. https://doi.org/10.1016/j.shaw.2015.02.004.

[27] Jahnke SA, Poston WSC, Haddock CK, Jitnarin N. Injury among a population based sample of career firefighters in the central USA. *Injury Prevention.* 2013:injuryprev-2012-040662. https://doi.org/10.1136/injuryprev-2012-040662.

[28] Nowak A, Molik B, Wójcik A, Rutkowska I, Nowacka-Dobosz S, Kowalczyk M, et al. Physical Activity and Injuries Relating to Physical Fitness of Professional Firefighters. *Advances in Rehabilitation.* 2018;32:13–22. https://doi.org/10.5114/areh.2018.77933.

http://etd.uwc.ac.za/

[29] Punakallio A, Lindholm H, Luukkonen R, Lusa S. Lifestyle factors predicting changes in aerobic capacity of aging firefighters at 3-and 13-year follow-ups. *J Occup Environ Med.* 2012;54:1133–41. https://doi.org/10.1097/JOM.0b013e3182554b11.

[30] Smith DL, Haller JM, Benedict R, Moore-Merrell L. Firefighter incident rehabilitation: Interpreting heart rate responses. *Prehospital Emergency Care.* 2016;20:28–36. https://doi.org/10.3109/10903127.2015.1037477.

[31] Goldenberg I, Goldkorn R, Shlomo N, Einhorn M, Levitan J, Kuperstein R, et al. Heart Rate Variability for Risk Assessment of Myocardial Ischemia in Patients Without Known Coronary Artery Disease: The HRV-DETECT (Heart Rate Variability for the Detection of Myocardial Ischemia) Study. *J Am Heart Assoc.* 2019;8:e014540. https://doi.org/10.1161/JAHA.119.014540.

[32] Yook YS. Firefighters' occupational stress and its correlations with cardiorespiratory fitness, arterial stiffness, heart rate variability, and sleep quality. *PLoS One.* 2019;14:1–9. https://doi.org/10.1371/journal.pone.0226739.

[33] Jeklin AT, Perrotta AS, Davies HW, Bredin SSD, Paul DA, Warburton DER. The association between heart rate variability, reaction time, and indicators of workplace fatigue in wildland firefighters. *Int Arch Occup Environ Health.* 2021. https://doi.org/10.1007/s00420-020-01641-3.

[34] Wulsin LR, Horn PS, Perry JL, Massaro JM, D'Agostino RB. Autonomic imbalance as a predictor of metabolic risks, cardiovascular disease, diabetes, and mortality. *Journal of Clinical Endocrinology and Metabolism.* 2015;100:2443–8. https://doi.org/10.1210/jc.2015-1748.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

[35] Tomes C, Schram B, Orr R. Relationships Between Heart Rate Variability, Occupational Performance, and Fitness for Tactical Personnel: A Systematic Review. *Front Public Health.* 2020;8. https://doi.org/10.3389/fpubh.2020.583336.

[36] Williams S, Booton T, Watson M, Rowland D, Altini M. Heart Rate Variability is a Moderating Factor in the Workload-Injury Relationship of Competitive CrossFit Athletes. *J Sports Sci Med.* 2017:443–9.

[37] Tracy LM, Ioannou L, Baker KS, Gibson SJ, Georgiou-karistianis N. Meta-analytic evidence for decreased heart rate variability in chronic pain implicating parasympathetic nervous system dysregulation. *PAIN.* 2016;157.

[38] Nazari G, MacDermid JC, Sinden KE, Overend TJ. The Relationship between Physical Fitness and Simulated Firefighting Task Performance. *Rehabil Res Pract.* 2018;2018:1–7. https://doi.org/10.1155/2018/3234176.

[39] Abate M, Vanni D, Pantalone A, Salini V. Cigarette smoking and musculoskeletal disorders. *Muscles Ligaments Tendons J.* 2013;3:63–9. https://doi.org/10.11138/mltj/2013.3.2.063.

[40] Nikolakaros G, Vahlberg T, Auranen K, Sillanmäki L, Venetoklis T, Sourander A. Obesity, Underweight, and Smoking Are Associated with Worse Cardiorespiratory Fitness in Finnish Healthy Young Men: A Population-Based Study. *Frontiers in Public Health*. 2017;5:206.

[41] Kim YK, Ahn YS, Kim K, Yoon JH, Roh J. Association between job stress and occupational injuries among Korean firefighters: A nationwide cross-sectional study. *BMJ Open.* 2016;6. https://doi.org/10.1136/bmjopen-2016-012002.

http://etd.uwc.ac.za/

[42] Nazari G, Osifeso TA, MacDermid JC. Distribution of Number, Location of Pain and Comorbidities, and Determinants of Work Limitations among Firefighters. *Rehabil Res Pract.* 2020;2020:1942513. https://doi.org/10.1155/2020/1942513.

[43] Yoon J-H, Kim Y-K, Kim KS, Ahn Y-S. Characteristics of Workplace Injuries among Nineteen Thousand Korean Firefighters. *J Korean Med Sci.* 2016;31:1546. https://doi.org/10.3346/jkms.2016.31.10.1546.

[44] Vaulerin J, d'Arripe-Longueville F, Emile M, Colson SS. Physical exercise and burnout facets predict injuries in a population-based sample of French career firefighters. *Appl Ergon.* 2016;54:131–5. https://doi.org/10.1016/j.apergo.2015.12.007.

[45] Nazari G, Macdermid JC, Sinden K, D'Amico R. Prevalence of musculoskeletal symptoms among Canadian firefighters. *Work.* 2020;67:185–91. https://doi.org/10.3233/WOR-203264.

[46] Negm A, MacDermid J, Sinden K, D'Amico R, Lomotan M, MacIntyre NJ. Prevalence and distribution of musculoskeletal disorders in firefighters are influenced by age and length of service. *J Mil Veteran Fam Health.* 2017;3:33–41. https://doi.org/10.3138/jmvfh.2017-0002.

[47] Poplin GS, Roe DJ, Burgess JL, Peate WF, Harris RB. Fire fit: assessing comprehensive fitness and injury risk in the fire service. *Int Arch Occup Environ Health.* 2016;89:251–9. https://doi.org/10.1007/s00420-015-1068-4.

[48] Damrongsak M, Prapanjaroensin A, Brown KC. Predictors of Back Pain in Firefighters. *Workplace Health Saf.* 2018;66:61–9. https://doi.org/10.1177/2165079917709020.

[49] Gordon H, Lariviere M. Physical and psychological determinants of injury in Ontario forest firefighters. *Occupational Medicine-Oxford.* 2014;64:583–8. https://doi.org/10.1093/occmed/kqu133.

http://etd.uwc.ac.za/

[50] Norris MS, McAllister M, Gonzalez AE, Best SA, Pettitt R, Keeler JM, et al. Predictors of Work Efficiency in Structural Firefighters. *J Occup Environ Med.* 2021;63.

[51] Xu D, Song Y, Meng Y, István B, Gu Y. Relationship between Firefighter Physical Fitness and Special Ability Performance: Predictive Research Based on Machine Learning Algorithms. *International Journal of Environmental Research and Public Health.* 2020;17. https://doi.org/10.3390/ijerph17207689.

[52] Rhea MR, Alvar BA, Gray R. Physical fitness and job performance of firefighters. *J Strength Cond Res.* 2004;18:348–52. https://doi.org/10.1519/r-12812.1.

[53] Phelps SM, Drew-Nord DC, Neitzel RL, Wallhagen MI, Bates MN, Hong OS. Characteristics and Predictors of Occupational Injury Among Career Firefighters. *Workplace Health Saf.* 2018;66:291–301. https://doi.org/10.1177/2165079917740595.

[54] Skinner TL, Kelly VG, Boytar AN, Peeters G (Geeske), Rynne SB. Aviation Rescue Firefighters physical fitness and predictors of task performance. *J Sci Med Sport.* 2020;23:1228–33. https://doi.org/10.1016/j.jsams.2020.05.013.

[55] Michaelides MA, Parpa KM, Henry LJ, Thompson GB, Brown BS. Assessment of Physical Fitness Aspects and Their Relationship to Firefighters' Job Abilities. *The Journal of Strength & Conditioning Research.* 2011;25.

[56] Williams-Bell FM, Villar R, Sharratt MT, Hughson RL. Physiological demands of the firefighter candidate physical ability test. *Med Sci Sports Exerc.* 2009;41:653–62. https://doi.org/10.1249/MSS.0b013e31818ad117.

[57] von Heimburg E, Medbø JI, Sandsund M, Reinertsen RE. Performance on a work-simulating firefighter test versus approved laboratory tests for firefighters and applicants. International

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Journal of Occupational Safety and Ergonomics. 2013;19:227–43. https://doi.org/10.1080/10803548.2013.11076981.

[58] Sheaff AK, Bennett A, Hanson ED, Kim Y-S, Hsu J, Shim JK, et al. Physiological determinants of the candidate physical ability test in firefighters. *J Strength Cond Res.* 2010;24:3112–22. https://doi.org/10.1519/JSC.0b013e3181f0a8d5.

[59] Mckune, Schmidt. Association between physical fitness and job performance in fire-fighters. *Ergonomics SA : Journal of the Ergonomics Society of South Africa.* 2012;24:44–57. https://doi.org/10.10520/EJC132052.

[60] Billman GE, Huikuri H v., Sacha J, Trimmel K. An introduction to heart rate variability: methodological considerations and clinical applications. *Front Physiol.* 2015;6:2013–5. https://doi.org/10.3389/fphys.2015.00055.

[61] Ras J, Leach L. Firefighters' Health Knowledge, Cardiovascular Disease Risk Factors and Sociodemographic Characteristics as Predictors of Firefighters Attitudes Toward Health. *J Occup Environ Med. 2022*. 64(11):p e705-e713.

[62] Ras J, Mosie D, Strauss M, Leach L. Knowledge of and attitudes toward health and cardiovascular disease risk factors among firefighters in Cape Town, South Africa. *J Public Health Res.* 2021;11. https://doi.org/10.4081/jphr.2021.2307.

[63] Dobson M, Choi B, Schnall PL, Wigger E, Garcia-Rivas J, Israel L, et al. Exploring Occupational and Health Behavioral Causes of Firefighter Obesity: A Qualitative Study. *Am J Ind Med.* 2013;56:776–90. https://doi.org/10.1002/ajim.22151.

[64] Bucala M, Sweet E. Obesity in the fire service: An inside look at the perceptions of firefighters towards obesity and other health issues. *Res Sq.* 2019. https://doi.org/10.21203/rs.2.15518/v1.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

[65] Smith DL, Haller JM, Korre M, Fehling PC, Sampani K, Grossi Porto LG, et al. Pathoanatomic Findings Associated With Duty-Related Cardiac Death in US Firefighters: A Case–Control Study. *J Am Heart Assoc.* 2018;7:e009446. https://doi.org/10.1161/JAHA.118.009446.

[66] Smith DL, Haller JM, Korre M, Sampani K, Porto LGG, Fehling PC, et al. The Relation of Emergency Duties to Cardiac Death Among US Firefighters. *American Journal of Cardiology.* 2019;123:736–41. https://doi.org/10.1016/j.amjcard.2018.11.049.

[67] Oosthuizen. RM, Koortzen. P. An empirical investigation of job and family stressors amongst firefighters in the south african context. *SA Journal of Industrial Psychology.* 2007;33:49–58. https://doi.org/10.10520/EJC89125.

[68] Sen S, Palmieri T, Greenhalgh D. Cardiac fatalities in firefighters: An analysis of the U.S. fire administration database. *Journal of Burn Care and Research.* 2016;37:191–5. https://doi.org/10.1097/BCR.0000000000000225.

[69] Chizewski A, Box A, Kesler R, Petruzzello SJ. Fitness fights fires: Exploring the relationship between physical fitness and firefighter ability. *Int J Environ Res Public Health.* 2021;18. https://doi.org/10.3390/ijerph182211733.

[70] Kahn SA, Leonard C, Siordia C. Firefighter fatalities: Crude mortality rates and risk factors for line of duty injury and death. *Journal of Burn Care and Research.* 2019;40:196–201. https://doi.org/10.1093/jbcr/iry037.

[71] Korre M, Porto LGG, Farioli A, Yang J, Christiani DC, Christophi CA, et al. Effect of Body Mass Index on Left Ventricular Mass in Career Male Firefighters. *American Journal of Cardiology.* 2016;118:1769–73. https://doi.org/10.1016/j.amjcard.2016.08.058.

http://etd.uwc.ac.za/

[72] Armstrong R, Hall BJ, Doyle J, Waters E. 'Scoping the scope' of a cochrane review. *J Public Health (Bangkok)*. 2011;33:147–50. https://doi.org/10.1093/pubmed/fdr015.

[73] Gurevitch J, Koricheva J, Nakagawa S, Stewart G. Meta-analysis and the science of research synthesis. *Nature.* 2018;555:175–82. https://doi.org/10.1038/nature25753.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

CHAPTER TWO: PUBLICATION ONE - A NARRATIVE LITERATURE REVIEW

Cardiovascular Disease Risk Factors, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters – A Narrative Review

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Hindawi
Journal of Environmental and Public Health
Volume 2022, Article ID 7346408, 20 pages
https://doi.org/10.1155/2022/7346408

Review Article

Cardiovascular Disease Risk Factors, Musculoskeletal Health, Physical Fitness, and Occupational Performance in Firefighters: A Narrative Review

Jaron Ras,[1] **Denise L. Smith**,[2] **Andre P. Kengne**,[3,4] **Elpidoforos E. Soteriades**,[5,6] **and Lloyd Leach**[1]

[1]*Department of Sport, Recreation and Exercise Science, Faculty of Community and Health Sciences, University of the Western Cape, Cape Town, South Africa*
[2]*Health and Human Physiological Sciences, Skidmore College, Saratoga Springs, NY, USA*
[3]*Non-Communicable Diseases Research Unit, South African Medical Research Council, Cape Town, South Africa*
[4]*Department of Medicine, Faculty of Health Sciences, University of Cape Town, Cape Town 7700, South Africa*
[5]*Harvard T. H. Chan School of Public Health, Department of Environmental Health, Environmental and Occupational Medicine and Epidemiology (EOME), Boston, USA*
[6]*Open University of Cyprus, School of Economics and Management, Healthcare Management Program, Nicosia, Cyprus*

Correspondence should be addressed to Jaron Ras; 3405618@myuwc.ac.za

Received 10 May 2022; Accepted 20 August 2022; Published 19 September 2022

Academic Editor: Ike S. Okosun

Copyright © 2022 Jaron Ras et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Introduction. Firefighting is a strenuous occupation that requires firefighters to be in peak physical condition. However, many firefighters have risk factors for cardiovascular disease, impaired musculoskeletal health, and are not physically fit for duty, which all negatively impact their occupational performance. Therefore, the aim of this review is to determine the relationship between cardiovascular disease risk factors, musculoskeletal health, physical fitness, and occupational performance in firefighters. *Methods*. The electronic databases PubMed, SCOPUS, and Web of Science were searched online via the library portal of the University of the Western Cape. Publications and grey literature between the years 2000 to present were used. In total, 2607 articles were identified; after the removal of duplicates 1188 articles were then screened, and were excluded for not meeting initial screening criteria. The remaining 209 full-text articles were screened based on the inclusion and exclusion criteria, where 163 articles were excluded. Only studies that were quantitative were included. This left 46 articles that were then finally included in the current narrative review. *Results*. The current literature indicated that significant relationships existed between cardiovascular risk factors, musculoskeletal health, physical fitness, and occupational performance. The results indicated firefighters who were aged, obese, physically inactive, cigarette smokers, and unfit were at the highest risk for cardiovascular and musculoskeletal health complications, and unsatisfactory occupational performance. Musculoskeletal health complications significantly affected occupational performance and work ability and were related to physical fitness of firefighters. Most cardiovascular risk factors were related to physical fitness, and all physical fitness parameters were related to occupational performance in firefighters. *Conclusion*. The overwhelming evidence in the current review established that physical fitness is related to occupational performance. However, the relationship between cardiovascular risk factors and musculoskeletal health in relation to occupational performance is less clear and still understudied. Significant gaps remain in the literature.

1. Introduction

Firefighting is a strenuous occupation that places tremendous strain on the body, where firefighters are routinely exposed to life-threatening situations, severe temperatures, hazardous chemicals, and fumes [1, 2]. These severe conditions necessitate that firefighters wear personal protective equipment that is heavy and insulated, augmenting the

http://etd.uwc.ac.za/

physiological load already placed on the cardiovascular and musculoskeletal systems [3]. These types of strenuous working conditions cause high levels of chronic cardiovascular and physical strain, predisposing firefighters to cardiovascular disease, musculoskeletal injury, morbidity and in extreme cases, mortality [1, 4, 5]. Firefighters are, therefore, required to be in optimal physical conditioning to overcome many of these work-related challenges to their health [6–8].

Previous research indicates that amongst the emergency services, firefighters have the highest percentage of mortality (45%) due to sudden cardiac death (SCD), which is related to the presence of multiple cardiovascular disease (CVD) risk factors and low levels of physical fitness [1, 4, 5]. Current literature indicates that the majority of firefighters are either obese (63%) or physically inactive (49%) and unfit (27.1%), and engaged in poor dietary practices [9–14]. In addition, many of them were hypertensive (42%), smokers (21%), diabetic (15%), or had a muscular disorder (25%) [9–14]. The presence of multiple CVD risk factors substantially increased the cardiovascular strain, and negatively affected their cardiovascular fitness and occupational performance [3, 15, 16]. Musculoskeletal injuries amongst firefighters occurred most commonly in the fire station, and were due to trips, slips, or falls. Either while performing physical activities in the fire station or when responding to emergency situations, and occurred more frequently in aged, obese, and inactive firefighters [17, 18]. The lower limbs, back, and shoulders were the most common anatomical sites of injury and musculoskeletal disorders [17–21]. These injuries and disorders frequently caused chronic pain and inflammation, and decreased the work-ability of firefighters, and negatively affected their musculoskeletal health and occupational performance [17, 21, 22]. Cardiovascular disease and musculoskeletal health are significantly related to and affect the occupational performance of firefighters [9, 23–27]. Maintenance of physical fitness is an essential preventative tool not only in maintaining cardiovascular and musculoskeletal health but also in maintaining satisfactory occupational performance in firefighters [6, 28, 29].

There have been very few studies investigating the relationship between CVD risk factors, musculoskeletal health, physical fitness, and occupational performance in firefighters. Therefore, this narrative review will investigate the relationships between these variables in firefighters, and how these may affect the overall health, wellness, and performance of firefighters. The objectives are to examine the relationship between each of these key outcome variables independently, and to highlight gaps in the literature for future research. The authors hypothesise that there will be significant relationships between CVD risk factors, musculoskeletal health, physical fitness, and occupational performance in firefighters.

1.1. Understanding the Key Concepts in the Review. In the present review, CVD risk factors encompass all the metrics related to increased cardiovascular risk status or decreased cardiovascular health. These parameters include aging, obesity, hypertension, diabetes, dyslipidaemia (hypercholesteremia), cigarette smoking, physical inactivity, a poor diet, and heart rate variability (HRV) [30, 31]. Heart rate variability is the variation in the time interval between consecutive heartbeats in milliseconds [1, 32].

Musculoskeletal health encompasses all factors related to the reduced integrity of the musculoskeletal system, and includes acute and/or chronic injuries, musculoskeletal disorders, discomfort, and pain [33–35].

Physical fitness includes all the components of health-related physical fitness that refers to the ability to perform muscular work satisfactorily and includes cardiorespiratory fitness, body composition, muscular strength, muscular endurance, and flexibility [36]. All components of health-related physical fitness are linked to occupational performance in firefighters.

Occupational performance refers to the ability to perform one's job adequately, to the standards that are required in the specific occupation, which, in this case, refers to firefighting [37]. For firefighters, occupational performance includes the ability to perform core duties, such as hose drag, victim drag, equipment carry, door breaches, and ceiling breaches.

2. Methods

2.1. Literature Search Strategy. The following electronic databases were searched: PubMed, SCOPUS, and Web of Science. Grey literature included the Networked Digital Library of Theses and Dissertations. Only publications between the years 2001 to December 2021 were used. Keywords and medical subject heading (MeSH) terms were used in various arrangements according to the specific database searched. An example of a search string used for a database search can be seen in Table 1:

2.2. Graphical Bibliography of Literature Search. Figure 1 explains the search results from PubMed, SCOPUS, and Web of Science as a diagram. The search results were saved and exported to Zotero**TM**, where references were checked for duplicates. Thereafter, the citations were exported to VOSviewer**TM** where the bibliographic analysis was conducted. The diagram explains the central themes of the study, which were identified during the literature search procedure. The diagram indicates the commonly used terms, keywords, themes, and subthemes in the various articles from the electronic databases and their association with each other. The diagram was normalized using LinLog/modu- larity. The size of the node and line width between nodes indicates the commonality and popularity of the search terms, keywords, and co-occurrences. The co-occurrence and network strength of the keywords are represented by the size of the node and the degree of spread of the network from individual nodes. The colour schemes are coded by thematic area and web/link strength between the keywords. For example, the adult male node is the largest node located close to the middle of the diagram, indicating that adult male firefighters are the most frequently studied key terms in

http://etd.uwc.ac.za/

Table 1: Search strategy for PubMed.

Order	Search terms
#1	"firefighter" [MeSH] OR "fire and rescue personnel" [MeSH] OR "fire fighters" [MeSH] OR "fire fighter" [MeSH]
#2	"Cardiovascular system"[MeSH] OR ("cardiovascular"[All fields] AND "system"[All fields]) OR "cardiovascular system"[All fields] OR "cardiovascular"[All fields] OR "cardiovasculars"[All fields] OR "cardiovascular abnormalities"[MeSH] OR "cardiovascular health" OR "HRV"[All fields] OR "heart rate variability" [All fields] OR "Heart Rate "Interval" [All fields] OR "RR variability" [All fields] OR "cycle length variability" [All fields] OR "heart period variability" [All fields] OR "autonomic function" [All fields] OR "vagal control" [All fields] OR "lipid profile" [MeSH] OR "cholesterol" [MeSH] "diabetes" OR "blood glucose" OR "age" OR "obesity" OR "blood pressure" OR "blood glucose" OR "Diet" OR "eating habits" OR "eating culture"
#3	"muscular injury" (MeSH) OR ("musculoskeletal" [All fields] AND "system" [All fields]) OR "muscular pain" OR "chronic pain" OR "acute pain" "acute injury" OR "muscular health"
#4	"Physical fitness" [MeSH] OR "exercise" [All fields] OR "physical exertion" [All fields] OR "fitness" OR "body composition" [MeSH] OR "muscle" AND ("strength" OR "endurance" OR "flexibility" OR "power") OR "cardiorespiratory"
#5	"work performance" [All fields] OR "endurance" [All fields] OR "fitness" [All fields] OR "performance" [MeSH] AND "work performance/classification" [MeSH] OR "occupational health" OR "employee health" [MeSH] OR "occupational performance" OR "work ability" OR "health, industrial" [MeSH] OR "industrial health" [MeSH] OR "occupational safety" [MeSH] OR "safety, occupational" [MeSH] "body composition" [MeSH] OR "muscle" AND ("strength" OR "endurance" OR "flexibility" OR "power") OR "cardiorespiratory"
#6	#1 AND #2 OR #1 AND #3 OR #1 AND #4 OR #1 AND #2 AND #3 OR #1 AND #2 AND #4 OR #1 AND #3 AND #4 OR #1 AND #2 AND #3 AND #4 OR #1 AND #5 OR #2 AND #5

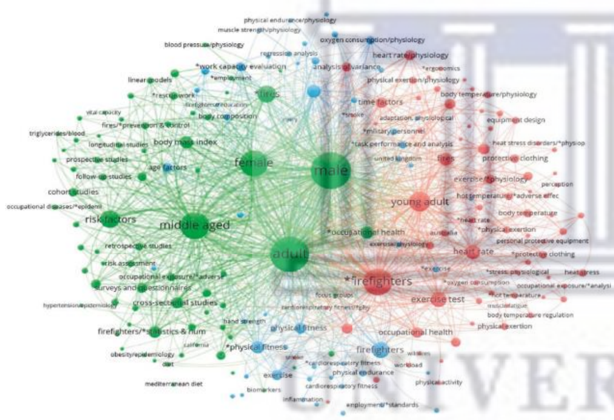


Figure 1: Bibliometric analysis of database search results.

firefighters. Nodes located on the periphery of the diagram are the least occurring keywords, with the lowest network strength to other nodes/co-occurrences.

2.3. Inclusion and Exclusion Criteria. The inclusion criteria were studies involving all types of firefighters, that used CVD risk factors and/or musculoskeletal health/disorders/injuries and/or physical fitness and/or occupational/professional/work/job performance (Table 2). Studies involving all types of firefighters, active duty, seasonal, contract, volunteer, new recruits, of all ages, genders, and ethnicities were included. Studies that did not meet the purpose of the literature review (e.g., not using two or more of the variables, i.e., CVD risk factors, musculoskeletal health, physical fitness, or occupational performance) were excluded. In addition, intervention and review studies were excluded from this review. To limit the possibility of selection or reviewer bias, all studies related to the present review were included.

Key terms were searched in various combinations in PubMed, Web of Science, and Scopus (Table 3). In total, 807 articles were found in PubMed, 973 in Web of Science, and 823 in SCOPUS, totalling 2603 articles. Four studies were found from grey literature searchers. After each search, the search results were exported as either txt, RIS or BibTeX files, and files were then imported into Zotero™ reference manager, for further screening and checking for duplications.

2.4. Screening Procedure. In total, 2603 articles were identified through electronic database searches and four articles through a search of the grey literature (Figure 2). After removal of the duplicates (Zotero™), 1188 articles remained, which were then screened for eligibility using the titles and abstracts, and 980 articles were excluded for not meeting the review requirements (title, abstract, and keywords). The remaining 209 articles were screened based on the inclusion and exclusion criteria, as well as the full-text, where 161 articles were excluded for the following reasons: being an intervention study; the relationship between the variables not clearly described; inconclusive results reported; the outcome variables were not aligned with the scope of this review. A total of 46 articles were finally identified, which were included in the narrative review.

2.5. Data Extraction. The principal investigator designed a spreadsheet in Microsoft Excel® for the data extraction. The extraction of data is a descriptive summary of the results that align with the objectives of the current review [38]. Five categories of data were extracted from each article and were populated in the spreadsheet. The categories included reference (author), year, sample size, research design, and outcomes of the study. Data were extracted by the authors JR and LL.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 2: Inclusion and exclusion criteria of the literature search.

Inclusion criteria	Exclusion criteria
(i) Studies involving firefighters, either career, part-time, or volunteer.	(i) Studies that did not include firefighters only (other emergency services and populations excluded).
(ii) Studies investigating the relationships between cardiovascular disease risk factors, musculoskeletal health/disorders/injuries, physical fitness metrics, and occupational performance.	(ii) Review studies.
(iii) Studies published after the year of 2000.	(iii) Intervention studies.
(iv) Quantitative or mixed methods studies.	(iv) Qualitative studies that do not include quantitative statistical analysis.
	(v) Languages other than English.
	(vi) Articles where full-text was not available.

Table 3: Search results from electronic databases.

Database	Search results
PubMed	807
Web of science	973
SCOPUS	823
Grey literature	4
Total	2607

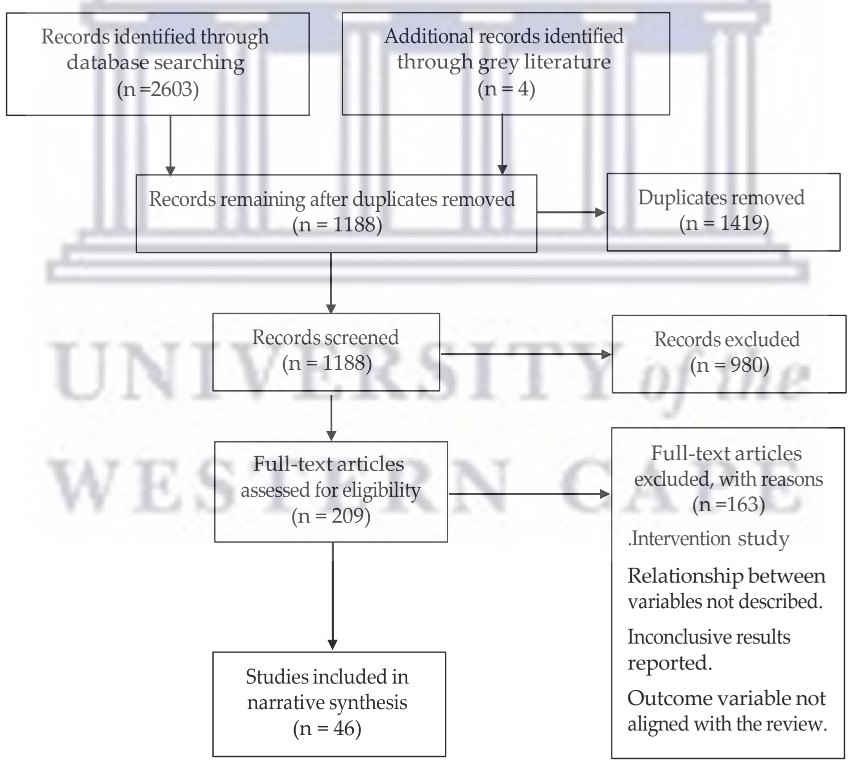


Figure 2: Flowchart of the study selection.

3. Results

From the 46 studies, 26 were published from North America (USA = 21; Canada = 5), 10 studies were published from Europe (Central Europe = 8; United Kingdom = 2), 3 studies were published from Asia (1 = Korea; 1 = Tehran; 1 = China), 2 were published from Australia, and 1 study from Africa (Ghana). In the literature, most studies investigated the relationship between CVD risk factors and physical fitness or the relationship between physical fitness and occupational performance. The high morbidity and mortality rates seen in firefighters reflected the relatively high volume of literature in these areas, as over 45% of firefighter fatalities were due to poor or deleterious cardiovascular health [15].

The effects of musculoskeletal health have been understudied in firefighters, particularly in relation to CVD risk

http://etd.uwc.ac.za/

status and occupational performance [39, 40]. These factors, ultimately, result in impaired occupational performance in firefighters, placing them at significant risk of CVD and musculoskeletal injury [15, 39]. The following results are separated into themes concerning the relationships between the variables.

3.1. Cardiovascular Disease Risk Factors and Musculoskeletal Health. Six studies investigated the relationship between cardiovascular and musculoskeletal health. The results of the studies are summarized in Table 4. The results indicated that age, obesity, and cigarette smoking were significantly associated with reduced musculoskeletal health, specifically, in the lower back and lower extremities [19, 21, 22].

Negm et al. [45] conducted a cross-sectional study on 294 full-time male firefighters in Hamilton Trenholm, Canada, investigating their musculoskeletal health. The study reported that aged firefighters (≥42) were significantly related to poorer musculoskeletal health, specifically to lower extremity disability ($p = 0.03$) and severe low back pain ($p < 0.001$). In addition, aged firefighters were more likely to have multiple sites with poor or severe musculoskeletal health. Similarly, Jang et al. [43] conducted a study on 392 full-time firefighters in Dongguk, Goyang, Korea, and found that age was a significant predictor of lumbar intervertebral disc degeneration ($p < 0.05$) in firefighters. This was supported in another study, which reported that age was a significant predictor of back pain ($p = 0.002$) in firefighters [44]. Likewise, an earlier study by Gordon and Lariviere [42] on 252 full-time male and female firefighters from Ontario, Canada, reported that age was a significant predictor of musculoskeletal injury (OR = 6.49, $p < 0.05$). Aged firefighters are more likely to have poor musculoskeletal health compared to their younger counterparts. [42].

Damrongsak et al. [44] conveniently sampled 298 male firefighters in the South-eastern regions of the United States (US). The study investigated the predictors of back pain and reported that the combination of occupational stress, age, history of back pain, and obesity (BMI) were significant predictors of current back pain in firefighters ($\chi^2 = 127.84$, df = 4, $p < 0.0001$). Jahnke et al. [22] conducted a cross-sectional study on 347 full-time firefighters from Kansas, Missouri, Iowa, Nebraska, North Dakota, South Dakota, Colorado, and Wyoming which investigated the factors that affected injury prevalence. The study noted that obesity (BMI and WC) was significantly related to poor musculoskeletal health, and increased the risk of firefighters sustaining acute musculoskeletal injuries when on duty by 5.2 and 2.8 times, respectively. In addition, another study reported that cigarette smoking was significantly related to musculoskeletal injuries in firefighters [21]. Similarly, Poston et al. [41] reported that, in 478 full-time male firefighters age, obesity and smoking status were significant predictors of poor musculoskeletal health ($p < 0.001$). Moreover, firefighters categorised with class II and III obesity were more likely to sustain injuries (OR = 4.89). Likewise, Jahnke et al. [21] reported that firefighters who were former smokers were more likely to sustain a musculoskeletal injury compared to nonsmokers (OR = 1.84).

3.2. Cardiovascular Disease Risk Factors and Physical Fitness. Fourteen studies investigated the relationship between CVD risk factors and physical fitness in firefighters. The results of the studies are summarized in Table 4. Overall, higher levels of physical fitness, particularly cardiorespiratory fitness, were related to improved CVD risk status in firefighters [8, 29, 46–48, 78]. This relationship has been studied, more thoroughly in firefighters, as both factors represent essential components in firefighters' health, wellness, and occupational performance [8, 47].

Kiss et al. [51] investigated cardiorespiratory fitness in 1225 firefighters from East-Flanders Province, Belgium. The study reported that age ($R^2 = 0.28$, $p < 0.001$) and obesity ($R^2 = 0.28$, $p < 0.001$) were significant predictors of cardio- respiratory fitness (Table 4). The study noted that age and obesity should be monitored closely in firefighters, especially between the ages of 30–50 years, when the risk escalates exponentially. A limitation of the study was that only male firefighters were included, due to the low number of female firefighters. Kirlin et al. [54] investigated the effect of age on physical fitness in a sample of 97 female firefighters from San Diego, USA. The study reported that, in female firefighters, age was significantly related to cardiorespiratory fitness ($p < 0.001$). Interestingly, age was not associated with muscular endurance in females.

Phillips et al. [7] investigated the effect of obesity on physical fitness in 414 full-time male firefighters from Alberta, Canada. The study found that obese firefighters had a significantly shorter treadmill time ($p < 0.05$) and lower cardiorespiratory fitness ($p < 0.05$) compared to firefighters with normal body weight. A study that investigated the CVD risk factors in 294 full-time firefighters in Colorado, USA, reported that improved cardiorespiratory fitness was a significant predictor of better cardiovascular risk status (OR = 2.87, $p < 0.05$) [55]. This was supported by another study which reported that increased cardiorespiratory fitness was inversely related to deleterious cardiovascular risk status ($p < 0.001$) in male firefighters [46]. Barry et al. [56] investigated the relationship between body composition and physical activity on cardiorespiratory fitness in 29 conveniently sampled full-time male firefighters and found that central obesity ($\beta = 0.482$, $p < 0.001$) and vigorous physical activity ($\beta = 0.560$, $p < 0.001$) were significant predictors of cardiorespiratory fitness. However, the small sample size limited the generalizability of the results. The results of Barry et al. were supported by an earlier study by Punakallio et al. [24] which found that firefighters who exercised at least four to five times a week ($p = 0.016$) maintained cardiorespiratory fitness throughout their careers, and that aging ($p = 0.048$), regular smoking ($p = 0.048$), and alcohol consumption ($p = 0.018$) were significant predictors of a decline in cardiorespiratory fitness.

Baur et al. [47] conducted a large-scale cross-sectional study on 968 male firefighters from the US and reported that higher cardiorespiratory fitness was significantly associated with improved CVD risk status, specifically, to lower systolic blood pressure (SBP) ($p < 0.001$), body fat percentage (BF%) ($p < 0.001$), triglycerides ($p < 0.001$), low-density lipoprotein

http://etd.uwc.ac.za/

Table 4: Relationship between CVD risk factors musculoskeletal health, physical fitness, and occupational performance (n = 46).

References	Year	Sample and setting	Study design (sampling)	Outcome
Cardiovascular disease risk factors and musculoskeletal health (n = 7)				
Poston et al. [41]	2011	478 full-time male firefighters USA	Cross-sectional	(i) Age, BMI, smoking status, and general health were significant predictors of work injury ($p < 0.001$). (ii) Firefighters categorised with class II and III obesity were significantly more likely to sustain injuries (OR: 4.89).
Jahnke et al. [22]	2013	347 full-time firefighters Kansas, Missouri, Iowa, Nebraska, North Dakota, South Dakota, Colorado, and Wyoming, US	Prospective cohort	(i) Obese firefighters were 5.2 times more likely to experience musculoskeletal injury. (ii) Firefighters with central obesity were 2.8 times more likely to experience musculoskeletal injury.
Jahnke et al. [21]	2013	462 full-time firefighters Kansas, Missouri, Iowa, Nebraska, North Dakota, South Dakota, Colorado, and Wyoming, US	Cross-sectional	(i) Cigarette smokers were more likely to sustain injuries compared to nonsmokers.
Gordon and Lariviere [42]	2014	252 full-time male and female firefighters Ontario, Canada	Cross-sectional	(i) Age (OR: 6.49) and years of experience (OR: 0.1) were significant predictors of injury.
Jang et al. [43]	2016	392 full-time firefighters Dongguk, Goyang, Korea	Cross-sectional	(i) Age was a significant predictor of lumbar intervertebral disc degeneration ($p < 0.05$), regardless of core job description.
Damrongsak et al. [44]	2017	298 male firefighters conveniently sampled Southeastern United States, USA	Cross-sectional	(i) Age ($p = 0.002$), BMI ($\chi^2 = 127.84$, df = 4, $p < 0.0001$), current back pain, occupational stress, history of back pain were significant predictors of current back pain.
Negm et al. [45]	2017	294 full-time firefighters Hamilton, Trenholme, Canada	Cross-sectional	(i) Older (≥42 years) firefighters had significantly more severe lower-extremity disability and more severe back pain (ii) Older firefighters were significantly more likely to have multiple musculoskeletal disorders.
Cardiovascular disease risk factors and physical fitness (n = 17)				
Donovan et al. [46]	2009	214 male firefighters Colorado, USA	Cross-sectional	(i) Cardiorespiratory fitness was inversely related to metabolic abnormalities ($p < 0.001$).
Baur et al. [47]	2011	968 male firefighters, USA	Cross-sectional	(i) Metabolic equivalents (METs) were inversely related to diastolic blood pressure (DBP), body fat, triglycerides, low-density lipoprotein cholesterol (LDL-C) and total/high-density cholesterol (TC/HDL-C) ratio, and high-density lipoprotein cholesterol (HDL-C).
Punakallio et al. [24]	2012	70 male firefighters aged 30 to 44 years Finland	Longitudinal	(i) Increased weekly exercise reduced the decline in cardiorespiratory fitness. (ii) Regular smoking and more than 15 units of alcohol a week were significant predictors of a decline in cardiorespiratory fitness.
Baur et al. [48]	2012	1149 male firefighters, USA	Cross-sectional	(i) Cardiorespiratory fitness was inversely associated with ECG and autonomic exercise testing abnormalities before and after adjustment for age, BMI and metabolic syndrome.
Mayer et al. [49]	2012	83 full-time firefighters Tampa, Florida, USA	Cross-sectional	(i) Back and core muscular endurance was 27% lower in obese firefighters. Back and core muscle endurance were related to obesity. (ii) Significant negative correlations were reported between back endurance and age ($p < 0.05$), BMI ($p < 0.01$), and BF% ($p < 0.01$), and between core endurance and BMI ($p < 0.01$), BF% ($p < 0.01$), and fat free mass ($p < 0.05$).

http://etd.uwc.ac.za/

Table 4: Continued.

References	Year	Sample and setting	Study design (sampling)	Outcome
Poplin et al. [50]	2013	577–799 full-time firefighters Southwestern States, USA	Longitudinal	(i) Age was a significant modifier of VO_{2max} ($p < 0.001$).
Kiss et al. [51]	2014	1225 firefighters East-Flanders Province, Belgium	Cross-sectional	(i) Cardiorespiratory fitness was significantly related to age-group, body mass index (BMI) groups, and body fat percentage.
Walker et al. [52]	2014	73 full-time male firefighters, Australia	Cross-sectional	(i) Aging was significantly related to poor cardiorespiratory fitness ($p < 0.05$). (ii) Aging was related to a significant decrease in cardiorespiratory fitness between the 35–44 and 45–54-year age groups ($p < 0.001$).
Poplin et al. [53]	2015	799 full-time firefighters Southwestern states, USA	Retrospective occupational cohort	(i) Age was negatively correlated with VO_{2max} ($r = -0.368$, $p < 0.05$), flexibility ($r = -0.160$, $p < 0.05$). (ii) BF% was negatively correlated with VO_{2max} ($r = -0.448$, $p < 0.05$), grip strength ($r = -0.191$, $p < 0.05$), and flexibility ($r = -0.135$, $p < 0.05$).
Seyedmehdi et al. [29]	2016	157 full-time male firefighters, Tehran	Cross-sectional	(i) Cardiorespiratory fitness (VO_{2max}) was significantly correlated with age, BMI, cigarette smoking, physical activity, LDL-C, HDL-C, SBP, DBP, and heart rate ($p \leq 0.05$).
Kirlin et al. [54]	2017	97 female firefighters, San Diego, USA	Cross-sectional	(i) Relative VO_2, absolute VO_2 and maximum METs were significantly associated with age.
Li et al. [55]	2018	294 full-time firefighters, Colorado, USA	Cross-sectional	(i) BF% ($p < 0.01$), estimated VO_{2max} ($p < 0.05$), metabolic syndrome ($p < 0.05$), and age group ($p < 0.001$) were significantly related to 10-year atherosclerotic cardiovascular disease risk.
Barry et al. [56]	2019	29 male full-time firefighters conveniently sampled, USA	Cross-sectional	(i) Waist circumference (WC) was a significant predictor of VO_{2max}. (ii) More physically active firefighters had a higher VO_{2max}.
Espimoza et al. [57]	2019	76 volunteer male firefighters, Chile	Cross-sectional	(i) Age, BMI, WC, waist-to-hip ratio (WHR), BF% and fat mass was significantly correlated with VO_{2max}. (ii) Resting heart rate (RHR), SBP, DBP, and blood glucose were significantly correlated with VO_{2max}.
Porto et al. [58]	2019	64 full-time firefighters (38 on-duty and 26 off-duty), federal District (Brasilia), Brazil	Cross-sectional	(i) Cardiorespiratory fitness (VO_{2max}) was positively correlated with overall cardiac autonomic function and higher parasympathetic activity ($p = 0.03$).
Yang et al. [59]	2019	1562 full-time firefighters participated at baseline and 1104 of these firefighters participated at follow-up, Indiana, USA	Retrospective longitudinal cohort	(i) Age, BMI, SBP, DBP, total cholesterol (TC), LDL-C, triglycerides, glucose concentration, and smoking status were significantly different between push-up categories (upper body endurance).
Strauss et al. [8]	2021	97 full-time firefighters <60 years. Westphalia, Germany	Cross-sectional	(i) BMI, WC, BF%, and resting SBP, triglycerides, and total cholesterol values were significantly lower with increased cardiorespiratory fitness (VO_{2max}) ($p < 0.05$, age-adjusted).
Cardiovascular disease risk factors and occupational performance ($n = 6$)				
Airila et al. [60]	2012	403 male firefighters, Kuopio, Finland.	Longitudinal	(i) Age ($r = -0.33$, $p < 0.01$) and BMI ($r = -0.15$, $p < 0.05$) were negatively related to work ability, and cigarette smoking was negatively related to work demands ($r = -0.10$ $p < 0.05$), and physical exercise was positively related to work ability index ($r = 0.015$, $p < 0.01$) and work demands ($r = 0.018$, $p < 0.01$).

http://etd.uwc.ac.za/

Table 4: Continued.

References	Year	Sample and setting	Study design (sampling)	Outcome
Walker et al. [52]	2014	73 full-time male firefighters, Australia	Cross-sectional	(i) Aging was significantly related to worse performance of simulated operational power testing tasks ($p < 0.001$). (ii) Hose-drag times significantly increased between 25–34 and 45–54 ($p < 0.001$) and 35–44 and 45–54 year age-groups ($p < 0.001$). Dummy-drag times significantly increased between 25–34 and 45–54 ($p < 0.001$), and 35–44 and 45–54-year age-groups ($p < 0.001$).
Firoozeh et al. [61]	2017	375 full time male firefighters, Tehran	Cross-sectional	(i) Age (r = -0.277, p = 0.001), BMI (r = −0.187, p = 0.001) and work experience (r = −0.281, p = 0.001) were negatively correlated with work ability. (ii) Leisure time physical activity (r = 0.206, p = 0.001) was related to work ability.
Phillips et al. [7]	2017	414 male firefighters, Alberta, Canada	Longitudinal	(i) The obese firefighting group had a significantly shorter treadmill time, lower relative VO_{2max} and absolute VO_{2max}. (ii) The heaviest groups had significantly lower completion times for the hose drag, weighted sled pull, forcible entry, and victim rescue. (iii) The lightest firefighters had a significantly lower time for the ladder climb.
Nazari et al. [26]	2018	46 male and 3 female firefighters between the ages of 20–69 years, Canada	Secondary analysis	(i) Age and grip strength were significant predictors of hose drag and stair climb completion times ($p < 0.05$).
Saari et al. [62]	2020	74 full-time male firefighters were conveniently sampled, Kentucky, USA	Cross-sectional	(i) Older firefighters (≥37 years) had an 8.8% increase in completion time for the firefighting course. (ii) Age was positively correlated with course time (r = 0.297, p = 0.017).
Xu et al. [63]	2020	20 full-time male firefighters, Southeast China	Cross-sectional	(i) High BF% was associated with poor performance in ability tests.
Norris et al. [64]	2021	19 full-time male firefighters, Texas, USA	Cross-sectional	(i) Age and fat mass were significant predictors of work efficiency.
		Musculoskeletal health and physical fitness (n = 5)		
Wynn and Hawdon [65]	2012	Firefighter recruits with minimum cardiorespiratory fitness standard (398 full-time and 48 part-time recruits) and without fitness standard (198 full-time and 206 part-time subjects). Northern England	Cohort	(i) Injury-related restrictions were more likely where no cardiorespiratory fitness standard was applied. (ii) Firefighters with a higher VO_{2max} correlated with a lower incidence of injuries ($p < 0.01$)
Butler et al. [66]	2013	108 trainee firefighters, Orange County, USA	Cohort	(i) Three functional movement screening (FMS) movements were significant predictors of injury i.e., the sit-and-reach (OR: 1.24), the deep-squat (OR: 1.21), and the push-up (OR: 1.30).
Jahnke et al. [21]	2013	462 full-time firefighters, Kansas, Missouri, Iowa, Nebraska, North Dakota, South Dakota, Colorado, and Wyoming, USA	Cross-sectional	(i) Injuries were 4.6 times more likely to be sustained when firefighters regularly exercised, while on duty. Increased VO_{2max} (OR: 1.06) and strength (OR: 4.03) were significantly associated with injury while exercising or training.

http://etd.uwc.ac.za/

Table 4: Continued.

References	Year	Sample and setting	Study design (sampling)	Outcome
Poplin et al. [50]	2013	577–799 full-time firefighters, Southwestern States, USA	Longitudinal	(i) Firefighters in the lowest fitness category ($VO_{2max} < 43$ mL·kg^{-1}·min^{-1}) were 2.2 times more likely to sustain injury than firefighters in the highest fitness level category ($VO_{2max} > 48$ mL·kg^{-1}·min^{-1}). (ii) A VO_{2max} between 43 and 48 mL·kg^{-1}·min^{-1} were 1.38 times more likely to incur injury. (iii) Improving relative aerobic capacity by one metabolic equivalent reduced the risk of injury by 14%.
Poplin et al. [53]	2015	799 full-time firefighters, Southwestern States, USA	Retrospective occupational cohort	(i) Firefighters with lower cardiorespiratory fitness were at increased risk of injury. (ii) The risk of injury was 1.82 times more likely for the least fit firefighters. (iii) When restricted to sprains and strains, the risk of injury increased to 2.90.
Musculoskeletal health and occupational performance ($n = 5$)				
Punakallio et al. [67]	2014	411 full-time male firefighters, Helsinki, Finland	Longitudinal	(i) Musculoskeletal pain (MSP) in more than one site diminished work ability. (ii) Low back pain (OR = 1.9) forearm and hands pain (OR = 1.9) predicted diminished work ability (iii) Participants who were on disability pension were older, more often had poor work ability, and had slightly more MSP at baseline. (iv) Average-(OR: 3.1)-to-high (5.3) physical workload was a significant risk factor for retiring on disability pension.
Kodom-Weredu [68]	2018	320 full-time firefighters The greater Accra region of Ghana	Cross-sectional	(i) Work-related musculoskeletal disorders (WMSD) were significantly related to work demands ($r = 0.023$) and task characteristics ($r = 0.026$). Work demands ($\beta = 0.226$, $p < 0.01$) and task characteristics ($\beta = 0.214$, $p < 0.01$) were significant predictors of WRMSDs.
MacDermid et al. [40]	2019	293 full-time male and female firefighters Hamilton, Ontario, Canada	Cross-sectional	(i) Firefighters who reported moderate-severe muscle and joint problems took 10 seconds longer to perform the stair climb, but were not statistically significant.
Saremi et al. [69]	2019	250 full-time firefighters Tehran (North, South, East, and West)	Cross-sectional	(i) Work ability index had negative correlation with discomfort in the wrists ($r = -0.170$, $p = 0.007$), legs ($r = -0.129$, $p = 0.042$), and ankles ($r = -0.176$, $p = 0.005$.
Nazari et al. [39]	2020	325 full-time firefighters Hamilton, Ontario, Canada	Cross-sectional survey	(i) Firefighters with spinal pain experienced significantly more output limitation. Firefighters above 45 years experienced more physical work limitations. The number of musculoskeletal pain sites, age, and years of service predicted occupational output and work limitations.
Physical fitness and occupational performance ($n = 11$)				
von Heimburg et al. [70]	2006	13 full-time male firefighters aged between 24 and 56 years. Nord-Trøndelag County, Norway	Cross-sectional	(i) VO_{2max} was a significant predictor of simulation performance time. Better work performance was related to firefighters who were stronger, heavier, and taller.

http://etd.uwc.ac.za/

Table 4: Continued.

References	Year	Sample and setting	Study design (sampling)	Outcome
Elsner and Kolkhorst [84]	2008	20 full-time male firefighters San Diego, USA	Cross-sectional	(i) There was a moderately strong inverse relationship between the average VO_{2max} during the firefighting simulation protocol and performance time.
Sheaff et al. [72]	2010	33 full time firefighters, male (26) and female (7) aged between 18 and 45 years Baltimore, Washington, USA	Cross-sectional	(i) VO_{2max}, upper body strength, grip strength, and the HR response to stair climbing were significantly related to better performance on the candidate physical ability test ($p < 0.01$). Absolute VO_{2max} predicted candidate physical ability test performance ($p = 0.001$).
Michaelides et al. [73]	2011	90 full-time firefighters Arkansas, USA	Cross-sectional	(i) Ability test (AT) completion time was associated with abdominal strength ($p < 0.01$), relative power ($p < 0.01$), upper-body muscular endurance and upper-body strength ($p < 0.01$). Poor performance on the AT was associated with high resting heart rate ($p < 0.01$), high BMI ($p < 0.01$), high BF% ($p < 0.01$), aging ($p < 0.01$), and high WC ($p < 0.01$).
Heimburg et al. [74]	2013	63 full-time firefighters. Trondheim, Norway.	Cross-sectional	(i) Firefighters with higher a VO_{2max} who were stronger completed the simulation protocol faster ($p < 0.05$). Some firefighters with below average strength were among the quickest, indicating that a minimal strength was needed to perform well, and strength beyond that point did not improve performance times.
Kleinberg et al. [75]	2016	46 full-time male firefighters aged 24 to 50 years North Carolina, USA	Cross-sectional	(i) Quadriceps muscle strength was significantly associated with stair climb time ($r = 20.492$, $p = 0.001$), and remained significant after adjustment for age and BMI.
Siddal et al. [76]	2018	68 (63 male; 5 female) full-time firefighters Bath, England, United Kingdom	Cross-sectional	(i) Age, sex, height and/or lean mass were not significant predictors of the firefighter simulation test (FFST) performance time. The strongest predictor of FFST time was absolute VO_2 and fat mass.
Nazari et al. [26]	2018	46 male and 3 female firefighters between the ages of 20–69 years. Canada	Secondary analysis	(i) Grip strength and lower body strength were significant predictors of hose drag and stair climb completion times ($p < 0.05$), respectively.
Skinner et al. [77]	2020	42 male aviation rescue firefighters (ARFF) Queensland, Australia	Cross-sectional	(i) VO_{2max} ($p < 0.001$), anaerobic step test ($p < 0.001$), height ($p = 0.038$) and lean mass ($p = 0.005$) were inversely correlated with ARFF emergency protocol simulation performance time. Slower performance time was associated with higher fat mass ($p = 0.043$) and BF% ($p = 0.001$). Muscular strength, muscular endurance and flexibility were not related to performance on the simulated ARFF emergency protocol.
Xu et al. [63]	2020	20 full-time male firefighters Southeast China	Cross-sectional	(i) High BF% was associated with poor performance in ability tests, VO_{2max} was associated with increased performance, and upper and lower body muscular power were both inversely related to firefighter ability test completion time.
Norris et al. [64]	2021	19 full-time male firefighters Texas, USA	Cross-sectional	(i) Experience, jump height, inverted row endurance, relative bench and squat strength, and relative VO_2 were significant predictors of work efficiency ($p < 0.05$).

Note. Studies that were included were categorised chronologically. Few studies compared variables in more than one relationship and, therefore, few studies are repeated in the table.

http://etd.uwc.ac.za/

cholesterol (LDL-C) ($p < 0.001$) total cholesterol (TC) (p = 0.005), and total/high-density lipoprotein cholesterol ratio (TC/HDL-C) ($p < 0.001$). Higher cardiorespiratory fitness was also associated with higher HDL-C [47]. Similarly, Seyedmehdi et al. [29], in 157 full-time male firefighters in Tehran, reported that cardiorespiratory fitness was significantly correlated with age (OR = 4.86, p = 0.011), obesity (BM and WC) (OR = 4.69, p = 0.009), cigarette smoking (OR = 6.64, p = 0.045), physical inactivity (OR = 5.53, p = 0.003), blood cholesterol (OR = 5.44, p = 0.010), SBP (OR = 7.50, p = 0.045) and diastolic blood pressure (DBP) (OR = 2.70, p = 0.045), and heart rate (p = 0.001). Strauss et al. [8] also studied about 97 full-time firefighters in Germany and reported that age ($\beta = -2.04$, $p < 0.001$), obesity (BMI, WC, and BF%) ($\beta = -1.07$; $\beta = -3.23$; $\beta = -2.20$, $p < 0.001$), SBP ($\beta = -1.58$, r = 0.007), DBP ($\beta = -1.36$, p = 0.001), triglycerides ($\beta = -12.38$, p = 0.0024), and total cholesterol ($\beta = -4.90$, p = 0.0067) were significant predictors of cardiorespiratory fitness. Likewise, Espinoza et al. [57] investigated 76 volunteer Chilean male firefighters and reported that obesity ($\beta = -10.8$, $p < 0.001$), central obesity ($\beta = -7.71$, OR = 12.35, $p < 0.001$), and altered glucose ($\beta = -4.4$, OR = 2.87, p = 0.019) were significant predictors of cardiorespiratory fitness. The study also found that age ($r = -0.36$, $p < 0.001$), heart rate ($r = -0.27$, $p < 0.01$), SBP ($r = -0.24$, $p < 0.03$), and DBP ($r = -0.25$, $p < 0.02$) were negatively correlated with cardiorespiratory fitness. [57] The previous studies only investigated male firefighters, which limits the generalizability of the results.

Yang et al. [59] investigated the association between muscular endurance (push-up capacity) and CVD risk factors in 1562 full-time firefighters in Indiana, USA, and found that push-up capacity was significantly related to CVD risk factors, specifically, age ($p < 0.001$), obesity ($p < 0.001$), blood pressure (BP) ($p < 0.001$), TC (p = 0.02), LDL-C (p = 0.04), triglycerides ($p < 0.001$), blood glucose ($p < 0.001$), and smoking ($p < 0.001$). A limitation of the study was that the researchers investigated push-ups only and did not control for other physical fitness measures, which could have influenced the results. Also, the result cannot be generalized to women or older firefighters, as the cohort consisted of middle-aged male firefighters only. Another study on the impact of obesity on back and ab- dominal muscular endurance in 83 full-time firefighters from Florida, USA, 57 reported that back and core muscular endurance was 27% lower for obese firefighters compared to nonobese firefighters, and that significant negative corre- lations were reported between back endurance and age ($r = -0.22$, $p < 0.05$) and obesity ($r = -0.44$, $p < 0.01$) and between core endurance and obesity ($r = -0.47$, $p < 0.01$). Studies by Poplin et al. [50, 53] reported similar results in which aging was negatively correlated with $\dot{V}O_{2max}$ ($r = -0.368$, $p < 0.05$), and flexibility ($r = -0.160$, $p < 0.05$), and that BF% was negatively correlated with $\dot{V}O_{2max}$ ($r = -0.448$, $p < 0.05$), grip strength ($r = -0.191$, $p < 0.05$), and flexibility ($r = -0.135$, $p < 0.05$).

Baur et al. [48] investigated the relationship between physical fitness and autonomic abnormalities (heart rate recovery, chronotropic insufficiencies, ST elevation or depression, ventricular tachycardia, sustained supraventricular tachycardia, and exercise-induced left or right bundle branch block) in 1149 full-time male firefighters from the USA and reported that cardiorespiratory fitness was inversely associated with ECG and autonomic abnormalities (OR = 0.63, $p < 0.001$), and remained significant after being adjusted for age ($p < 0.001$), BMI ($p < 0.001$), and metabolic syndrome ($p < 0.001$). Similarly, Porto et al. [58] reported that a positive correlation existed between higher cardiorespiratory fitness and overall cardiac autonomic function and parasympathetic activity ($p < 0.001$). Autonomic function provides a valuable measure in determining CVD risk in firefighters and requires more research to investigate its use.

3.3. Cardiovascular Disease Risk Factors and Occupational Performance. Six studies examined the relationship between CVD risk factors and occupational performance in firefighters. The results of the studies are shown in Table 4. Walker et al. [52], in 73 full-time male Australian firefighters, found significant differences between age-groups for cardiorespiratory fitness (ω^2 = 0.23, $p < 0.001$), overall strength (ω^2 = 0.21, p = 0.001), dummy drag (ω^2 = 0.26, $p < 0.001$), and hose drag (ω^2 = 0.46, $p < 0.001$). Similarly, Nazari et al. [26] reported that age was a significant predictor of hose drag (β = 0.48, p = 0.003) and stair climb (β = 0.46, p=0.030) in firefighters. Saari et al. [62] investigated the influence of age on occupational performance in 74 full-time male firefighters in Kentucky, USA, reported that aging correlated with occupational course time (r = 0.297, p=0.017). Aged firefighters (≥37 years) had an 8.8% longer completion time compared to younger firefighters. The study also reported a trend between obesity and course time, but the relationship was not statistically significant. Another study found that aging (r = 0.42, $p < 0.01$) and obesity (r=0.57, $p < 0.01$) were significantly correlated with poorer performance in the physical ability test (PAT) in firefighters [73]. In addition, a high resting heart rate as correlated with poorer occupational performance (r = 0.36, $p < 0.01$). These results were supported by two studies which reported that high BF% was associated with poor performance in the physical ability tests [63], and that aging and fat mass were significant predictors of work inefficiency in firefighters [64]. Firoozeh et al. [61] conducted a study on 375 full-time male Australian firefighters and reported that age ($r = -0.277$, p = 0.001) and obesity ($r = -0.187$, p = 0.001) were negatively correlated with work ability, and that lei- sure-time physical activity (LTPA) (r = 0.206, p = 0.001) correlated to work ability. Similarly, an earlier study by Airila et al. [60] reported that, in 403 male Finnish fire- fighters, age ($r = -0.33$, $p < 0.01$), obesity ($r = -0.15$, $p < 0.01$), and cigarette smoking (r = 0.10, $p < 0.05$) were negatively correlated with work ability, and that physical exercise ($r = -0.15$, $p < 0.01$) correlated with work ability and work demands. A model reported that various CVD risk factors, such as alcohol consumption, obesity, cigarette smoking, and physical activity were significant predictors of work ability (R^2 = 0.48, $p < 0.001$) [60]. Nazari et al. [39]

http://etd.uwc.ac.za/

reported that aged firefighters (≥45 years) experienced significantly more physical work limitations than their younger counterparts ($\beta = 0.27$, $p = 0.004$). In the studies by Firoozah et al., Airila et al., and Nazari et al., work ability was self-reported, and not verified using simulation tasks, which could include subjective bias in the reporting.

In contrast to the previous studies, Phillips et al. [7] reported that obese firefighters had significantly faster completion times for the hose drag ($r = -0.44$, $p < 0.05$), weighted-sled pull ($r = -0.36$, $p < 0.05$), forcible entry (r=-0.27, $p < 0.05$), and victim rescue ($r = -0.21$, $p < 0.05$), whereas normal weight firefighters only performed better on the ladder climb task ($r = -0.24$, $p < 0.05$). However, the uniformity of body mass across participants was not controlled, and the results may not be a true reflection of the effect of obesity on occupational performance.

3.4. Musculoskeletal Health and Physical Fitness. Five studies investigated the relationship between musculoskeletal health and physical fitness in firefighters. The results are summarized in Table 4. All aspects of physical fitness play an important role in the maintenance of musculoskeletal health, through increased skeletal muscle strength, con- nective tissue integrity, and increased bone mineral density [45, 79–81]. High levels of physical fitness may prove beneficial for firefighters and can significantly reduce the incidence of injuries [79].

Butler et al. [66] reported that three flexibility movements (fundamental movements) were significant predictors of injuries in firefighters, namely, the sit-and-reach ($\beta = 0.218$, $p < 0.05$), push-up ($\beta = 0.190$, $p < 0.05$), and deep squat ($\beta = 0.266$, $p < 0.05$). Firefighters who performed poorly on the sit-and-reach, deep squat, and push-up were 1.21, 1.24, and 1.30 times more likely to sustain injury, respectively [66]. Flexibility, particularly related to fundamental movements, may prove to be an important measure in preventing injuries in firefighters.

Wynn and Hawdon [65] conducted a study in 398 full-time and 48 part-time recruits with no fitness standard, and 198 full-time and 206 part time recruits where a minimum cardiorespiratory fitness standard of 42 mL·kg·min was applied, and reported that poor musculoskeletal health was more likely to occur in the service where no physical fitness standard was required. In addition, higher cardiorespiratory fitness was a significant predictor of lower incidence of musculoskeletal health issues [65]. A similar result was reported by Poplin et al. [50] where a longitudinal study was conducted investigating the effect of cardiorespiratory fitness on musculoskeletal health in 577 full-time firefighters in the Southwestern States, USA. The results indicated that firefighters in the lowest fitness categories were 2.2 times more likely to sustain injuries, compared to those in the highest fitness categories. Furthermore, the study found that firefighters with a cardiorespiratory fitness between 43 and 48 $mL \cdot kg^{-1} \cdot minute^{-1}$ were 1.38 times more likely to sustain injury. Improving cardiorespiratory fitness by one metabolic equivalent was shown to reduce the risk of any injury by 14%. A later study by Poplin et al. [53] reported a similar result with 799 full-time firefighters which noted that firefighters with lower cardiorespiratory fitness were 1.82 times more likely to sustain injury. When injury types were restricted to sprains and strains exclusively, firefighters with lower cardiorespiratory fitness were 2.90 times more likely sustain an injury [53].

In contrast to the previous studies, a study by Damrongsak et al. [44] found that high physical fitness did not reduce the incidence of back pain in firefighters. Similarly, Gordon and Lariviere [42] noted that higher cardiorespiratory fitness was not significantly associated with better musculoskeletal health in firefighters. Butler et al. [66] also reported a similar result, where cardiorespiratory fitness was not a predictor of injuries in firefighters. Interestingly, a study by Jahnke et al. [21] in 462 full-time firefighters reported that firefighters who exercised regularly while on duty were 4.6 times more likely to sustain an exercise-related injury. In addition, higher levels of cardiorespiratory fitness and muscular strength increased exercise-related musculoskeletal injury risk by 1.06 and 4.03 times, respectively, while on-duty. However, regular exercise when on duty did reduce the incidence of injuries outside of the workplace. High workload when on duty, compounded by exercise or training workload and inadequate recovery possibly pro- duced a burdensome triad that reduced musculoskeletal health and contributed to the increased incidence of duty- related injury [78, 82].

3.5. Musculoskeletal Health and Occupational Performance. Five studies investigated the relationship between musculoskeletal health and occupational performance in firefighters. The results of the studies are indicated in Table 4. Firefighting is a physically demanding occupation that requires the musculoskeletal system to be in good condition for firefighters to perform at peak performance [17, 39, 45, 83]. Chronic musculoskeletal pain and chronic disorders negatively affect performance and reduce endurance capacity and force production [79]. Musculoskeletal health is essential for satisfactory work performance in any emergency occupation, particularly in firefighting [80, 83]. Punakallio et al. [67] investigated the effect of musculoskeletal health on self-reported work ability in 411 male firefighters from Helsinki Finland and reported that musculoskeletal pain (MSP) in more than one site was at increased risk of diminished work ability. The study also found that musculoskeletal health isolated to the low back (OR = 1.9), forearm, and hand (OR = 1.9) predicted diminished work ability. In addition, firefighters who were on disability pension reported having poor work ability and more musculoskeletal health concerns at baseline. Furthermore, firefighters engaging in average-to-high physical workload when on duty was a significant risk factor for retiring due to deteriorated musculoskeletal health (OR: 3.1 to OR: 5.3, respectively). Similarly, Saremi et al. [69] in 250 Tehran firefighters reported an inverse relationship between work-ability index and musculoskeletal discomfort in the wrists ($p = 0.007$, $r = -0.170$), legs ($p = 0.042$, $r = -0.129$), and ankles ($p = 0.005$, $r = -0.176$). Kodom–Wiredu [68]

http://etd.uwc.ac.za/

examined 320 full-time firefighters in the Greater Accra region of Ghana found that work-related musculoskeletal disorders (WRMSD) were significantly related to work demands ($r = 0.03$) and task characteristics ($r = 0.26$), and that increased work demands ($\beta = 0.226$, $p < 0.01$) and task characteristics ($\beta = 0.214$, $p < 0.01$) were significant predictors of WRMSDs. Similarly, Nazari et al. [39] in 325 full-time Canadian firefighters found a significant relationship between musculoskeletal health and self-reported physical work limitations. The study noted that firefighters with spinal pain ($p = 0.01$) experienced significantly limited occupational output. In addition, the number of musculoskeletal pain sites ($p = 0.02$) were significant predictors of limited occupational output and work performance [39]. MacDermid et al. [40] in the sample of 293 full-time Canadian firefighters reported that firefighters with moderate-to-severe muscle and joint complaints took on average 10 seconds longer to complete functional performance tasks, but the results were not statistically significant [40]. However, the majority of studies were self-reported measures for work ability and, therefore, may be subject to reporting bias. More research needs to be conducted in this particular area, where firefighters with pain or deteriorating musculoskeletal health are assessed while performing simulated tasks, that would be faced while on active duty.

3.6. Physical Fitness and Occupational Performance. Ten studies investigated the relationship between physical fitness and occupational health in firefighters. The results are summarized in Table 4. Due to the inherently physical nature of firefighting, physical fitness is regarded as a fundamental component for optimum occupational performance. Various studies showed that muscular strength, muscular endurance, and cardiorespiratory fitness were significantly related to firefighter occupational ability and performance [83, 84].

von Heimburg et al. [70] in 13 male Norwegian firefighters reported that cardiorespiratory fitness was a significant predictor of simulation performance times ($r = 0.53$, $p = 0.05$). Furthermore, stronger, heavier, and taller firefighters had a significantly lower performance time ($p = 0.01$). The authors noted that the small sample size of the study negatively impacted the generalizability of the results. Another study with 20 male firefighters reported a moderately strong and inverse relationship between cardiorespiratory fitness and performance time in firefighter simulation protocols [84]. The small sample size and using male firefighters only limits the generalizability of the results. Skinner et al. [77] examined the predictors of task performance in 42 male aerial firefighters from Queensland Australia and found that cardiorespiratory fitness and body composition were inversely correlated to firefighting simulation protocol performance time. Poor body composition was significantly related to slower performance time on the simulation. Similarly, Xu et al. [63] reported that poor body composition (higher BF%) was associated with poor performance on the work ability test in 20 full-time Chinese firefighters. Superior cardiorespiratory fitness, and upper and lower body muscular power, was inversely related to the completion times in the work ability test.

Sheaff et al. [72] in 33 firefighters reported that certain physical fitness parameters, such as cardiorespiratory fitness ($r = 0.602$, $p < 0.001$), upper body strength ($r = 0.485$, $p < 0.001$), and grip strength ($r = 0.504$, $p = 0.009$), were significantly related to performance times in the Candidate Physical Ability Test (CPAT). Cardiorespiratory fitness was a significant predictor of CPAT performance. Similarly, Michaelides et al. [73] reported that firefighter ability test completion times were significantly related to abdominal strength, relative power, upper-body muscular endurance, and upper body strength. The study also noted that poor performance on the ability test was associated with poor body composition. However, the studies by Sheaff et al. and Michaelides et al. used small sample sizes with few females, which negatively impacted the statistical power and generalizability of the results. Nazari et al. [26] noted that right-hand grip strength was a significant predictor of hose drag times, and that lower body strength was a significant predictor of stair climb in firefighters. In addition, cardiorespiratory fitness was significantly correlated with the task times for the hose drag ($r = -0.30$, $p = 0.01$) and stair climb ($r=0.31$, $p = 0.01$), and that increased lower body strength was significantly correlated with hose drag time ($r = -0.20$, $p = 0.01$) [26]. The importance of muscular strength in occupational performance was emphasized by Kleinberg et al. [75] who reported that lower body strength ($r = 0.560$, $p < 0.001$) was significantly associated with stair climb time in firefighters that remained significant after adjustment for age and BMI.

A later study by Heimburg et al. [74] in 63 full-time Norwegian firefighters reported that the treadmill and push up tests ($r = -0.42$, $p < 0.001$), squat and raise ($r = -0.54$, $p < 0.001$), and horizontal chest to bar pullups ($r = -0.34$, $p = 0.1$) were significantly related to faster simulation task times. Firefighters had a higher cardiorespiratory fitness and were stronger completed the simulation protocol faster ($p < 0.05$). Anomalies in the results existed, where firefighters with below average strength completed the test the quickest, indicating that a minimal strength was needed to perform well, and strength beyond that point did not improve performance times [74]. Comparably, a study on 68 full-time English firefighters from the United Kingdom reported that cardiorespiratory fitness was the strongest predictor of firefighter simulation task time [76]. However, contrary to the previous studies, muscular strength was not found to be a significant predictor of firefighter simulation task time [76].

4. Discussion

In the present review, the most frequent relationships investigated were between CVD risk factors and physical fitness (fourteen studies) and between physical fitness and occupational performance (ten studies). This may be due to CVD risk factors and physical fitness being especially important for firefighters' career longevity and work performance [2, 3, 15]. In addition, the relationships between CVD

http://etd.uwc.ac.za/

risk factors, musculoskeletal health, and between musculoskeletal health and physical fitness were understudied, especially in relation to occupational performance. However, studies investigating musculoskeletal health and occupational performance reported that musculoskeletal health negatively affected firefighter performance.

There was a significant inverse relationship between increased CVD risk factors and reduced musculoskeletal health in firefighters, which was particularly related to increased age, obesity, cigarette smoking, and physical inactivity. [22, 24, 43–45] Aging caused a decrease in bone mineral density, a decrease in ligament and tendon elasticity, and reduced tissue recovery and healing time that predisposed firefighters to injury while on duty [35, 45]. Obesity increased the overall force placed on the musculoskeletal system, particularly when engaged in activities of vigorous-intensity, such as firefighting [12, 85, 86]. As seen in Figure 3, obese firefighters fatigue at a faster rate, resulting in acute traumatic injuries and chronic overuse injuries [22]. Fatigue causes inadequate energy absorption, as well as reduced control and regulation of limb movements [87]. The present review shows that smoking has a negative effect on tendon health, bone mineral density, and hormone regulation, particularly oestrogen and cortisol [34], and may partially explain the decreased musculoskeletal health and increased injury risk in firefighters. Physical activity has a protective effect on the musculoskeletal system, particularly vigorous-intensity activity [88]. Unfortunately, research shows that firefighters tended to be physically inactive, with many not reaching the minimum weekly recommended amount of physical activity [9, 27, 47, 56, 78]. Aging, obesity, cigarette smoking, and physical inactivity negatively affected both cardiovascular and musculoskeletal health (Figure 3), and should be identified early in firefighters and given particular attention in the latter stages of their careers.

Cardiovascular disease risk factors, such as age, obesity, lipid profile, blood glucose, blood pressure, cigarette smoking, and physical inactivity were shown to be significantly related to cardiorespiratory fitness and muscular endurance in firefighters [9, 27, 29, 47, 48, 51, 54, 56, 58, 59]. In addition, back and core endurance were significantly related to age and obesity in firefighters [49]. Furthermore, CVD risk factors were significantly related to cardiorespiratory fitness in firefighters [46, 55]. The progressive deterioration in cardiovascular, pulmonary, and musculoskeletal health with increasing age accounted for the decrease in cardiorespiratory fitness and muscular endurance in firefighters [27, 89]. This is further exacerbated by the constant chemical and fume inhalation, which negatively effects pulmonary functioning in firefighters [90]. In the case of obesity, the increased weight and peripheral resistance to blood flow increased the stress and workload placed on the musculoskeletal and cardiovascular systems, resulting in a decrease in endurance capacity [22, 91]. Consequently, with aging, this effect is further compounded by the biological deterioration in cardiovascular, musculoskeletal, and pulmonary health [89].

An altered lipid profile negatively affected cardiorespiratory fitness in firefighters [9, 29, 47]. This relationship can be explained in a study conducted by Rumora et al. [92], where the results showed that dyslipidaemia caused altered mitochondrial functioning that decreased energy production. Reduced mitochondrial function negatively affects aerobic performance [93]. High blood glucose concentrations negatively affects glucose homeostasis and glucose metabolism, and together with altered mitochondrial function in skeletal muscles, these negatively affect endurance capacity [94]. Elevated DBP and SBP also negatively affect cardiorespiratory capacity, due to altered diastolic atrial and ventricular filling, subsequently reducing the stroke volume of the heart. In addition, the increase in blood pressure increases the cardiac afterload, further reducing stroke volume and cardiac output (Figure 3) [95]. Cigarette smoking causes pulmonary damage and reduces the oxygen-carrying capacity in the blood that may explain the inverse relationship seen between the two factors [34]. Physical inactivity augments the progressive decline in the cardiovascular, pulmonary, and musculoskeletal systems and, thereby, partially explains the linear relationship with cardiorespiratory fitness [48, 96].

Aging, obesity, cigarette smoking, and physical inactivity were the CVD risk factors related to poor physical fitness, occupational performance, and work ability in firefighters [26, 52, 60–62, 69, 73]. In addition, increased leisure time physical activity was positively related to work ability in firefighters [61]. Firefighting often requires firefighters to perform complex, vigorous-intensity activities that strain all systems of the body. Aging generally reduces muscular force production, cardiorespiratory efficiency, tissue elasticity, healing, and repair, more especially when combined with an unhealthy lifestyle [89]. This directly affects the performance of occupational tasks and partially explains the reduction in work performance with progressively advancing age [27, 62]. The pervasive physical inactivity and unhealthy lifestyle that often accompanies firefighters as they age further exacerbates the deleterious effects of aging [9, 56, 78]. In addition, obesity places significant strain on all bodily systems, causing premature fatigue and, consequently, reduced occupational performance [73]. As a result of cigarette smoking, the reduction in pulmonary capacity and oxygen-carrying capacity also adversely affects occupational performance [27, 96].

One study reported that increased body mass of firefighters related to better performance on certain firefighter specific tasks, especially tasks requiring significant muscular [7]. The relationship between increased body weight and a reduction in task completion times may be related to the increase in muscle mass that accounted for the increase in body mass rather than an increase in fat [7]. Muscle strength can be a significant factor in the optimal performance of firefighters. Heavier firefighters may perform better on strength-based occupational tasks but perform worse on cardiorespiratory fitness tests [7, 26, 29, 47, 97]. Consequently, for optimal work performance, firefighters require delicate balance between cardiovascular fitness and muscular strength for occupational task performance.

Current literature indicated that increased cardiorespiratory fitness was significantly related to fewer

http://etd.uwc.ac.za/

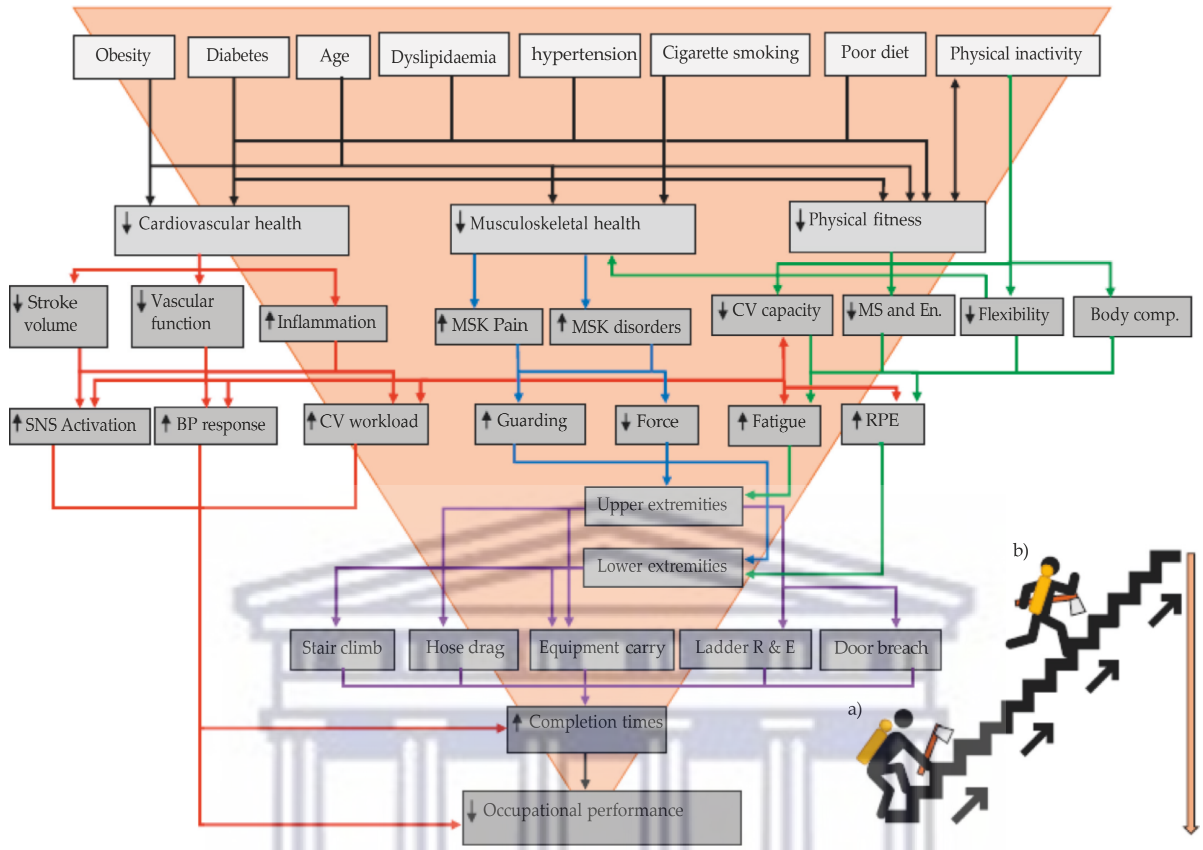


Figure 3: Flow diagram illustrating the relationship between CVD risk factors, musculoskeletal health, physical fitness, and occupational performance in firefighters. (a) Indicates an unfit firefighter performing the stair climb test with much difficulty, and representing decreased occupational performance; (b) indicates a fit firefighter performing the stair climbtest with ease, representing optimal occupational performance. Black lines indicate cardiovascular disease risk factors; red lines indicates cardiovascular health and all related outcomes; blue lines indicate musculoskelatal health and all related outcomes; green lines indicate physical fitness and all related outcomes; purple lines indicate occupational performance and all related outcomes.

musculoskeletal injuries in firefighters, and that three fundamental movements related to flexibility could predict injuries, i.e., the sit-and-reach, push-up, and deep squat [50, 53, 65]. Any form of physical activity has a protective effect on musculoskeletal health, whether aerobic or an- aerobic in nature and, furthermore, performing regular aerobic exercise translates into improved cardiorespiratory fitness [9, 21]. Flexibility, particularly in the lower back, hamstrings, and hips, is related to reduced injury incidence [66]. Functional flexibility is a critical fitness parameter in firefighters, as their work requires awkward movement patterns, such as bending, lifting, and crawling [66, 98].

In contrast, one study reported that firefighters who exercised were not at lower risk of sustaining musculoskeletal injury [44]. Another study found that firefighters who exercised, while on duty, were at higher risk for sustaining work-related injury [21]. A possible reason for the increase in injury incidence in firefighters who exercised while on-duty may be due to the chronic overload placed on the muscular system, which led to acute overload injuries [19, 99]. Firefighters who participate in regular physical activity should monitor their overall workload and balance the workload with adequate recovery time in order to reduce the incidence of injury. Finding this "sweet spot" may prove essential to maintaining optimal musculoskeletal health and preventing injury.

Poor musculoskeletal health negatively affected occupational performance and work ability in firefighters, and was particularly related to low back, forearm, wrist, hand, and leg discomfort [67–69]. Increased work demands and the various types of task performed were significantly related to musculoskeletal disorders [68]. Spinal pain and multiple injuries were significantly related to limitations in occupational output and work performance [39]. Firefighters with moderate-to-severe muscle and joint problems took 10 seconds longer to complete occupational performance tasks [40]. Injuries and chronic pain reduced muscular force production, and altered movement patterns to compensate for the workload on the injured or painful area [39]. The reduced force production and protective movement patterns acted as a subconscious protective mechanism that may negatively affect on-duty performance [39, 80, 100]. These altered movement patterns may become particularly apparent in emergency situations, which require maximum force production, muscular endurance, and coordination, such as door breaches, equipment carries, and hose drags.

http://etd.uwc.ac.za/

However, more research is needed on the extent to which the location and severity of injuries negatively affected occupational performance, especially in firefighter specific tasks.

Cardiorespiratory fitness was significantly related to all components of occupational task performance in firefighters [26, 63, 72, 73, 77, 84, 101]. In addition, upper body muscular strength and endurance were significant predictors of occupational performance [26, 72, 73]. Quadriceps strength was a significant predictor of stair climb performance in firefighters [75]. Firefighters routinely have to perform activities that are exhaustive on the upper body, such as door breaches, hose carries, hose drags, victim drags, and victim carries [74, 76, 102]. In addition, firefighting simulation tasks require predominantly upper body strength and endurance [63, 70, 74, 76, 77]. Therefore, firefighters with greater upper body strength and endurance generally perform better on these tasks increased fat mass and lower lean mass were significantly related to poor occupational performance [63, 77]. Poor performance in firefighters with unhealthy body composition may be related to the increased muscular workload, as a result of the increased adiposity and lower proportion of lean body mass [6, 7, 26, 63, 76, 77].

In firefighting, all health-related physical fitness parameters positively affected occupational performance [70, 74]. However, beyond the threshold of desirable physical fitness, this point further improves in fitness that had little benefit on occupational performance [74]. This indicated that firefighters may be competent in performing the occupational tasks, due to having sufficient physical fitness, despite having underlying cardiovascular and musculoskeletal health challenges. Consequently, firefighters may be on active duty, while having underlying health concerns, which may account for the high cardiovascular-related morbidity and mortality [2, 11, 15, 103], and the high rate of musculoskeletal related complaints that resulted in early retirement in this population [19, 20, 69, 81]. All aspects of the firefighters' health should be thoroughly monitored throughout the firefighters' career to ensure career longevity and decrease the incidence of duty related- deaths and early retirement. As previously discussed, larger and heavier firefighters, who are often obese, tended to perform better on strength-based tasks, such as the door breach, equipment carry, and victim drags, but performed worse on the cardiorespiratory fitness tests, such as the stair climb and ladder raise tests, due to their excess body weight that acted as a hindrance in these tasks [6, 26, 74, 76]. While overweight and obese firefighters may pass the simulation protocols, they remain at increased risk for early retirement, morbidity, and mortality.

As seen in Figure 3, CVD risk factors, musculoskeletal health, and physical fitness play a significant role in firefighter occupational performance. Increased CVD risk increases the cardiovascular strain associated with firefighting and, in the same vein, reduced musculoskeletal health, increased musculoskeletal pain and the risk of musculoskeletal disorders, thereby, reducing muscular force and occupational. Poor physical fitness increases the cardiovascular strain and reduces musculoskeletal health that causes an overall decrease in cardiorespiratory capacity and musculoskeletal strength, endurance, and flexibility, which is further compounded by poor body composition. Together, these factors cause increased fatigue and reduced the occupational performance for any given task and, as a consequence, leads to slower task completion times and poor overall occupational performance in firefighters.

The literature indicates that most CVD risk factors have a negative effect on physical fitness [9, 27, 29, 47, 48, 51, 54, 56, 58, 59], and that physical fitness and musculoskeletal health are significantly related [50, 53, 65]. Because physical fitness is related to occupa- tional performance, the assumption can be made that in- creased CVD risk factors and reduced musculoskeletal health would result in reduced occupational performance in firefighters. However, this needs to be investigated further.

4.1. Strengths of the Study. The majority of studies were conducted in the USA, with relatively small sample sizes, and involved males primarily, thus limiting the generalizability of the results to the broader firefighting population. The narrative review involved an iterative process of checking and cross-checking in order to ensure a narrative review of the highest quality and rigour. The quality assessment process started with the identification of the search terms and constructing the search string that was database specific, and ended with the data extraction and interpretation of the findings.

4.2. Limitations of the Study. The limited number of electronic databases searched and that only articles in English and in full-text were considered for selection are limitations to the current literature review. There were no qualitative studies included in the current study and, therefore, only quantitative studies were used. No critical appraisal or risk of bias tools were used to grade the included studies, however, the authors attempted to maintain methodological transparency and rigor throughout the review process.

5. Conclusion

Cardiovascular disease risk factors and physical fitness were the most frequently studied areas in firefighters and were significantly related. Cardiovascular disease risk factors were significantly related to cardiorespiratory fitness in firefighters, particularly age, obesity hypertension, dyslipidaemia, cigarette smoking, and physical inactivity. In addition, physical fitness, especially cardiorespiratory fitness, was found to be significantly related to overall occupational performance. Certain CVD risk factors were significantly related to musculoskeletal health, and in particular, obesity and cigarette smoking. Cardiovascular risk factors, such as obesity and age were significantly related to worse occupational performance. Musculoskeletal health, in relation to occupational performance, is understudied; however, the results indicated that poor musculoskeletal health was related to work and performance limitations. Overall, the research indicated that aged, obese, and unfit firefighters who smoked cigarettes and were physically inactive were at

http://etd.uwc.ac.za/

the highest risk for CVD and musculoskeletal health complications, and produced unsatisfactory occupational performance. Moreover, most CVD risk factors were related to low levels of physical fitness. Due to limited research, significant gaps still remain in the literature and, in particular, regarding the relationship between musculoskeletal health and occupational performance. In addition, firefighters are understudied in developing countries, and, in particular, African countries.

5.1. Recommendations. More research should be conducted investigating the relationship between CVD risk factors and occupational performance, between musculoskeletal health and physical fitness, and between musculoskeletal health and occupational performance. In addition, females were underrepresented in many of the studies and, therefore, more research involving female firefighters should be conducted. The majority of studies on firefighters were conducted in developed countries and the results cannot be generalized to firefighters in developing countries. Consequently, more research is needed in developing countries to provide a more holistic view of firefighters globally. This will inform policy makers, as well as fire departments on the most significant factors influencing occupational performance in both developed and developing countries. There is a need by the fire services to implement corrective intervention strategies early, such as educational and lifestyle modification programmes, including physical training regimes designed to address the high prevalence of CVD, musculoskeletal disorders, and complaints, and the low levels of physical fitness amongst the majority of firefighter and, thereby, attempt to reduce the elevated morbidity and mortalities rates in the fire services, globally.

Data Availability

This is a review article and, therefore, no direct data will be available.

Conflicts of Interest

The authors have no conflicts of interest.

Acknowledgments

The Ryoichi Sasakawa Young Leaders Fellowship Fund (Sylff) Program (Grant number: N/A) and the National Research Foundation (NRF) (Grant number: 141282).

References

[1] J. H. Shin, J. Y. Lee, S. H. Yang, M. Y. Lee, and I. S. Chung, "Factors related to heart rate variability among firefighters," *Annals of Occupational and Environmental Medicine*, vol. 28, no. 1, pp. 25–29, 2016.

[2] D. L. Smith, D. A. Barr, and S. N. Kales, "Extreme sacrifice: sudden cardiac death in the US fire service," *Extreme Physiology & Medicine*, vol. 2, no. 1, pp. 6–9, 2013.

[3] D. L. Smith, J. P. DeBlois, S. N. Kales, and G. P. Horn, "Cardiovascular strain of firefighting and the risk of sudden cardiac events," *Exercise and Sport Sciences Reviews*, vol. 44, no. 3, pp. 90–97, 2016.

[4] S. S. Al-Zaiti and M. G. Carey, "The prevalence of clinical and electrocardiographic risk factors of cardiovascular death among on-duty professional firefighters," *Journal of Cardiovascular Nursing*, vol. 30, no. 5, pp. 440–446, 2015.

[5] D. L. Feairheller, "Blood pressure and heart rate responses in volunteer firefighters while wearing personal protective equipment," *Blood Pressure Monitoring*, vol. 20, no. 4, pp. 194–198, 2015.

[6] M. Schmit and M. DeBeliso, "The relationship between firefighters' physical performance aspects and simulated firefighting demands," *Turkish Journal of Kinesiology*, vol. 5, no. 2, pp. 63–75, 2019.

[7] D. B. Phillips, M. P. Scarlett, and S. R. Petersen, "The influence of body mass on physical fitness test performance in male firefighter applicants," *Journal of Occupational and Environmental Medicine*, vol. 59, no. 11, pp. 1101–1108, 2017.

[8] M. Strauss, P. Foshag, U. Jehn, A. Brzęk, H. Littwitz, and R. Leischik, "Higher cardiorespiratory fitness is strongly associated with lower cardiovascular risk factors in firefighters: a cross - sectional study in a German fire brigade," *Scientific Reports*, vol. 11, no. 1, pp. 2445–2447, 2021.

[9] G. Durand, A. J. Tsismenakis, S. A. Jahnke, D. M. Baur, C. A. Christophi, and S. N. Kales, "Firefighters' physical activity: relation to fitness and cardiovascular disease risk," *Medicine & Science in Sports & Exercise*, vol. 43, no. 9, pp. 1752–1759, 2011.

[10] N. Jitnarin, W. S. Poston, C. K. Haddock, S. A. Jahnke, and R. S. Day, "Tobacco use pattern among a national firefighter cohort," *Nicotine & Tobacco Research*, vol. 17, no. 1, pp. 66–73, 2015.

[11] J. Yang, D. Teehan, A. Farioli, D. M. Baur, D. Smith, and S. N. Kales, "Sudden cardiac death among firefighters ≤45 years of age in the United States," *The American Journal of Cardiology*, vol. 112, no. 12, pp. 1962–1967, 2013.

[12] C. M. Kaipust, S. A. Jahnke, W. S. C. Poston et al., "Sleep, obesity, and injury among US male career firefighters," *Journal of Occupational and Environmental Medicine*, vol. 61, no. 4, pp. E150–E154, 2019.

[13] Z. J. McKinney, R. S. Bovard, M. N. Starchook-Moore et al., "Cardiorespiratory fitness of firefighters: initial results of a multi-phased study," *Journal of Occupational and Environmental Medicine*, vol. 63, no. 1, pp. 57–63, 2021.

[14] B. della Torre, S. Management, and H. S. Geneva, "Impact of a healthy eating promotion program Keywords," vol. 61, no. 5, 2019.

[15] D. L. Smith, J. M. Haller, M. Korre et al., "The relation of emergency duties to cardiac death among US firefighters," *The American Journal of Cardiology*, vol. 123, no. 5, pp. 736–741, 2019.

[16] T. W. Storer, B. A. Dolezal, M. L. Abrazado et al., "Firefighter health and fitness assessment: a call to action," *The Journal of Strength & Conditioning Research*, vol. 28, no. 3, pp. 661–671, 2014, https://journals.lww.com/nsca-jscr/Fulltext/2014/03000/Firefighter_Health_and_Fitness_Assessment__A_Call.11.aspx.

[17] D. M. Frost, T. A. C. Beach, I. Crosby, and S. M. McGill, "Firefighter injuries are not just a fireground problem," *Work*, vol. 52, no. 4, pp. 835–842, 2015.

[18] J. Vaulerin, F. d'Arripe-Longueville, M. Emile, and S. S. Colson, "Physical exercise and burnout facets predict injuries in a population-based sample of French career firefighters," *Applied Ergonomics*, vol. 54, pp. 131–135, 2016.

http://etd.uwc.ac.za/

[19] O. Hong, S. Phelps, J. Feld, and S. Vogel, "Occupational injuries, duty status, and factors associated with injuries among firefighters," *Workplace Health & Safety*, vol. 60, no. 12, pp. 517–523, 2012.

[20] J. H. Yoon, Y. K. Kim, K. S. Kim, and Y. S. Ahn, "Characteristics of workplace injuries among nineteen thousand Korean firefighters," *Journal of Korean Medical Science*, vol. 31, no. 10, pp. 1546–1552, 2016.

[21] S. A. Jahnke, W. S. C. Poston, C. K. Haddock, and N. Jitnarin, "Injury among a population based sample of career firefighters in the central USA," *Injury Prevention*, vol. 19, no. 6, pp. 393–398, 2013, Published online March 1, 2013:injuryprev-2012-040662.

[22] S. A. Jahnke, W. S. C. Poston, C. K. Haddock, and N. Jitnarin, "Obesity and incident injury among career firefighters in the central United States," *Obesity*, vol. 21, no. 8, pp. 1505–1508, 2013.

[23] C. Tomes, B. Schram, and R. Orr, "Relationships between heart rate variability, occupational performance, and fitness for tactical personnel: a systematic review," *Frontiers in Public Health*, vol. 8, p. 583336, 2020.

[24] A. Punakallio, H. Lindholm, R. Luukkonen, and S. Lusa, "Lifestyle factors predicting changes in aerobic capacity of aging firefighters at 3-and 13-year follow-ups," *Journal of Occupational and Environmental Medicine*, vol. 54, no. 9, pp. 1133–1141, 2012.

[25] G. Nazari, S. Lu, and J. C. MacDermid, "Quantifying physiological responses during simulated tasks among Canadian firefighters: a systematic review and meta-analysis," *Journal of Military, Veteran and Family Health*, vol. 7, no. 1, pp. 55–75, 2021.

[26] G. Nazari, J. C. MacDermid, K. E. Sinden, and T. J. Overend, "The relationship between physical fitness and simulated firefighting task performance," *Rehabilitation Research and Practice*, vol. 2018, pp. 1–7, 2018.

[27] D. M. Baur, C. A. Christophi, E. F. Cook, and S. N. Kales, "Age-related decline in cardiorespiratory fitness among career firefighters: modification by physical activity and adiposity," *Journal of Obesity*, vol. 2012, pp. 1–6, 2012.

[28] A. M. Nowak, B. Molik, A. Wo´jcik et al., "Physical activity and injuries relating to physical fitness of professional firefighters," *Advances in Rehabilitation*, vol. 32, no. 2, pp. 13–22, 2018.

[29] S. M. Seyedmehdi, M. Attarchi, A. S. Cherati, S. Hajsadeghi, R. Tofighi, and H. Jamaati, "Relationship of aerobic fitness with cardiovascular risk factors in firefighters," *Work*, vol. 55, no. 1, pp. 155–161, 2016.

[30] E. J. Ketelaar, A. G. Vos, N. G. Godijk et al., "Ideal cardiovascular health index and its determinants in a rural South African population," *Global Heart*, vol. 15, no. 1, pp. 76–11, 2020.

[31] D. K. Arnett, R. S. Blumenthal, M. A. Albert et al., "2019 ACC/AHA guideline on the primary prevention of cardiovascular disease: a report of the american college of cardiology/american heart association task force on clinical practice guidelines," *Circulation*, vol. 140, no. 11, pp. e596–e646, 2019.

[32] G. E. Billman, H. v. Huikuri, J. Sacha, and K. Trimmel, "An introduction to heart rate variability: methodological considerations and clinical applications," *Frontiers in Physiology*, vol. 6, pp. 55–2015, 2015;6(February.

[33] I. Vuori, "Exercise and physical health: musculoskeletal health and functional capabilities," *Research Quarterly for Exercise & Sport*, vol. 66, no. 4, pp. 276–285, 1995.

[34] M. Abate, D. Vanni, A. Pantalone, and V. Salini, "Cigarette smoking and musculoskeletal disorders," *Muscles, ligaments and tendons journal*, vol. 3, no. 2, pp. 63–69, 2013.

[35] W. R. Frontera, "Physiologic changes of the musculoskeletal system with aging: a brief review," *Physical Medicine and Rehabilitation Clinics of North America*, vol. 28, no. 4, pp. 705–711, 2017.

[36] C. J. Caspersen, K. E. Powell, and G. M. Christenson, "Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research," *Public Health Reports*, vol. 100, no. 2, pp. 126–131, 1985, https://pubmed.ncbi.nlm.nih.gov/3920711.

[37] C. Chapparo and J. Ranka, "Occupational performance model (Australia): definition of terms," *Occupational performance model (Australia): Monograph*, vol. 1, pp. 58–60, 1997.

[38] M. D. J. Peters, C. M. Godfrey, H. Khalil, P. McInerney, D. Parker, and C. B. Soares, "Guidance for conducting systematic scoping reviews," *International Journal of Evidence-Based Healthcare*, vol. 13, no. 3, pp. 141–146, 2015.

[39] G. Nazari, T. A. Osifeso, and J. C. MacDermid, "Distribution of number, location of pain and comorbidities, and determinants of work limitations among firefighters," in *Rehabilitation Research and Practice*, A. Rimmerman, Ed., vol. 2020, Article ID 1942513, 2020.

[40] J. C. MacDermid, K. Tang, K. E. Sinden, and R. D'Amico, "Work functioning among firefighters: a comparison between self-reported limitations and functional task performance," *Journal of Occupational Rehabilitation*, vol. 29, no. 1, pp. 194–204, 2019.

[41] W. S. C. Poston, N. Jitnarin, C. K. Haddock, S. A. Jahnke, and B. C. Tuley, "Obesity and injury-related absenteeism in a population-based firefighter cohort," *Obesity*, vol. 19, no. 10, pp. 2076–2081, 2011.

[42] H. Gordon and M. Lariviere, "Physical and psychological determinants of injury in Ontario forest firefighters," *Occupational Medicine*, vol. 64, no. 8, pp. 583–588, 2014.

[43] T. W. Jang, Y. S. Ahn, J. Byun et al., "Lumbar intervertebral disc degeneration and related factors in Korean firefighters," *BMJ Open*, vol. 6, no. 6, pp. e011587–8, 2016.

[44] M. Damrongsak, A. Prapanjaroensin, and K. C. Brown, "Predictors of back pain in firefighters," *Workplace Health & Safety*, vol. 66, no. 2, pp. 61–69, 2018.

[45] A. Negm, J. MacDermid, K. Sinden, R. D'Amico, M. Lomotan, and N. J. MacIntyre, "Prevalence and distribution of musculoskeletal disorders in firefighters are influenced by age and length of service," *Journal of Military, Veteran and Family Health*, vol. 3, no. 2, pp. 33–41, 2017.

[46] R. Donovan, T. Nelson, J. Peel, T. Lipsey, W. Voyles, and R. G. Israel, "Cardiorespiratory fitness and the metabolic syndrome in firefighters," *Occupational Medicine*, vol. 59, no. 7, pp. 487–492, 2009.

[47] D. M. Baur, C. A. Christophi, A. J. Tsismenakis, E. F. Cook, and S. N. Kales, "Cardiorespiratory fitness predicts cardiovascular risk profiles in career firefighters," *Journal of Occupational and Environmental Medicine*, vol. 53, no. 10, pp. 1155–1160, 2011.

[48] D. M. Baur, A. Leiba, C. A. Christophi, and S. N. Kales, "Low fitness is associated with exercise abnormalities among asymptomatic firefighters," *Occupational Medicine (London)*, vol. 62, no. 7, pp. 566–569, 2012;(July.

[49] J. M. Mayer, J. L. Nuzzo, R. Chen et al., "The impact of obesity on back and core muscular endurance in firefighters," *Journal of Obesity*, vol. 2012, pp. 1–7, 2012.

http://etd.uwc.ac.za/

[50] G. S. Poplin, D. J. Roe, W. Peate, R. B. Harris, and J. L. Burgess, "Original contribution the association of aerobic fitness with injuries in the fire service," *American Journal of Epidemiology*, vol. 179, no. 2, 2013.

[51] P. Kiss, M. de Meester, C. Maes, S. de Vriese, A. Kruse, and L. Braeckman, "Cardiorespiratory fitness in a representative sample of Belgian firefighters," *Occupational Medicine (London)*, vol. 64, no. 8, pp. 589–594, 2014;(September.

[52] A. Walker, M. Driller, C. Argus, J. Cooke, and B. Rattray, "The ageing Australian firefighter: an argument for age-based recruitment and fitness standards for urban fire services," *Ergonomics*, vol. 57, no. 4, pp. 612–621, 2014.

[53] G. S. Poplin, D. J. Roe, J. L. Burgess, W. F. Peate, and R. B. Harris, "Fire fit: assessing comprehensive fitness and injury risk in the fire service," *International Archives of Occupational and Environmental Health*, vol. 89, no. 2, Published online, 2015.

[54] L. K. Kirlin, J. F. Nichols, K. Rusk, R. A. Parker, and M. J. Rauh, "The effect of age on fitness among female firefighters," *Occupational Medicine*, vol. 67, no. 7, pp. 528–533, 2017.

[55] K. Li, E. Ochoa, T. Lipsey, and T. Nelson, "Correlates of atherosclerotic cardiovascular disease risk in older Colorado firefighters," *Occupational Medicine*, vol. 68, no. 1, pp. 51–55, 2018.

[56] A. M. Barry, K. J. Lyman, N. D. Dicks et al., "firefighters' physical activity and waist circumference as predictors of VO2max," *Journal of Occupational and Environmental Medicine*, vol. 61, no. 10, pp. 849–853, 2019.

[57] F. Espinoza, P. Delgado-Floody, C. Mart´ınez-Salazar et al., "The influence of cardiometabolic risk factors on cardiorespiratory fitness in volunteer Chilean firefighters," *American Journal of Human Biology: The Official Journal of the Human Biology Council*, vol. 31, no. 5, p. e23280, 2019.

[58] L. G. G. Porto, A. C. B. Schmidt, J. M. de Souza et al., "Firefighters' basal cardiac autonomic function and its associations with cardiorespiratory fitness," *Work*, vol. 62, no. 3, pp. 485–495, 2019.

[59] J. Yang, C. A. Christophi, A. Farioli et al., "Association between push-up exercise capacity and future cardiovascular events among active adult men," *JAMA Network Open*, vol. 2, no. 2, pp. e188341–11, 2019.

[60] A. Airila, J. Hakanen, A. Punakallio, S. Lusa, and R. Luukkonen, "Is work engagement related to work ability beyond working conditions and lifestyle factors," *International Archives of Occupational and Environmental Health*, vol. 85, no. 8, pp. 915–925, 2012.

[61] M. Firoozeh, M. Saremi, A. Kavousi, and A. Maleki, "Demographic and occupational determinants of the work ability of firemen," *Journal of Occupational Health*, vol. 59, no. 1, pp. 81–87, 2017.

[62] A. I. Saari, G. Renz, P. Davis, and M. G. Abel, "The influence of age on firefighter combat challenge performance and exercise training habits," *The Journal of Strength & Conditioning Research*, vol. 34, no. 9, pp. 2500–2506, 2020.

[63] D. Xu, Y. Song, Y. Meng, B. Istva´n, and Y. Gu, "Relationship between firefighter physical fitness and special ability performance: predictive research based on machine learning algorithms," *International Journal of Environmental Research and Public Health*, vol. 17, no. 20, p. 7689, 2020.

[64] M. S. Norris, M. McAllister, A. E. Gonzalez et al., "Predictors of work efficiency in structural firefighters," *Journal of Occupational and Environmental Medicine*, vol. 63, no. 7, pp. 622–628, 2021, https://journals.lww.com/joem/Fulltext/2021/07000/Predictors_of_Work_Efficiency_in_Structural.12.aspx.

[65] P. Wynn and P. Hawdon, "Cardiorespiratory fitness selection standard and occupational outcomes in trainee firefighters," *Occupational Medicine*, vol. 62, no. 2, pp. 123–128, 2012.

[66] R. J. Butler, M. Contreras, L. C. Burton et al., "Modifiable risk factors predict injuries in firefighters during training academies," *Work*, vol. 46, pp. 1–7, 2013.

[67] A. Punakallio, S. Lusa, R. Luukkonen, A. Airila, and P. Leino-Arjas, "Musculoskeletal pain and depressive symptoms as predictors of trajectories in work ability among Finnish firefighters at 13-year follow-up," *Journal of Occupational and Environmental Medicine*, vol. 56, no. 4, pp. 367–375, 2014.

[68] J. K. Kodom-Wiredu, "The relationship between firefighters' work demand and work-related musculoskeletal disorders: the moderating role of task characteristics," *Safety and Health at Work*, vol. 10, no. 1, pp. 61–66, 2019.

[69] M. Saremi, R. fallah, L. fereydoon, N. Noorizade, and E. Rahimi, "Assessment of mental workload, work ability and musculoskeletal disorders of firefighters TT," *SSU*, vol. 8, no. 3, pp. 139–147, 2019.

[70] E. D. von Heimburg, A. K. R. Rasmussen, and J. I. Medbø, "Physiological responses of firefighters and performance predictors during a simulated rescue of hospital patients," *Ergonomics*, vol. 49, no. 2, pp. 111–126, 2006.

[71] S. Kianoush, M. Y. Yakoob, M. Al-Rifai et al., "Associations of cigarette smoking with subclinical inflammation and atherosclerosis: ELSA-Brasil (The Brazilian Longitudinal Study of Adult Health)," *Journal of American Heart Association*, vol. 6, no. 6, p. e005088, 2017.

[72] A. K. Sheaff, A. Bennett, E. D. Hanson et al., "Physiological determinants of the candidate physical ability test in firefighters," *The Journal of Strength & Conditioning Research*, vol. 24, no. 11, pp. 3112–3122, 2010.

[73] M. A. Michaelides, K. M. Parpa, L. J. Henry, G. B. Thompson, and B. S. Brown, "Assessment of physical fitness aspects and their relationship to firefighters' job abilities," *The Journal of Strength & Conditioning Research*, vol. 25, no. 4, pp. 956–965, 2011, https://journals.lww.com/nsca-jscr/Fulltext/2011/04000/Assessment_of_Physical_Fitness_Aspects_and_Their.11.aspx.

[74] E. v Heimburg, J. Ingulf Medbø, M. Sandsund, and R. E. Reinertsen, "Performance on a work-simulating firefighter test versus approved laboratory tests for firefighters and applicants," *International Journal of Occupational Safety and Ergonomics*, vol. 19, no. 2, pp. 227–243, 2013.

[75] C. R. Kleinberg, E. D. Ryan, A. J. Tweedell, T. J. Barnette, and C. W. Wagoner, "INFLUENCE of lower extremity muscle size and quality on stair-climb performance in career firefighters," *The Journal of Strength & Conditioning Research*, vol. 30, no. 6, pp. 1613–1618, 2016.

[76] A. G. Siddall, R. D. M. Stevenson, P. J. F. Turner, and J. L. J. Bilzon, "Physical and physiological performance determinants of a firefighting simulation test," *Journal of Occupational and Environmental Medicine*, vol. 60, no. 7, pp. 637–643, 2018, https://journals.lww.com/joem/Fulltext/2018/07000/Physical_and_Physiological_Performance.10.aspx.

[77] T. L. Skinner, V. G. Kelly, A. N. Boytar, G. G. Peeters, and S. B. Rynne, "Aviation Rescue Firefighters physical fitness and predictors of task performance," *Journal of Science and Medicine in Sport*, vol. 23, no. 12, pp. 1228–1233, 2020.

http://etd.uwc.ac.za/

[78] C. C. W. Yu, C. T. Au, F. Y. F. Lee et al., "Association between leisure time physical activity, cardiopulmonary fitness, cardiovascular risk factors, and cardiovascular workload at work in firefighters," *Safety and Health at Work*, vol. 6, no. 3, pp. 192–199, 2015.

[79] L. L. Bpe, J. R. Randall, D. P. Gross, A. Senthilselvan, and D. Voaklander, "The relationship between physical fitness and occupational injury in emergency responders: a systematic review," *American Journal of Industrial Medicine*, vol. 62, no. 1, pp. 3–13, 2019.

[80] G. Nazari, J. C. Macdermid, K. Sinden, and R. D'Amico, "Prevalence of musculoskeletal symptoms among Canadian firefighters," *Work*, vol. 67, no. 1, pp. 185–191, 2020.

[81] N. L. A. M. Azmi and M. G. Masuri, *Work-related Musculoskeletal Disorder (WMSDs) and Functional Status of Firefighters in Klang Valley*, Healthscope: The Official Research Book of Faculty of Health Sciences, UiTM, 2019, http://healthscopefsk.com/index.php/research/article/view/74.

[82] P. Gendron, C. Lajoie, L. Laurencelle, J. Lemoyne, and F. Trudeau, "Physical training in the fire station and firefighters' cardiovascular health," *Occupational Medicine*, vol. 70, no. 4, pp. 224–230, 2020.

[83] G. Nazari, J. MacDermid, and H. Cramm, "Prevalence of musculoskeletal disorders among Canadian firefighters: a systematic review and meta-analysis," *Journal of Military, Veteran and Family Health*, vol. 6, no. 1, pp. 83–97, 2020.

[84] K. L. Elsner and F. W. Kolkhorst, "Metabolic demands of simulated firefighting tasks," *Ergonomics*, vol. 51, no. 9, pp. 1418–1425, 2008.

[85] W. S. C. Poston, C. K. Haddock, S. A. Jahnke, N. Jitnarin, B. C. Tuley, and S. N. Kales, "The prevalence of overweight, obesity, and substandard fitness in a population-based firefighter cohort," *Journal of Occupational and Environmental Medicine*, vol. 53, no. 3, pp. 266–273, 2011.

[86] E. S. Soteriades, R. Hauser, I. Kawachi, D. C. Christiani, and S. N. Kales, "Obesity and risk of job disability in male firefighters," *Occupational Medicine*, vol. 58, no. 4, pp. 245–250, 2008.

[87] S. D. Mair, A. V. Seaber, R. R. Glisson, and W. E. J. Garrett, "The role of fatigue in susceptibility to acute muscle strain injury," *The American Journal of Sports Medicine*, vol. 24, no. 2, pp. 137–143, 1996.

[88] K. L. Andrews, S. Gallagher, and M. P. Herring, "The effects of exercise interventions on health and fitness of firefighters: a meta-analysis," *Scandinavian Journal of Medicine & Science in Sports*, vol. 29, no. 6, pp. 780–790, 2019.

[89] G. Berthelot, S. Johnson, P. Noirez et al., "The age-performance relationship in the general population and strategies to delay age related decline in performance," *Archives of Public Health*, vol. 77, no. 1, p. 51, 2019.

[90] K. C. Mathias, E. Graham, D. Stewart, and D. L. Smith, "Decreased pulmonary function over 5 years in US firefighters," *Journal of Occupational and Environmental Medicine*, vol. 62, no. 10, pp. 816–819, 2020.

[91] A. Pandey, K. v. Patel, and C. J. Lavie, "Obesity, central adiposity, and fitness: understanding the obesity paradox in the context of other cardiometabolic parameters," *Mayo Clinic Proceedings*, vol. 93, no. 6, pp. 676–678, 2018.

[92] A. E. Rumora, S. I. Lentz, L. M. Hinder et al., "Dyslipidemia impairs mitochondrial trafficking and function in sensory neurons," *The FASEB Journal*, vol. 32, no. 1, pp. 195–207, 2018.

[93] E. Murphy, H. Ardehali, R. S. Balaban et al., "Mitochondrial function, biology, and role in disease," *Circulation Research*, vol. 118, no. 12, pp. 1960–1991, 2016.

[94] E. Phielix, J. Szendroedi, and M. Roden, "Mitochondrial function and insulin resistance during aging – a mini-review," *Gerontology*, vol. 57, no. 5, pp. 387–396, 2011.

[95] S. Mazic, J. Suzic Lazic, M. Dekleva et al., "The impact of elevated blood pressure on exercise capacity in elite athletes," *International Journal of Cardiology*, vol. 180, pp. 171–177, 2015.

[96] C. J. Lavie, R. Arena, D. L. Swift et al., "Exercise and the cardiovascular system: clinical science and cardiovascular outcomes," *Circulation Research*, vol. 117, no. 2, pp. 207–219, 2015.

[97] K. Noh, K. Lee, P. Jamrasi et al., "Physical fitness levels of South Korean national male and female firefighters," *Journal of Exercise Science & Fitness*, vol. 18, no. 3, pp. 109–114, 2020.

[98] D. J. Cornell, S. L. Gnacinski, A. Zamzow, J. Mims, and T. Kyle, "Measures of health, fitness, and functional movement among firefighter recruits," *International Journal of Occupational Safety and Ergonomics*, vol. 3548, no. May, 2016.

[99] L. C. Hespanhol Junior, S. D. Barboza, W. van Mechelen, and E. Verhagen, "Measuring sports injuries on the pitch: a guide to use in practice," *Brazilian Journal of Physical Therapy*, vol. 19, no. 5, pp. 369–380, 2015.

[100] K. Park, K. S. Rosengren, G. P. Horn, D. L. Smith, and E. T. Hsiao-Wecksler, "Assessing gait changes in firefighters due to fatigue and protective clothing," *Safety Science*, vol. 49, no. 5, pp. 719–726, 2011.

[101] A. Siddall, M. Standage, K. Stokes, and J. Bilzon, *Development of Occupational Fitness Standards for the UK Fire and Rescue Services (FRS)*, University of Bath, Bath, UK, 2014; (October.

[102] P. Magyari, T. Fonger, and J. May, "Upper body muscular endurance among active duty male and female firefighters," *The Journal of Strength & Conditioning Research*, vol. 24, p. 1, 2010, https://journals.lww.com/nsca-jscr/Fulltext/2010/01001/Upper_Body_Muscular_Endurance_Among_Active_Duty.99.aspx.

[103] A. Farioli, J. Yang, D. Teehan, D. M. Baur, D. L. Smith, and S. N. Kales, "Duty-related risk of sudden cardiac death among young US firefighters," *Occupational Medicine*, vol. 64, no. 6, pp. 428–435, 2014.

http://etd.uwc.ac.za/

CHAPTER THREE: PUBLICATION TWO - SYSTEMATIC REVIEW PROTOCOL

Effects of Cardiovascular Health, Musculoskeletal Health, and Physical Fitness on Occupational Performance of Firefighters: Protocol For A Systematic Review and Meta-Analysis

---

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

BMJ Open

Effects of cardiovascular health, musculoskeletal health and physical fitness on occupational performance of firefighters: protocol for a systematic review and meta-analysis

Jaron Ras ,[1] Andre Pascal Kengne,[2,3] Denise Smith,[4] Elpidoforos Soterakis Soteriades,[5,6] Lloyd Leach[7]

To cite: Ras J, Kengne AP, Smith D, *et al*. Effects of cardiovascular health, musculoskeletal health and physical fitness on occupational performance of firefighters: protocol for a systematic review and meta-analysis. *BMJ Open* 2022;**12**:e061435. doi:10.1136/bmjopen-2022-061435

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2022-061435).

Received 26 January 2022
Accepted 13 July 2022

Check for updates

© Author(s) (or their employer(s)) 2022. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

For numbered affiliations see end of article.

Correspondence to
Mr Jaron Ras;
3405618@myuwc.ac.za

ABSTRACT

Introduction Firefighting is a hazardous occupation, where firefighters are involved in life-threatening situations, being placed under tremendous physical strain, while wearing heavy and insulated equipment to protect them from chemicals, fumes and high temperatures. This necessitates that firefighter stay in good physical condition and maintain adequate cardiovascular fitness to cope with these stressors and perform their duties with minimal health risks. The aim of this systematic review and meta-analysis is to determine the effect of cardiovascular health, musculoskeletal health and physical fitness on the occupational performance of firefighters.

Methods and analysis All study types and designs will be included and appraised. The following electronic databases will be searched: PubMed/Medline, Scopus, Web of Science, Embase, EBSCOHost and CINAHL, with no restrictions on publication date. The literature search will be conducted comprehensively to enable the capturing of as many relevant articles as possible but will be limited to English-language papers only. A combination of the appropriate terms (search string) will be used to ensure the inclusion of the relevant components of the participants, exposure, comparison and outcome. A researcher-generated form with the key characteristics of each study will be used to retrieve all relevant details from the selected studies for initial eligibility screening. The Rayyan Intelligent Systematic Review tool will be used to screen and select studies for inclusion, and information from the included studies will be captured on the researcher-generated data extraction form. The The appraisal tool for cross-sectional studies (AXIS) checklist and the Critical Appraisal Skills Programme toolkit will be used to conduct the methodological assessment of each study. Data will be analysed using Review Manager V.5.3. Generated results will be presented using a combination of figures, graphs and tables. The synthesis of quantitative data (using a meta-analysis methodology) will involve the integration of quantitative findings from multiple studies to achieve coherence.

Ethics and dissemination This study obtained ethical clearance from the University of the Western Cape Biomedical Research Ethics Committee (BM21/10/9). We will disseminate the findings of in peer-reviewed journals and at national and international conferences. The protocol will form part of a chapter for a doctoral thesis.

PROSPERO registration number CRD42021258898.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ A strength of this review is the use of reference methodologies to guide the study design, from study selection to synthesis.
- ⇒ A further strength of this review is the planned inclusion of studies that were conducted in various global regions and fire departments.
- ⇒ Additionally, all types of study designs and methodologies will be included in this review.
- ⇒ A limitation of this study is that considerable heterogeneity may be introduced through firefighters' age and gender.
- ⇒ A further limitation of this review is that only English-language articles will be included, which may lead to the exclusion of some relevant studies.

INTRODUCTION

Firefighting is a hazardous occupation, where firefighters are involved in life-threatening situations and routinely exposed to high temperatures, physical and psychological strain, hazardous chemicals, fumes and other health hazards.[1 2] These severe conditions necessitate that firefighters wear protective equipment, including breathing apparatus that is heavy and insulated, putting tremendous strain on their cardiovascular system.[3] Apart from extinguishing fires, firefighters also have additional strenuous work duties, such as rescuing people in dangerous situations and providing first aid and emergency medical services while working irregular hours.[1 4] These types of strenuous working conditions place significant strain on firefighters' musculoskeletal and cardiovascular

http://etd.uwc.ac.za/
Page | 55

BMJ Open: first published as 10.1136/bmjopen-2022-061435 on 21 July 2022. Downloaded from http://bmjopen.bmj.com/ on January 20, 2023 at University of the Western Cape. Protected by copyright.

systems, predisposing them to higher risk of severe injuries and sudden cardiac events while on duty.[1 4–10]

Many firefighters have multiple cardiovascular disease (CVD) risk factors, primarily obesity, hypertension and dyslipidaemia, inadequate health-related physical fitness and numerous musculoskeletal health concerns affecting optimal functioning, such as previous injuries, moderate-to-severe musculoskeletal pain or discomfort, which significantly and negatively affects occupational performance.[11–19] Throughout firefighters' careers, they develop multiple CVD risk factors, negatively affecting their cardiovascular health, most notably physical inactivity, obesity, hypertension and dyslipidaemia,[11 20–25] which deteriorate as they age.[2 23–25] The literature in the USA indicated that among emergency services professionals, firefighters have the highest percentage of mortality (45%) due to sudden cardiac death, with the majority related to underlying CVD risk factors.[1 4 5] These sudden cardiac events are also due to inadequate health-related physical fitness that results in overexertion and increased cardiovascular strain.[26 27] Health-related physical fitness includes body composition, cardiorespiratory fitness, muscular strength, muscular endurance and flexibility.[28] Body composition, cardiorespiratory fitness, muscular strength and endurance have been reported to decrease throughout their careers and as they age, particularly those that are physically inactive.[29–34] Maintenance of good overall levels of health-related physical fitness is crucial for career longevity and overall well-being in firefighters.[2 35 36]

In addition, firefighters have been reported to have the highest incidence of musculoskeletal injuries among all emergency services personnel.[1] Firefighters performing fire suppression routinely exceed their maximum heart rates for prolonged periods of time, placing tremendous stress on their cardiovascular system. Coupled with the additional stressors, such as worsening cardiovascular health metrics, most frequently: physical inactivity, hypertension, dyslipidaemia and obesity, and poor health-related physical fitness, specifically cardiorespiratory fitness and muscular endurance, may lead to significant morbidity and mortality.[5 37–39] Lower physical fitness levels cause increased risk for musculoskeletal injuries in firefighters.[35 40–42] In addition, worsening cardiovascular health, increased cardiovascular risk profiles, deteriorating musculoskeletal health, especially moderate to severe pain and discomfort in the lower limbs, and poor health-related physical fitness, particularly cardiorespiratory fitness, significantly and negatively affects firefighters' occupational performance.[11–19]

Occupational performance in firefighters

Occupational performance is an important public and personal consideration, as substandard occupational fitness significantly increases the likelihood of cardiovascular and musculoskeletal adverse events while on duty.[3 43 44] Reduced occupational task performance is indicative of firefighters who are not fit for active duty and may be at increased risk of cardiovascular and musculoskeletal injuries. The simulated tasks in firefighting, such as the stair climb, hose drag and victim drag place significant strain on the cardiovascular and musculoskeletal systems that incorporate all aspects of physical fitness.[3 13 45–48] However, a review of the effects of cardiovascular health, musculoskeletal health and physical fitness on occupational performance has not been previously investigated. In the current review, as in previous literature, occupational performance will be quantified as firefighters passing or failing each individual occupational performance tasks and/or the overall ability test. In addition, the overall time taken, in seconds, to perform each simulated occupational task and the completion time of the overall occupational ability test will be assessed. These will include tasks such as the stair climb, hose drag and pull, equipment carry, forcible entry, equipment hoist, ladder raise and extension, and victim drag.[14 45 49–51]

Purpose and justification for this review

This study originated from the challenges firefighters face globally and, in particular, in South Africa. A concerning number of firefighters are at increased cardiovascular disease risk, with worsening musculoskeletal health and physical fitness negatively impacting their occupational performance.[16 52–55] These factors reduce the ability of firefighters to cope with the physical strain of firefighting, which many firefighters have described as being comparable with the physical demands of elite sportspersons.[56] There have been no previous systematic reviews investigating the effects of cardiovascular health, musculoskeletal health and physical fitness on the occupational performance of firefighters, which motivated the need for the present study. The intention of this review includes, among others, informing policy makers in South Africa of the need for corrective action and developing strategies to improve and maintain the cardiovascular health, musculoskeletal health and physical fitness of firefighters.

Aims, objectives and research questions

Review aim

The aim of this systematic is to determine the effects of cardiovascular health, musculoskeletal health and physical fitness on the occupational performance of firefighters.

Research question

What effects do cardiovascular health, musculoskeletal health and physical fitness have on the occupational performance of firefighters?

Review objectives

The objectives of the study are:

1. To investigate the effects of cardiovascular health on the occupational performance of firefighters.
2. To investigate the effects of musculoskeletal health on the occupational performance of firefighters.
3. To investigate the effects of physical fitness on the occupational performance of firefighters.

http://etd.uwc.ac.za/

BMJ Open: first published as 10.1136/bmjopen-2022-061435 on 21 July 2022. Downloaded from http://bmjopen.bmj.com/ on January 20, 2023 at University of the Western Cape. Protected by copyright.

4. To investigate the relationship between cardiovascular health, musculoskeletal health and physical fitness on the occupational performance of firefighters.

METHODS AND ANALYSIS

The guidelines for Meta-analysis of Observational Studies in Epidemiology studies and Quality of Reporting of Meta-analysis will guide the methods when conducting the review.[57 58] When considering studies for this review, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for systematic reviews will be followed, and the outcomes for each step will be described in a flow diagram.[59]

Study characteristics

We have chosen to address firefighters' occupational performance, which we describe as performance on simulated tasks or firefighter simulation protocols. This review will have a particular focus on the relationship between cardiovascular health, musculoskeletal health and health-related physical fitness on the occupational performance of firefighters. The study design of choice is a quantitative systematic review, assessing the relationship between the aforementioned variables on occupational performance in adult, full-time firefighters. All study types and designs will be included and appraised accordingly.

Participants

Full-time firefighters that are 18 years or older.

Exposures

Cardiovascular health, musculoskeletal health and health-related physical fitness in relation to the occupational performance of firefighters.

Outcomes

1. Cardiovascular health measures related to the occupational performance of firefighters.
2. Musculoskeletal health measures related to the occupational performance of firefighters.
3. Health-related physical fitness measures related to the occupational performance of firefighters.

Inclusion criteria

1. Studies that recruit full-time adult firefighters, with no limitations to publication year.
2. Cross-sectional, observational and experimental (intervention) study designs.
3. Studies investigating the effects of cardiovascular health, musculoskeletal health and/or health-related physical fitness on the occupational performance of firefighters.
4. Studies available in full-text.

Exclusion criteria

1. Studies focusing on other outcome measures as the main exposures or outcomes.
2. Systematic reviews or other types of reviews.
3. Articles that are non-English.

Search strategy

A detailed literature search will be conducted to identify studies investigating the effects of cardiovascular health, musculoskeletal health and physical fitness on the occupational performance of firefighters. Relevant studies, irrespective of publication date, will be searched, with guidance from a specialist librarian.

The team will be made up of three main contributors:

1. Reviewer I (JR) will be the primary investigator, who will take responsibility for all aspects of the review and independently extract the data, verify the data collected, analyse the results, grade the quality of the data and write up the first review draft.
2. Reviewer II (RN) will be responsible for independently extracting the data, verifying the data collected, analysing the results and grading the quality of the data.
3. Reviewer III (LL) will be the adjudicator and resolve any disagreements between the two independent reviewers.

Electronic literature search

The literature search for this systematic review will be conducted comprehensively to enable the capturing of as many relevant articles as possible but limited to English papers only. The following journal databases will be searched: PubMed/Medline, Scopus, Web of Science, Embase, EBSCOHost and CINAHL, with no limitation to publication year. Keywords and medical subject heading terms will be used in various arrangements depending on the specific database. A combination of the appropriate terms (search string) will be used to ensure the inclusion of the relevant components of the participants, exposure, comparison and outcome. The details of the search strategy in PubMed are given further. The search strategies for the other databases are presented in online supplemental appendix 1.

Search terms in PubMed

1. "firefighter" [MeSH] OR "fire and rescue personnel" [MeSH] OR "fire fighters" [MeSH] OR "fire fighter" [MeSH] OR "firefight" [MeSH]
2. "cardiovascular system"[MeSH] OR ("cardiovascular" [All Fields] AND "system" [All Fields]) OR "cardiovascular system" [All Fields] OR "cardiovascular" [All Fields] OR "cardiovasculars" [All Fields] OR "cardiovascular abnormalities" [MeSH] OR "HRV" [All Fields] OR "heart rate variability" [All Fields] OR "Heart Rate Interval" [All Fields] OR "RR variability" [All Fields] OR "cycle length variability" [All Fields] OR "heart period variability" [All Fields] OR "autonomic function" [All Fields] OR "vagal control" [All Fields] OR "lipid profile" [All Fields] OR "cholesterol" [MeSH] OR "dyslipidaemia" OR "hypercholesteremia" OR "diabetes" AND "mellitus" OR "blood glucose" OR "age" OR "obesity" OR "hypertension" OR "blood pressure" OR "metabolic syndrome" OR "hyperglycaemia"
3. "muscular injury" [MeSH] OR ("musculoskeletal" [All Fields] AND "system" [All Fields]) OR "muscular

http://etd.uwc.ac.za/

BMJ Open: first published as 10.1136/bmjopen-2022-061435 on 21 July 2022. Downloaded from http://bmjopen.bmj.com/ on January 20, 2023 at University of the Western Cape. Protected by copyright.

pain" OR "chronic pain" [All Fields] OR "acute pain" [All Fields] "acute injury" [All Fields] OR "muscular health" [MeSH]

4. "physical fitness"[MeSH] OR "exercise" [All Fields] OR "physical exertion" [All Fields] OR "muscular strength" OR "muscular endurance" OR "aerobic fitness" OR "cardiorespiratory fitness" OR "cardiorespiratory capacity" OR "VO_2max OR "aerobic fitness" OR "power"
5. "work performance" [All Fields] OR "endurance" [All Fields] OR "fitness" [All Fields] OR "work performance" [MeSH Terms] AND "work classification" [All Fields] OR "occupational health" [MeSH] OR "employee health" [MeSH] OR "health, industrial" [MeSH] OR "industrial health" [MeSH] OR "occupational safety" [MeSH] OR "safety, occupational" [MeSH] OR "simulated work tasks" OR simulated "firefighting" OR "CPAT" OR "physical ability test"
6. #1 AND #2 OR #1 AND #3 OR #1 AND #4 OR #1 AND #5 OR #1 AND #2 AND #3 OR #1 AND #2 AND #4 OR #1 AND #3 AND #4 OR #1 AND #2 AND #3 AND #4 OR #2 AND #5 OR # 3 AND #5 OR #4 AND #5

Grey literature

The search strategy will be completed by searching the following databases for grey literature: Google, Google Scholar and Networked Digital Library of Theses and Dissertation. JR and RN will search the reference lists of identified articles to identify potential titles of articles possibly meeting the inclusion criteria.

Study selection

All studies, as full-text articles, that meet the inclusion criteria will be selected for screening. Every attempt will be made to contact the authors for full-text articles or missing data. Thereafter, the full-text articles will be assessed independently by two reviewers using the Rayyan Intelligent Systematic Review tool.[60] When screening the studies, three categories will be used, namely, included, excluded and unsure. Any uncertainties regarding study inclusion will be discussed between the two reviewers. In the event of disagreement, a discus- sion will be held with the third reviewer and resolved by the latter.

The first step in conducting this review includes performing the literature search, which involves: (1) searching all preselected databases to identify and screen the titles and abstracts of potential studies for eligibility; (2) compiling the search outputs into a reference software, namely, Mendeley Desktop V.1.19.8; (3) removing any duplicates; (4) screening of full-text articles against the inclusion criteria and determining the final studies for inclusion in the review; (5) extracting the data from the included studies using a predesigned data extraction form; and (6) performing a meta-analysis using Review Manager V.5.3[61] for the analyses, interpretation and reporting the results of the review.

Data extraction and management

A researcher-generated data extraction form (online supplemental appendix 2), for extracting the key characteristics of each study, will be used by the two reviewers. Thereafter, information of included studies will be captured on the researcher-generated data extraction form (online supplemental appendix 3). The information extracted will be, first, the general study details, such as authors, date of study publication, study title, study design and country of study, the exposure assessed and the outcome measures. Second, the study characteristics will be collected, such as sampling method and sample size, and details of the participants (number of participants, age, gender, years of experience, marital status and core job description). Lastly, the details of exposure and the outcome variables will be extracted, that is, the study must report on at least one of the exposure variables in relation to firefighter occupational performance.

Critical appraisal of included studies

The appraisal tool for cross-sectional studies (AXIS) checklist[62] and the Critical Appraisal Skills Programme (CASP) toolkit (Middle Way, Oxford, UK) (https://casp-uk.net/casp-tools-checklists/) will be used to conduct the methodological assessment of each study included. The CASP toolkit (Middle Way, Oxford, UK) has been previously used in systematic reviews on firefighters and tactical personnel to assess study methodologies and allows for fair and equitable assessment of a variety of study types. The AXIS toolkit was shown to be a reliable and valid tool for assessing the quality of cross-sectional studies.[62 63] Both questionnaires assess for overall methodological quality and validity of the studies.[62–64] For questions that are answered dichotomously, an article will be awarded a point of '1' for each question that is answered 'yes', and scored a '0' if 'no' or 'can't tell'. Where the CASP checklist requires written grading, the question will be adapted to a dichotomous rating and, if a rating is not possible, then the question will be excluded from the checklist. The Rayan systematic review manager will be used to record the decisions of the two reviewers. Again, a third reviewer will be used to resolve any disagreements between reviewers.

Publication bias

To assess publication bias, the Begg's funnel chart will be used to perform a visual inspection and evaluation of publication bias on the selected data.

Data synthesis and analysis

The aim of the data analysis and synthesis is to describe, analyse and draw conclusions about the research evidence and to assess the effects of cardiovascular health, musculoskeletal health and physical fitness on the occupational performance of firefighters. The synthesis of quantitative data (using a meta-analysis) involves the integration of quantitative findings from multiple studies to achieve coherence.[65 66] Achieving coherence allows a more

BMJ Open: first published as 10.1136/bmjopen-2022-061435 on 21 July 2022. Downloaded from http://bmjopen.bmj.com/ on January 20, 2023 at University of the Western Cape. Protected by copyright.

http://etd.uwc.ac.za/

profound understanding of the exposure being investigated and the outcome thereof, in this case, firefighter occupational performance.[65] In addition, a systematic review and meta-analysis allows for determining the generalisability and applicability of the results of the review to a certain context or population.[65 66] An inherent limitation of using observational studies, which will make up the majority of the studies in the present review, is that there is usually high heterogeneity between studies and will require more careful consideration when synthesising data, as compared with randomised controlled trials.[57 66]

Once the systematic search of literature is complete and all relevant documents are identified, the process of analysing and synthesising the data will begin. For this review, a systematic synthesis of the results obtained from the literature will be used. The use of a systematic review synthesis allows the researcher to identify, evaluate and summarise similar study findings of all relevant individual studies.[65–67] For dichotomous data, the risk ratio and OR will be generated, whereas for continuous data, the standardised mean difference of estimation will be used to estimate the relationship between the cardiovascular health, musculoskeletal health and physical fitness measures on the occupational performance of firefighters.[68]

Measures of exposure effect

Data will be imported into Review Manager V.5.3 and then analysed.[61] The outcome measure (occupational performance) will be considered as categorical or continuous variables, where applicable. The meta-analyses will be performed on each of the subgroups and is explained in the subsequent section on subgroup analysis. The random-effects model will be used, where significant heterogeneity is found. The effectiveness of the interventions will be calculated as standard mean difference and 95% CI.

Assessment of heterogeneity

Heterogeneity will be evaluated using the χ^2 test and I^2 test.[58] Heterogeneity will be identified through visual inspection of the forest plots to judge the extent of CI overlap, including the I^2 statistic, which calculates heterogeneity across studies. This will measure the impact of heterogeneity of the meta-analysis.[61] The following will be used to explain I^2 statistics:

1. 0%–30%: may not be important.
2. 31%–60%: may indicate moderate heterogeneity.
3. 61%–80%: may indicate substantial heterogeneity.
4. 81%–100%: considerable heterogeneity.

In the case of identified heterogeneity, possible reasons will be determined by assessing individual studies and subgroup characteristics. A meta-analysis will be favoured by a low degree of heterogeneity.[58] However, if there is significant heterogeneity of the included studies, then a descriptive interpretation of the results will be presented. If homogeneity is found in the studies, then a pooled effect will be determined and a fixed-effects model will be used.[58] However, if studies have several intervention effects, then a random-effects model will be preferred.

Subgroup analysis and investigation of heterogeneity

The authors anticipate the following characteristics to introduce clinical heterogeneity, that is, firefighters' age, gender, marital status, years of experience and core job description, and plan to implement subgroup analysis, where possible. Although all exposures will be measured during firefighters' work or simulated performance, the methods used could be different, which will require comparing and converting certain measurements to produce similar findings for comparison. The authors will use Review Manager for the subgroup analysis if there are adequate numbers of included studies.[65 68 69]

Presenting and reporting of results

Generated results will be presented using a combination of figures, graphs and tables. This will include the methods and steps of how studies were sourced and selected using the PRISMA guidelines. Excluded studies and the reasons for exclusion will be tabulated and further explained in the methodology section of the systematic review. In addition, summary tables will be created, if the use of forest plots is not possible or appropriate.

Patient and public involvement

It was not appropriate or possible to involve patients or the public in the design, or conduct, or reporting, or dissemination plans of our research.

ETHICS AND DISSEMINATION

This study has been granted ethical clearance by the University of the Western Cape (BM21/10/9) and has been registered onto PROSPERO (CRD42021258898). There will be no direct engagement with human subjects. Accessible and published data will be used in the study; thus, no confidentiality or ethical procedures need to be considered for this review.[70]

The results of this review will be obtainable via the University of the Western Cape's repository (https://kikapu.uwc.ac.za/). We will disseminate the findings of in peer-reviewed journals and at national and international conferences. The protocol will form part of a chapter for a doctoral thesis. The information gathered will also be presented in webinars and to local firefighting organisations.

Study status

The study is expected to commence in July 2022 and be completed by December 2022.

DISCUSSION

To the best of the authors' knowledge, no conclusive evidence exists on the relationship between cardiovascular health, musculoskeletal health and physical fitness on the occupational performance of firefighters. As a

BMJ Open: first published as 10.1136/bmjopen-2022-061435 on 21 July 2022. Downloaded from http://bmjopen.bmj.com/ on January 20, 2023 at University of the Western Cape. Protected by copyright.

http://etd.uwc.ac.za/

consequence, all reviews performed on this subject are at risk of different types of heterogeneity due to various research designs, study settings, as well as of unavoidable bias due to the complicated nature of sampling firefighters, such as the variability in the age, sex and job description of firefighters. The inclusion of only English-language articles may result in the exclusion of relevant studies.

The results of this systematic review can help clarify the relationship between cardiovascular health metrics, musculoskeletal health and physical fitness on occupational performance, either individually or as a collective impact. This review is expected to make a significant contribution to the international scientific literature and will assist policy makers in developing intervention strategies to promote health, wellness and career longevity of firefighters in South Africa, and globally. In addition, the proposed review will assist researchers who wish to design novel primary or secondary studies concerning this issue and, potentially, aid in identifying research gaps for further studies. Reference methodologies will be used to guide the study design from study selection to the synthesis of results, significantly improving the overall reliability and reducibility of the study results. The broad inclusiveness of the current systematic review, such as not having a publication date limit and including studies from multiple global regions, increases the potential applicability and generalisability of the results. In addition, the inclusion of all types of study designs and methodologies allows for a broader scope of applicable articles for selection and screening.

Author affiliations

[1]Department of Sport, Recreation and Exercise Science, University of the Western Cape, Cape Town, Western Cape, South Africa
[2]Non-Communicable Diseases Research Unit, South African Medical Research Council, Cape Town, Western Cape, South Africa
[3]Department of Medicine, University of Cape Town, Cape Town, South Africa
[4]Department of Health and Human Physiological Sciences, Skidmore College, Saratoga Springs, New York, USA
[5]School of Economics and Management, Healthcare Management Program, Open University of Cyprus, Nicosia, Cyprus
[6]Department of Environmental Health, Environmental and Occupational Medicine and Epidemiology (EOME), Harvard T.H. Chan School of Public Health, Boston, Massachusetts, USA
[7]Department of Sport, Recreation and Exercise Science, University of the Western Cape, Bellville, South Africa

Contributors JR will be the primary investigator who will take responsibility for all aspects of the project and independently extract the data, verify the data collected, analyse the results, grade the quality of the data and write up the review; LL is the principal supervisor of the study and will be the adjudicator and resolve any disagreements between the two independent reviewers and be responsible for the final proof-reading of the review. APK is a cosupervisor who will be responsible for oversight of analyses and general guidance in conducting the review and proof-reading the review. DS is a cosupervisor and will provide guidance in completing and proof-reading the review; ESS is a cosupervisor and will provide guidance in completing and proof-reading the review.

Funding The Ryoichi Sasakawa Young Leaders Fellowship Fund (Sylff) Program (Grant number: N/A) and the National ResearchFoundation (Grant number: 141282).

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.

ORCID iD

Jaron Ras http://orcid.org/0000-0002-7915-4883

REFERENCES

1 Shin J-H, Lee J-Y, Yang S-H, *et al*. Factors related to heart rate variability among firefighters. *Ann Occup Environ Med* 2016;28:1–9.
2 Smith DL, Barr DA, Kales SN. Extreme sacrifice: sudden cardiac death in the US fire service. *Extrem Physiol Med* 2013;2:1–9.
3 Smith DL, DeBlois JP, Kales SN, *et al*. Cardiovascular strain of firefighting and the risk of sudden cardiac events. *Exerc Sport Sci Rev* 2016;44:90–7.
4 Feairheller DL. Blood pressure and heart rate responses in volunteer firefighters while wearing personal protective equipment. *Blood Press Monit* 2015;20:194–8.
5 Al-Zaiti SS, Carey MG. The prevalence of clinical and electrocardiographic risk factors of cardiovascular death among on-duty professional firefighters. *J Cardiovasc Nurs* 2015;30:440–6.
6 Liao L-M, Al-Zaiti SS, Carey MG. Depression and heart rate variability in firefighters. *SAGE Open Med* 2014;2:2050312114545530:2050312114545553.
7 Carey MG, Al-Zaiti SS, Dean GE, *et al*. Sleep problems, depression, substance use, social bonding, and quality of life in professional firefighters. *J Occup Environ Med* 2011;53:928–33.
8 Hom MA, Stanley IH, Rogers ML, *et al*. The association between sleep disturbances and depression among firefighters: emotion dysregulation as an explanatory factor. *J Clin Sleep Med* 2016;12:235–45.
9 Rodrigues S, Paiva JS, Dias D, *et al*. Stress among on-duty firefighters: an ambulatory assessment study. *PeerJ* 2018;6:e5967.
10 Gulliver SB, Zimering RT, Knight J, *et al*. A prospective study of firefighters' PTSD and depression symptoms: the first 3 years of service. *Psychol Trauma* 2021;13:44–55.
11 Ras J, Leach L. Prevalence of coronary artery disease risk factors in firefighters in the city of Cape Town fire and rescue service - A descriptive study. *J Public Health Res* 2021;10:2000.
12 Hunter AL, Chb MB, ShahASv. Fire simulation and cardiovascular health 2017:1284–95.
13 Siddall AG, Stevenson RDM, Turner PJF, *et al*. Physical and physiological performance determinants of a Firefighting simulation test. *J Occup Environ Med* 2018;60:637–43 https://journals.lww.com/joem/Fulltext/2018/07000/Physical_and_Physiological_Performance.10.aspx
14 Skinner TL, Kelly VG, Boytar AN, *et al*. Aviation rescue firefighters physical fitness and predictors of task performance. *J Sci Med Sport* 2020;23:1228–33.
15 Findley BW, Brown LE, Whitehurst M. Age-Group performance and physical fitness in male firefighters. *The Journal of Strength & Conditioning Research* 1995;9 https://journals.lww.com/nsca-jscr/Fulltext/1995/11000/Age_Group_Performance_and_Physical_Fitness_in_Male.12.aspx
16 Nazari G, MacDermid JC, Sinden KE, *et al*. The relationship between physical fitness and simulated Firefighting task performance. *Rehabil Res Pract* 2018;2018:1–7.
17 MacDermid JC, Tang K, Sinden KE, *et al*. Work functioning among firefighters: a comparison between self-reported limitations and functional task performance. *J Occup Rehabil* 2019;29:194–204.

http://etd.uwc.ac.za/

BMJ Open: first published as 10.1136/bmjopen-2022-061435 on 21 July 2022. Downloaded from http://bmjopen.bmj.com/ on January 20, 2023 at University of the Western Cape. Protected by copyright.

18 NLAM A, Masuri MG. Work-related musculoskeletal disorder (WMSDs) and functional status of firefighters in Klang Valley. Healthscope: The Official Research Book of Faculty of Health Sciences, *UiTM*, 2019. Available: http://healthscopefsk.com/index.php/research/article/view/74 [Accessed 07 Aug 2021].

19 Kodom-Wiredu JK. The relationship between firefighters' work demand and work-related musculoskeletal disorders: the moderating role of task characteristics. *Saf Health Work* 2019;10:61–6.

20 Savall A, Charles R, Bertholon A, *et al*. Volunteer and career French firefighters: cardiovascular risk factors and cardiovascular risk assessment. *Eur J Prev Cardiol* 2020;27:107–9.

21 Nogueira EC, Porto LGG, Nogueira RM, *et al*. Body composition is strongly associated with cardiorespiratory fitness in a large Brazilian military Firefighter cohort: the Brazilian firefighters study. *J Strength Cond Res* 2016;30:33–8 https://journals.lww.com/nsca-jscr/Fulltext/2016/01000/Body_Composition_is_Strongly_Associated_With.5.aspx

22 Martin ZT, Schlaff RA, Hemenway JK, *et al*. Cardiovascular disease risk factors and physical fitness in volunteer firefighters. *Int J Exerc Sci* 2019;12:764–76 http://www.ncbi.nlm.nih.gov/pubmed/31156744%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=

23 Gendron P, Lajoie C, Laurencelle L, *et al*. Cardiovascular disease risk factors in Québec male firefighters. *J Occup Environ Med* 2018;60:e300–6.

24 Soares EMKVK, Smith D, Grossi Porto LG. Worldwide prevalence of obesity among firefighters: a systematic review protocol. *BMJ Open* 2020;10:1–5.

25 Smith DL, Graham E, Stewart D, *et al*. Cardiovascular disease risk factor changes over 5 years among male and female us firefighters. *J Occup Environ Med* 2020;62:398–402 https://journals.lww.com/joem/Fulltext/2020/06000/Cardiovascular_Disease_Risk_Factor_Changes_Over_5.2.aspx

26 Smith DL, Haller JM, Korre M, *et al*. The relation of emergency duties to cardiac death among US firefighters. *Am J Cardiol* 2019;123:736–41.

27 Farioli A, Yang J, Teehan D, *et al*. Duty-related risk of sudden cardiac death among young us firefighters. *Occup Med* 2014;64:428–35.

28 Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep* 1985;100:126–31 https://pubmed.ncbi.nlm.nih.gov/3920711

29 Yu CCW, Au CT, Lee FYF, *et al*. Association between leisure time physical activity, cardiopulmonary fitness, cardiovascular risk factors, and cardiovascular workload at work in firefighters. *Saf Health Work* 2015;6:192–9.

30 Donovan R, Nelson T, Peel J, *et al*. Cardiorespiratory fitness and the metabolic syndrome in firefighters. *Occup Med* 2009;59:487–92.

31 Mehrdad R, Movasatian F, Momenzadeh AS. Fitness for work evaluation of firefighters in Tehran. *Acta Med Iran* 2013;51:265–9.

32 Houck JM, Mermier CM, Beltz NM, *et al*. Physical fitness evaluation of career urban and Wildland firefighters. *J Occup Environ Med* 2020;62:e302–7.

33 Kirlin LK, Nichols JF, Rusk K, *et al*. The effect of age on fitness among female firefighters. *Occup Med* 2017;67:528–33.

34 Noh K, Lee K, Jamrasi P, *et al*. Physical fitness levels of South Korean national male and female firefighters. *J Exerc Sci Fit* 2020;18:109–14.

35 Smith DL. Firefighter fitness: improving performance and preventing injuries and fatalities, 2011. Current sports medicine reports10. Available: https://journals.lww.com/acsm-csmr/Fulltext/2011/05000/Firefighter_Fitness__Improving_Performance_and.13.aspx

36 Soteriades ES, Smith DL, Tsismenakis AJ, *et al*. Cardiovascular disease in US firefighters: a systematic review. *Cardiol Rev* 2011;19:202–15.

37 Al-Zaiti S, Rittenberger JC, Reis SE, *et al*. Electrocardiographic responses during fire suppression and recovery among experienced firefighters. *J Occup Environ Med* 2015;57:938–42.

38 Schmit M, DeBeliso M. The Relationship between Firefighters' Physical Performance Aspects and Simulated Firefighting Demands. *Turkish Journal of Kinesiology* 2019;5:63–75.

39 Smith DL, Haller JM, Benedict R, *et al*. Firefighter incident rehabilitation: interpreting heart rate responses. *Prehosp Emerg Care* 2016;20:28–36.

40 Gordon H, Larivière M. Physical and psychological determinants of injury in Ontario forest firefighters. *Occup Med* 2014;64:583–8.

41 Kleinberg CR, Ryan ED, Tweedell AJ, *et al*. Influence of lower extremity muscle size and quality on Stair-Climb performance in career firefighters. *J Strength Cond Res* 2016;30:1613–8.

42 Nowak A, Molik B, Wójcik A, *et al*. Physical activity and injuries relating to physical fitness of professional firefighters. *Advances in Rehabilitation* 2018;32:13–22.

43 Hong O, Chin DL, Phelps S, *et al*. Occupational injuries, duty status, and factors associated with injuries among firefighters. *Workplace Health Saf* 2012;60:517–23.

44 Frost DM, Beach TAC, Crosby I, *et al*. Firefighter injuries are not just a fireground problem. *Work* 2015;52:835–42.

45 Williams-Bell FM, Villar R, Sharratt MT, *et al*. Physiological demands of the firefighter candidate physical ability test. *Med Sci Sports Exerc* 2009;41:653–62.

46 Sheaff AK, Bennett A, Hanson ED, *et al*. Physiological determinants of the candidate physical ability test in firefighters. *J Strength Cond Res* 2010;24:3112–22.

47 Taylor NAS, Lewis MC, Notley SR, *et al*. A fractionation of the physiological burden of the personal protective equipment worn by firefighters. *Eur J Appl Physiol* 2012;112:2913–21.

48 Nazari G, Lu S, MacDermid JC. Quantifying physiological responses during simulated tasks among Canadian firefighters: a systematic review and meta-analysis. *J Mil Veteran Fam Health* 2021;7:55–75.

49 Mamen A, Oseland H, Medbø JI. A comparison of two physical ability tests for firefighters. *Ergonomics* 2013;56:1558–68.

50 Michaelides MA, Parpa KM, Thompson J, *et al*. Predicting performance on a firefighter's ability test from fitness parameters. *Res Q Exerc Sport* 2008;79:468–75.

51 Chizewski A, Box A, Kesler R, *et al*. Fitness fights fires: exploring the relationship between physical fitness and firefighter ability. *Int J Environ Res Public Health* 2021;18. doi:10.3390/ijerph182211733. [Epub ahead of print: 09 11 2021].

52 Phelps SM, Drew-Nord DC, Neitzel RL, *et al*. Characteristics and predictors of occupational injury among career firefighters. *Workplace Health Saf* 2018;66:291–301.

53 Wynn P, Hawdon P. Cardiorespiratory fitness selection standard and occupational outcomes in trainee firefighters. *Occup Med* 2012;62:123–8.

54 McDonough SL, Phillips JS, Twilbeck TJ. Determining best practices to reduce occupational health risks in firefighters. *J Strength Cond Res* 2015;29:2041–4 https://journals.lww.com/nsca-jscr/Fulltext/2015/07000/Determining_Best_Practices_to_Reduce_Occupational.34.aspx

55 Nazari G, Osifeso TA, MacDermid JC. And comorbidities, and determinants of work limitations among firefighters. *Rehabilitation Research and Practice* 2020;2020:1942513.

56 Bucala M, Sweet E. Obesity in the fire service: an inside look at the perceptions of firefighters towards obesity and other health issues. *Research Square Published Online First* 2019.

57 Stroup DF, Berlin JA, Morton SC. Meta-Analysis of observational studies in EpidemiologyA proposal for reporting. *JAMA* 2000;283:2008–12.

58 Brand RA. Editorial: standards of reporting: the CONSORT, quorum, and STROBE guidelines. *Clinical Orthopaedics and Related Research®* 2009;467:1393–4.

59 Moher D, Liberati A, Tetzlaff J, *et al*. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 2009;6:e1000097.

60 Ouzzani M, Hammady H, Fedorowicz Z, *et al*. Rayyan—a web and mobile APP for systematic reviews. *Syst Rev* 2016;5:1–10.

61 Collaboration C. *Review manager (RevMan) version 5.3*. Copenhagen: The Nordic Cochrane Centre, 2014.

62 Downes MJ, Brennan ML, Williams HC, *et al*. Development of a critical appraisal tool to assess the quality of cross-sectional studies (axis). *BMJ Open* 2016;6:e011458.

63 Sanderson S, Tatt ID, Higgins JPT. Tools for assessing quality and susceptibility to bias in observational studies in epidemiology: a systematic review and annotated bibliography. *Int J Epidemiol* 2007;36:666–76.

64 Long HA, French DP, Brooks JM. Optimising the value of the critical appraisal skills programme (CASP) tool for quality appraisal in qualitative evidence synthesis. *Res Methods Med Health Sci* 2020;1:31–42.

65 Gurevitch J, Koricheva J, Nakagawa S, *et al*. Meta-Analysis and the science of research synthesis. *Nature* 2018;555:175–82.

66 Metelli S, Chaimani A. Challenges in meta-analyses with observational studies. *Evid Based Ment Health* 2020;23:83–7.

67 Harris JD, Quatman CE, Manring MM. The American Journal of sports medicine P. *P How to Write a Systematic Review* 2013.

68 Haidich AB. Meta-Analysis in medical research. *Hippokratia* 2010;14:29–37 https://pubmed.ncbi.nlm.nih.gov/21487488

69 Lin L. Comparison of four heterogeneity measures for meta-analysis. *J Eval Clin Pract* 2020;26:376–84.

70 Vergnes J-N, Marchal-Sixou C, Nabet C, *et al*. Ethics in systematic reviews. *J Med Ethics* 2010;36:771–4.

BMJ Open: first published as 10.1136/bmjopen-2022-061435 on 21 July 2022. Downloaded from http://bmjopen.bmj.com/ on January 20, 2023 at University of the Western Cape. Protected by copyright.

http://etd.uwc.ac.za/

CHAPTER FOUR: PUBLICATION THREE − SYSTEMATIC REVIEW ONE

Effects of Cardiovascular Disease Risk Factors, Musculoskeletal Health, and Physical Fitness on Occupational Performance in Firefighters − A Systematic Review and Meta-Analysis

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

International Journal of *Environmental Research and Public Health*

Systematic Review

Effects of Cardiovascular Disease Risk Factors, Musculoskeletal Health, and Physical Fitness on Occupational Performance in Firefighters—A Systematic Review and Meta-Analysis

Jaron Ras [1,*], Andre P. Kengne [2], Denise L. Smith [3], Elpidoforos S. Soteriades [4], Rucia V. November [1] and Lloyd Leach [1]

1 Department of Sport, Recreation and Exercise Science, Faculty of Community and Health Sciences, University of the Western Cape, Cape Town 7535, South Africa
2 Non-Communicable Diseases Research Unit, South African Medical Research Council, Cape Town 7505, South Africa
3 Health and Human Physiological Sciences, Skidmore College, Saratoga Springs, New York, NY 12866, USA
4 Healthcare Management Program, School of Economics and Management, Open University of Cyprus, Nicosia 2220, Cyprus
* Correspondence: 3405618@myuwc.ac.za; Tel.: +27-72-795-5518

check for updates

Citation: Ras, J.; Kengne, A.P.; Smith, D.L.; Soteriades, E.S.; November, R.V.; Leach, L. Effects of Cardiovascular Disease Risk Factors, Musculoskeletal Health, and Physical Fitness on Occupational Performance in Firefighters—A Systematic Review and Meta-Analysis. *Int. J. Environ. Res. Public Health* **2022**, *19*, 11946. https://doi.org/10.3390/ijerph191911946

Academic Editors: Maria Jose Aliaño-González, Marta Ferreiro-González and Gerardo Fernández Barbero

Received: 16 August 2022
Accepted: 18 September 2022
Published: 21 September 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Abstract: Background: Firefighting is a strenuous occupation, which necessitates that firefighters stay in good physical condition and maintain adequate cardiovascular and musculoskeletal fitness to perform their duties with minimal health and safety risks. The aim of this review is to determine the effects of cardiovascular disease risk factors, musculoskeletal health, and physical fitness on the occupational performance of firefighters. **Methods:** PubMed/Medline, SCOPUS, Web of Sci- ence, EBSCOHost, and ScienceDirect were searched without time-restriction. The appraisal tool for cross-sectional studies and the Critical Appraisal Skills Programme toolkit were used to conduct the methodological assessment. Data were analyzed using Review Manager 5.3, and MedCalc® statistical software. **Results:** Age had a moderate effect on occupational performance ($Z = 5.15$, $p < 0.001$), whereas gender had a large effect size on occupational performance ($Z = 4.24$, $p < 0.001$). A significant moderate negative correlation was found between cardiorespiratory fitness and occupational performance ($R = -0.584$, $p < 0.001$). Significant low negative correlations were found between upper body endurance ($R = -0.344$, $p < 0.001$), abdominal endurance ($R = -0.308$, $p < 0.001$), grip strength ($R = -0.421$, $p < 0.001$), upper body strength ($R = -0.318$, $p < 0.001$), and lower body strength ($R = -0.216$, $p = 0.020$) and occupational performance. **Conclusions:** Aged firefighters with poor body composition and lower levels of physical fitness performed worse on all occupational performance tasks.

Keywords: firefighters; cardiovascular health; risk factors; musculoskeletal health; physical fitness; occupational performance

1. Introduction

Firefighting is a hazardous occupation that places high physiological and psychological stressors on firefighters, thereby, posing significant risks to their health and wellbeing [1–3]. In addition, the environmental stressors include extreme temperatures, and hazardous chemicals and fumes [3–8]. The extreme environmental conditions necessitate that firefighters wear heavy, insulated personal protective equipment (PPE), which often includes self-contained breathing apparatus (SCBA) that places tremendous strain on their cardiovascular system [6,8,9]. Moreover, firefighters are required to perform strenuous work duties, such as emergency rescues, first aid and resuscitation, and emergency extrication from vehicles, all while working irregular hours [1,8,10,11]. These types of strenuous and

http://etd.uwc.ac.za/

irregular working conditions place significant strain on the musculoskeletal and cardiovascular systems of firefighters, increasing the risk of serious injuries and sudden cardiac events, while on duty [1,12–14].

Existing research indicates that many firefighters have multiple cardiovascular disease (CVD) risks factors or poor overall cardiovascular health [3,15–19], poor musculoskeletal health [20–23] and inadequate physical fitness [24–27], which significantly and negatively affect their occupational performance [20,21,28–31]. Extensive scientific literature indicates that among emergency services professionals, firefighters have one of the highest percentages of mortality (45%) due to sudden cardiac death (SCD), with the majority related to underlying CVD risk factors [1,10]. These deleterious consequences are likely, at least partially, attributed to inadequate physical fitness, which invariably results in overexertion and increased cardiovascular strain [7,8,32], particularly when wearing full protective gear. Under these conditions, studies have shown the induction of maximum physiological responses, and often with adverse health outcomes [9,32,33]. In addition, firefighters have been reported to have the highest incidence of musculoskeletal injuries among all emergency services personnel [1], which is likely attributable to a combination of the weight of the PPE [32], the high prevalence of obesity [34–36], the necessity for sudden changes in posture and gait on rescue [35,36] and the high musculoskeletal demand of their professional duties [37–39]. The combination of extraordinary musculoskeletal health demands, deteriorating cardiovascular health and inadequate physical fitness in many firefighters, may lead to significant morbidity and mortality in this population [40,41]. In addition, the progressively deteriorating cardiovascular and musculoskeletal health with increasing age, and the overall poor physical fitness significantly and negatively affect firefighters' occupational performance [15,17,20,21,28–30]. Consequently, firefighters who are unable to perform their duties with sufficient competency and rigour are at risk of underperformance while on-duty [30,42], thereby, placing their lives as well as those of other civilians at increased risk, and increasing the potential loss of property and infrastructure. Firefighters who are not fit for active duty may be at increased risk of sustaining cardiovascular events and musculoskeletal injuries [27,30,43,44].

Measuring firefighters job performance while on active duty is an inherently difficult and costly task, due to the physical nature of their occupation and the high likelihood of equipment becoming lost or damaged [45]. This is particularly true for fire departments in developing countries or those fire departments that cannot afford to equip firefighters with this equipment [46,47]. Therefore, to assess firefighters' work ability, fire and rescue departments use occupational simulation protocols to determine if firefighters are able to perform their duties with sufficient rigor [6,28,33]. Previous research has indicated that occupational simulation protocols are the closest representation of the stressors of firefighting [48]. Globally, an alarming number of firefighters are at increased cardiovascular disease (CVD) risk, while suffering from multiple musculoskeletal disorders and operating under suboptimal levels of physical fitness. This negatively effects their occupational performance and limits their ability to cope with the on-duty demands [2,6,31,39,49,50]. However, there have been no previous systematic reviews investigating the effects of CVD risk factors, musculoskeletal health, and physical fitness on the occupational performance of firefighters, which motivated the need for the present study.

The relative lack of systematic reviews on this current topic was somewhat surprising, given the nature of the occupation. Providing more information on the effect that cardiovascular disease risk factors, musculoskeletal health and physical fitness have on occupational performance may provide valuable evidence in informing policy makers and fire departments. For more information on the aim and objectives of this review, please refer to the published protocol: Ras et al. [51]. Briefly, the aim of this systematic review and meta-analysis was to determine the effects of CVD risk factors, musculoskeletal health and physical fitness on the occupational performance of firefighters. The objectives of the review were (i) to investigate the effects of cardiovascular health on the occupational performance of firefighters; (ii) to investigate the effects of musculoskeletal health on the occupational

http://etd.uwc.ac.za/

performance of firefighters; (iii) to investigate the effects of physical fitness on the occupational performance of firefighters, (iv) and, to investigate the relationship between cardiovascular health, musculoskeletal health and physical fitness on the occupational performance of firefighters.

2. Materials and Methods

The guidelines for Meta-analysis of Observational Studies in Epidemiology (MOOSE) and Quality of Reporting of Meta-analysis (QUOROM) guided our methods when conducting this review [52,53]. When considering studies for this review, the PRISMA guidelines for systematic reviews was followed, and the outcomes for each step was described in a flow-diagram [54] (Figure 1).

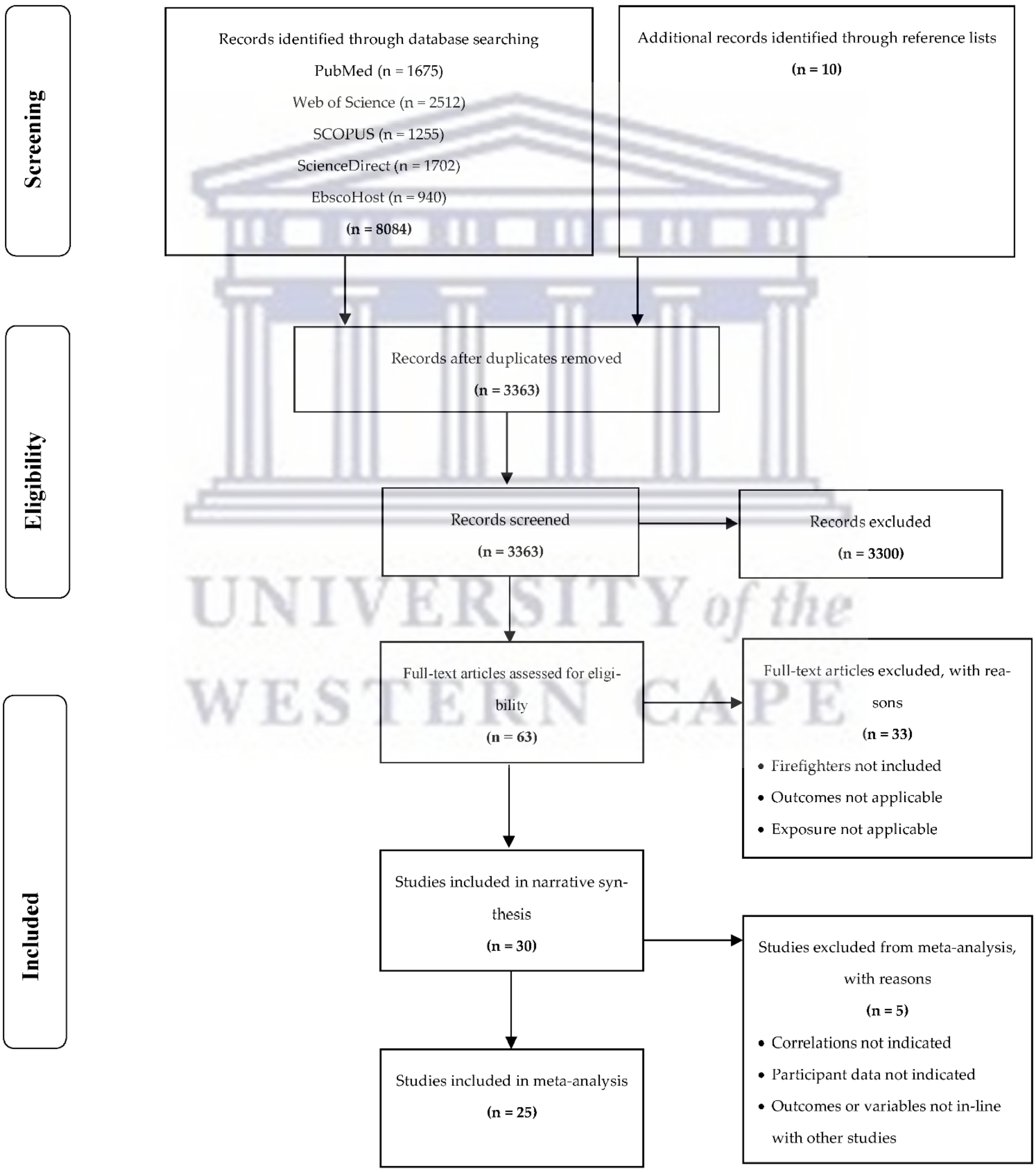


Figure 1. Flow chart of study selection in narrative review: Adapted from Moher et al. [54].

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

2.1. Summary of Methods

The study design of choice is a quantitative systematic review, where participants included adult, full-time, part-time and volunteer firefighters between the ages of 18 to 65 years. The exposures assessed included cardiovascular health, musculoskeletal health, and physical fitness in relation to the occupational performance of firefighters. The inclusion criteria were as follows: (i) studies that recruit full-time adult firefighters, with no limitations to publication year; (ii) studies investigating the effects of cardiovascular health, musculoskeletal health and/or physical fitness on the occupational performance of firefighters; (iii) studies available in full-text. Exclusion criteria included: (i) studies focusing on other outcome measures as the main exposures or outcomes; (ii) systematic reviews or other types of reviews; (iii) articles that are non-English. The protocol for this study has been published and more information on the methods involved in the current manuscript may be found at: Ras et al. [51].

2.2. Search Strategy for Identification of Studies

A detailed literature search was conducted by the two primary reviewers (JR and RN), tasked with independently identifying studies, extracting the data, verifying the data collected and grading the quality of the results. JR was the principal investigator tasked with data analysis, narratively synthesising the data and writing up of the systematic review. A third reviewer (LL) was tasked with adjudicating and resolving any disagreement between the two independent reviewers.

2.3. Electronic Literature Search

The following journal databases were searched: PubMed/Medline, SCOPUS, Web of Science, EBSCOHost and ScienceDirect with no limitation to publication year. Keywords and medical subject heading (MeSH) terms were used in various arrangements depending on the specific database. A combination of the appropriate terms (search string) was used to ensure the inclusion of the relevant components of the participants, exposure, comparison, and outcome (PECO). The details of the search strategy can be found in Supplementary S1.

2.4. Additional Searches for Grey Literature

The search strategy was completed by searching the following databases for grey literature: Google, Google Scholar and Networked Digital Library of Theses and Dissertation.

2.5. Selection of Studies

All studies, as full-text articles, that met the inclusion criteria were selected for screening. Every attempt was made to contact the authors for full-text articles or missing data. Thereafter, the full-text articles were assessed independently by two reviewers using the Rayyan® intelligent systematic review (RIS) tool [55]. When screening the studies, three categories were used, namely, included, excluded and unsure. Any uncertainties regarding study inclusion were discussed between the two reviewers. In the event of disagreement, a discussion was held with the third reviewer, and resolved by the latter.

2.6. Data Extraction and Data Management

A researcher-generated data extraction form was used (Supplementary S2 and Supplementary S3). The information extracted was the general study details, such as authors, date of study publication, study title, study design and country of study, the exposure assessed, and the outcome measures. Study characteristics were collected, such as sampling method and sample size, and details of the participants. In addition, the details of exposure and the outcome variables were extracted, i.e., the study must have reported on at least one of the exposure variables in relation to firefighter occupational performance.

http://etd.uwc.ac.za/

2.6.1. Critical Appraisal of Included Studies

The appraisal tool for cross-sectional studies (AXIS checklist) (Table 1) [56] and The Critical Appraisal Skills Programme (CASP) toolkit (Middle Way, Oxford, UK) (Table 2) (https://casp-uk.net/casp-tools-checklists/ (accessed on 1 March 2021)) were used to conduct the methodological assessment of each study included. The CASP toolkit (Middle Way, Oxford, UK) was previously used in systematic reviews on firefighters and tactical personnel to assess study methodologies, and allows for fair and equitable assessment of a variety of study types. The AXIS toolkit was shown to be a reliable and valid tool for assessing the quality of cross-sectional studies [56].

2.6.2. Classification of Age and Obesity and Physical Fitness for Meta-Analysis

Age was classified as male firefighters over the age of 45 years, and obesity was classified as a BMI of 30 kg·m^2 or higher or a bodyfat percentage (BF%) over 25%. For cardiorespiratory fitness, only studies that included either absolute (mL·kg·min) or relative (L·min) VO2max were used. These estimates included both from direct gas analysis and those estimated with maximal or submaximal VO2max. For upper body and abdominal muscular endurance, the push up and sit ups endurance tests were preferred. For upper body strength grip strength and the bench press were used as the preferred measures, and for lower body only studies including the leg press or squat were included. For flexibility, the sit and reach test was preferred. These physical fitness tests were favored due to their frequency of use across multiple studies when used to indicate overall health-related physical fitness in firefighters.

2.7. Data Analysis

2.7.1. Assessment of Overall Effect Size

The outcome measure (occupational performance) was analysed as a continuous variable. The mean difference (MD) and standardized mean difference (SMD), with 95% confidence intervals (CI), of estimation was used to estimate the effect, using the inverse variance method of meta-analysis, between cardiovascular health and occupational performance and physical fitness and occupation performance in firefighters [81]. For the correlation analysis, MedCalc® statistical software Ltd., Ostend, Belgium (version 20.104), was used to perform the correlation meta-analysis. Investigators grouped the "R" values according to cardiovascular disease risk factors, physical fitness components and overall performance, and combined them into a single representative effect estimate [82]. Meta-analysis techniques were applied using the number of studies, original "R" values and sample sizes to generate the pooled "R" values between each cardiovascular health component, fitness component and job task component [82]. Where one study, or insufficient studies were present, a meta-analysis on the pooled "R" was not calculated [82]. The original "R" values were converted to a common test metric using the Fisher's "R" to "Z" transformation [82]:

$$Z_{ri} = \frac{1}{2}\ln\left(\frac{1+ri}{1-ri}\right) \quad s_z^2 = \frac{1}{n-3}$$

The Fisher's Z values from the original studies were combined using random effect models for all analysis' performed [82]. The following was used to indicate the strength of correlation, 0.00 to 0.30 (−0.00 to −0.30) for negligible correlation; 0.30 to 0.50 (−0.30 to −0.50) for low correlation; 0.50 to 0.70 (−0.50 to −0.70) for moderate correlation; 0.70 to 0.90 (−0.70 to −0.90) for high correlation and 0.90 to 1.00 (−0.90 to −1.00) for very high correlation [82].

http://etd.uwc.ac.za/

Table 1. Critical appraisal of cross-sectional studies using AXIS checklist.

Question	**Michaelides et al. [57]**	**Skinner et al. [30]**	**von Heimburg et al. [58]**	**Perroni et al. [59]**	**Schonfeld et al. [60]**	**Lindberg et al. [61]**	**Lindberg et al. [62]**	**Siddal et al. [28]**	**Xu et al. [63]**	**Stevenson et al. [64]**	**Myhre et al. [65]**	**Chizewski et al. [66]**	**Kleinberg et al. [67]**	**Elsner and Kolkhorst**	**Ryan et al. [69]**	**von Heimburg et al. [70]**	**von Heimburg et al., [71]**	**Rhea et al. [42]**	**Sheaff et al. [72]**	**Michaelides et al. [73]**	**Saari et al. [74]**	**Windisch, et al. [75]**	**Misner et al. [76]**	**Williford et al. [77]**	**Davis et al. [78]**	**Nazari et al. [31]**	**Sothmann et al. [39]**
Introduction																											
Clear aims/objectives	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Methods																											
Study design appropriate for the stated aim(s)?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sample size justified?	×	×	×	×	×	×	×	×	×	×	×	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	×	✓	✓	✓	✓	✓
Target/reference population clearly defined?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
Sample frame taken from an appropriate population base to closely represent the target population?	×	×	×	×	×	×	×	×	×	×	✓	×	×	×	×	×	×	×	×	×	×	×	×	✓	✓	✓	✓
Selection process likely to select subjects that were representative of the target population?	×	×	×	×	×	×	×	×	×	×	✓	×	×	×	×	×	×	×	×	×	✓	×	×	✓	✓	✓	✓
Measures undertaken to address and categorize non-responders?	×	×	×	×	×	×	×	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Were the risk factor and outcome variables measured appropriate to the aims of the study?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Were the risk factor and outcome variables measured correctly using instruments/measurements that had been trialed, piloted or published previously?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Table 1. *Cont.*

Question	Michaelides et al. [57]	Skinner et al. [30]	von Heimburg et al. [58]	Perroni et al. [59]	Schonfeld et al. [60]	Lindberg et al. [61]	Lindberg et al. [62]	Siddal et al. [28]	Xu et al. [63]	Stevenson et al. [64]	Myhre et al. [65]	Chizewski et al. [66]	Kleinberg et al. [67]	Elsner and Kolkhorst	Ryan et al. [69]	von Heimburg et al. [70]	von Heimburg et al., [71]	Rhea et al. [42]	Sheaff et al. [72]	Michaelides et al. [73]	Saari et al. [74]	Windisch, et al. [75]	Misner et al. [76]	Williford et al. [77]	Davis et al. [78]	Nazari et al. [31]	Sothmann et al. [39]
Clear which tests were used to determine statistical significance and/or precision estimates?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Were the methods sufficiently described to enable them to be repeated?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Results																											
Were the basic data adequately described?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Does the response rate raise concerns about non-response bias?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
If appropriate, was information about non-responders described?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Were the results internally consistent?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Were the results presented for all the analyses described in the methods?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Discussion																											
Were the authors' discussions and conclusions justified by the results?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Were the limitations of the study discussed?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Other																											

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 1. *Cont.*

Question	M	i	c	h	a	e	l	i	d	e	s	e	t	a	l	.	[	5	7	]	S	k	i	n	n	e	r
Were there any funding sources or conflicts of interest that may affect the authors' interpretation of the results?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Was ethical approval or consent of participants attained?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TOTAL SCORE	15	15	15	15	15	15	15	16	16	16	16	17	17	17	17	17	17	17	17	17	17	17	18	19	19	19	19

Note: NA—indicated questions that were not applicable for grading of the overall study quality; ✓—indicates yes; ×—indicates no.

Table 2. Critical appraisal of cohort studies using the Critical Appraisal Skills Programme checklist.

Quality Assessment Criteria	Phillips et al. [79]	MacDermid et al. [29]	Hendersen et al. [80]
1. Did the study address a clearly focused issue?	✓	✓	✓
2. Was the cohort recruited in an acceptable way?	✓	✓	✓
3. Was the exposure accurately measured to minimize bias?	✓	✓	✓
4. Was the outcome accurately measured to minimize bias?	✓	✓	✓
5. (a) Have the authors identified all important confounding factors?	✓	✓	✓
5. (b) Have they taken account of the confounding factors in the design and/or analysis?	✓	✓	✓
6. (a) Was the follow up of subjects complete enough?	✓	✓	✓
6. (b) Was the follow up of subjects long enough?	✓	✓	✓
7. What are the results of this study?	NA	NA	NA
8. How precise are the results?	NA	NA	NA
9. Do you believe the results?	✓	✓	✓
10. Can the results be applied to the local population?	✓	✓	✓
11. Do the results of this study fit with other available evidence?	✓	✓	✓
12. What are the implications of this study for practice?	✓	✓	✓
TOTAL SCORE	12	12	12

Note: NA—indicated questions that were not applicable for grading of the overall study quality; ✓—indicates yes.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

2.7.2. Assessment of Heterogeneity

Heterogeneity was evaluated using the Chi-square test, I^2 test and Cohen's Q test [83]. The following was used to explain I^2 statistics: (1) 0% to 30%: may not be important; (2) 31% to 60%: may indicate moderate heterogeneity; (3) 61% to 80%: may indicate substantial heterogeneity; (4) 81% to 100%: considerable heterogeneity. Regardless of whether homogeneity or heterogeneity were present between studies, a random-effects model was preferred in order to maintain consistency in the interpretation of results [83]. To assess the risk of bias between studies, the Egger's test and Begg's test were performed.

2.7.3. Subgroup Analysis and Investigation of Heterogeneity

When heterogeneity was present, a subgroup analysis was performed to explore the sources of heterogeneity [81,83]. Where applicable, subgroup analysis included the following: weight of personal protective equipment (PPE), the sex of the firefighters (male and females), the number of tasks performed and if tasks were sequentially or discretely conducted, for full-time firefighters. For the weight of PPE, studies that had a combined weight of PPE above 22 kgs. The number of tasks performed included studies where firefighters performed five or more tasks during the occupational simulation protocols. Sequential tasks included studies that included tasks that were performed sequentially, i.e., followed a specific order, whereas discrete tasks included studies that had no specific order. An additional subgroup analysis was included for cardiorespiratory fitness, which included studies that estimated cardiorespiratory fitness directly by using gas analysis. Although all exposures were measured using a standard physical ability test or simulated work-related tasks, the methods used could be different, which required comparing and converting certain measurements to produce similar findings for comparison.

3. Results

3.1. Study Selection

Initially, the electronic database searches yielded 8084 publications, with an addition of 10 studies found through reference list searching (Figure 1). After removal of duplicates, 3363 studies remained and were screened using title and abstract information. Of these, 3300 studies were excluded for not meeting the inclusion criteria, leaving 63 studies that were designated for full-text screening. A total of 33 studies were excluded after screening the full text, and 30 studies were eligible to proceed to data extraction. After data extraction, 25 studies were included for the final meta-analysis.

3.2. Assessment of the Strengths and Weaknesses of Studies

The strengths and weaknesses of the studies were assessed and the most frequent weakness of the studies, according to the AXIS checklist, were: (a) the sample size was not justified (13/27); (b) the sample frame not taken from an appropriate sample base (22/27); (c) the sample selection not likely to select participants that represented the target population (21/27) (Table 1). These weaknesses were largely due to the nature of the study types and the relatively small sample sizes. The quality of the included studies was acceptable. A score of 15 point was given a score of "moderate", 16 to 17 point given a score of "good" and scores between 18−19 given a score of "high" quality (Table 1). Scores of lower quality (<15) were excluded from this review. Then strengths and weaknesses of cohort studies were assessed according to the CASP checklist for cohort studies, and all studies were of high quality, with N/A given to two questions, namely: (a) What are the results of this study? and (b) How precise are the results? (Table 2).

3.3. Study Characteristics

The included studies encompassed 27 cross-sectional studies and three cohort studies conducted between the period of 1987 and 2022, and included 2585 firefighters. Stud- ies were conducted in different global regions and encompassed multiple variations of occupational simulated tasks. A summary of the included studies is presented in Table 3.

http://etd.uwc.ac.za/

3.4. Cardiovascular Disease Risk Factors, Musculoskeletal Health and Occupational Performance

The results indicated that only two cardiovascular disease risk factors were consistently studied according to occupational performance in firefighters, and included age and obesity (Table 3). The studies reported that older firefighters' completion times and performance on each individual task was significantly lower compared to younger firefighters [39,58,74,77]. When firefighters were aged (over 45 years in males), overall performance was significantly reduced. Obesity was reported to significantly reduce overall occupational performance and performance on each individual task [30,57,60,65,73,74,77,79,80]. Resting diastolic blood pressure and diastolic blood pressure at completion of the simulation event was significantly related to occupational performance in firefighters [72,84]. The results indicated that, although males tended to be at higher risk for cardiovascular disease, they also performed significantly better overall and in each occupational task compared to female firefighters [39,58,64,72]. Only one study was found that investigated the rela- tionship between musculoskeletal health and occupational performance in firefighters. Although not statistically significant, the study found that firefighters who reported having moderate-to-severe muscle and joint problems took approximately 10 s longer to complete the five flights of stairs while carrying a 22 kg high-rise pack than firefighters not reporting those problems [29].

3.5. Physical Fitness and Occupational Performance in Firefighters

The results indicated that cardiorespiratory fitness [28,30,58,60,61,64–66,68,70,80,84], muscular endurance [30,42,57,62,65,66,70,73,77,80,84] and muscular strength [30,42,57,62,72,73,77,80,84] were significantly related to overall occupational performance in firefighters (Table 3). In addition, cardiorespiratory fitness was significantly related to the time required to complete the stair climb [30,31,42,60,62,65], hose drag [30,31,42,66], crawl [62,66], ladder raise [62,66], terrain crossing [62], demolition [62], rolled hose lift and move [57], equipment carry [66], hose pull [62], victim rescue [30,42,60,62,65,66], forcible entry [66] equipment hoist [42], and saw hold/cutting [30,61]. Upper body endurance was significantly related to tasks requiring upper body work, such as the hose drag [30,57,66,77], hose pull [61], hose connect, victim rescue [30,57,66,77], hose pull [61], rolled hose lift and move [57], crawl [66], ladder raise [66] terrain crossing [62], demolition [62], equipment carry [66], saw hold, forcible entry [57,66,77] and equipment hoist, and also a lower extremity dominated task such as the stair climb [30,57,77]. Abdominal endurance was significantly related to the stair climb [30,42,57,61,77], hose drag [30,42,57,66,77], hose pull [61], hose connect, victim rescue [30,42,57,61,66,77], hose pull [61], rolled hose lift and move [57], crawl [66], ladder raise [66], terrain crossing [62], demolition [62], equipment carry [66], forcible entry [57,66,77] and equipment hoist [42,77]. Grip strength was significantly related to hose drag [30,31,42,57,77], victim rescue [30,42,57,61,77], rolled hose lift and move [57], crawl, hose pull [61], terrain crossing [61], demolition [61], forcible entry [57,77] and equipment hoist [42,77], however, grip strength consistently appeared to have a stronger relationship with overall performance and each specific occupational task. Upper body strength was significantly related to hose drag [30,42,57], victim rescue [30,42,57] and rolled hose lift and move [57]. Surprisingly, lower body strength was most consistently reported not to be significantly related to stair climb times [30,31,42,57,76] in firefighters. However, lower body strength was significantly related to the hose drag [30,31,42,57], hose pull, victim rescue [30,42,57], and rolled hose lift and move [57]. Flexibility has been reported to be significantly related to stair climb times [77], however, in one study no relationship was found between these variables. A study reported a relationship between quadriceps muscle diameter and stair-climb time (R = 0.560, $p < 0.001$) [67], however, this does not coincide with the results of previous literature.

http://etd.uwc.ac.za/

Table 3. Study characteristics of included studies.

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
Chizewski et al. [66]	Cross-sectional study USA, Midwestern states	89 male firefighter recruits	Age: 26.8 ± 4.2 years Body mass: 89.24 ± 16.33 kgs Height: 1.78 ± 0.07 m BMI: 28.11 ± 4.19 kg·m^{-2} 1.5 Mile Run, push-ups, sit-ups bench press, flexibility, vertical jump.	1. Kiser Sled 2. SCBA Crawl 3. Victim Drag 4. Hose Advance 5. Equipment Carry 6. Ladder Raise	Full PPE SCBA gear Sequential tasks 20.4 kgs	Significant relationships between cardiovascular endurance (r = −0.49, $p < 0.01$), bench press (r = −0.51, $p < 0.01$), push-ups (r = −0.38, $p = 0.01$), sit-ups (r = −0.41, $p < 0.01$), power (r = −0.32, $p < 0.01$) and total firefighting ability (total completion time).
Davis et al. [74]	Cross sectional study USA, Washington D.C	100 full-time male firefighters	Age: 33.1 ± 7.63 Height: 176.7 ± 5.43 cm Weight: 83.4 ± 10.94 kgs LBM: 65.8 ± 5.98 kgs BF%: 21.1 ± 6.69% v̇O2max: 39.60 ± 5.94 mL·kg·min. Treadmill test, handgrip strength, sit-ups, push-ups, sit-and-reach.	1. Ladder extension 2. Standpipe carry 3. Hose pull 4. Simulated rescue 5. Simulated forcible entry	Full PPE SCBA gear Sequential tasks 24 kgs	Significant predictors of performance on simulated tasks included the firefighters' lean body mass, maximal heart rate, cardiorespiratory fitness, age, and BF%. High muscular strength and endurance and near maximal aerobic capacity was necessary to complete simulated tasks.
Elsner and Kolkhorst [68]	Cross-sectional study USA, San Diego	20 male firefighters	Age: 37.4 ± 8.5 years Height: 178 ± 6 cm Weight: 86.8 ± 8.9 kgs Body fat: 16.9 ± 4.7% Time: 11.65 ± 2.21 min Average v̇O2: 29.1 ± 8.0 mL·kg·min Treadmill test	1. Hose advance and connect 2. ladder carry and extension 3. Donning their SCBA 4. Advancing two sections of a fire hose 5. Breach 6. Stair climb 7. Equipment hoist. 8. Hose advance. 9. stair decent 10. Search and rescue	Full PPE and SCBA gear Sequential tasks	There was a moderately strong inverse relationship between v̇O2max and performance time as well as a strong positive relationship between v̇O2max and average v̇O2 during the firefighting protocol.

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
Henderson et al. [80]	Cohort study USA, Milwaukee	306 male and female firefighter recruits	Age: 26.1 ± 4.7 years Height: 180.5 ± 6.4 cm LBM: 74.4 ± 8.1 kgs BF%: 13.3 ± 4.5% Step test, bench press, lat pull-down, grip strength, sit-ups	1. Stair climb 2. Hose hoist 3. Forcible entry 4. Hose advance 5. Victim rescue	Full PPE and SCBA gear Sequential tasks 29.3 kgs	BF% (r = −0.17) and age (r = −0.03) was negatively correlated with combat test performance. Absolute v· O2max (r = 0.43), bench press (r = 0.33), grip strength (r = 0.50), sit-ups (r = 0.31) were positively correlated with combat test performance.
Kleinberg et al. [67]	Cross-sectional study USA, North Carolina	46 male firefighters	Age: 37.6 ± 7.2 years Stature: 180.2 ± 6.9 cm Body mass (kgs) 108.0 ± 19.8 kgs BMI: 33.1 ± 4.7 kg·m^{-2} Quadriceps cross-sectional area (Q_{CSA}) (cm^2/kgs): 0.50 ± 0.07 Quadriceps echo intensity (Q_{EI}): 109.3 ± 13.9	Stair-climb (s)	Fitted with weighted vest to simulate weight of PPE 22.7 kgs	Quadriceps cross-sectional area (QCSA) and quadriceps echo intensity (QEI) were significantly associated with stair-climb time (r = 20.492, p = 0.001; r = 0.363, p = 0.013, respectively). QCSA and QEI as significant predictors of stair-climb time (r = 0.560, p < 0.001) and a VIF of 1.046.
Lindberg et al. [62]	Cross sectional study Northern Sweden	38 male and female full-time, volunteer firefighters and civilians.	Age: 34 ± 9.8 years Weight: 78 ± 11.1 kgs Height: 177.2 ± 7.9 cm BMI: 25 ± 2.7 kg·m^{-2} Grip strength, sit-ups, grip endurance, squat endurance, bench press endurance, chin ups, dips, upright barbell row, standing broad jump, barbell shoulder press	1. cutting 2. Stairs 3. Hose pulling 4. Demolition 5. Victim rescue 6. Terrain crossing	19 kgs	Significant correlations were present between all field tests and all the firefighter specific tasks (r = 0.45 to 0.85).
Lindberg et al. [61]	Cross sectional study Northern Sweden	38 male and female full-time, volunteer firefighters and civilians.	Age: 34 ± 9.8 years Weight: 78 ± 11.1 kgs Height: 177.2 ± 7.9 cm BMI: 25 ± 2.7 kg·m^{-2} Treadmill test, track running, step test, rowing.	1. cutting 2. Stairs 3. Hose pulling 4. Demolition 5. Victim rescue 6. Terrain crossing	24 kgs	Absolute and relative v· O2max were significantly correlated to cutting (r = 0.55; r = 0.47), stairs (r = −0.75; r = −0.52), pulling (r = −0.74; r = −0.46), demolition (r = −0.79; r = −0.57), rescue (r = −0.79; r = −0.48) and terrain (r = −0.70; r = −0.74) performance.

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
MacDermid et al. [29]	Cross-sectional study Canada, Hamilton	293 male and female firefighters	Age: 42.6 ± 9.7 years Height: N/A Weight: N/A BMI: N/A	Work Limitations Questionnaire (WLQ-26) 1. Hose Drag 2. Stair Climb with a High-Rise Pack	Not specified Discrete tasks Not specified	Firefighters who reported having moderate to severe muscle and joint problems took approximately 10s longer to complete the stair climb task than did firefighters not reporting those problems.
Michaelides et al. [73]	Cross-sectional study USA, Arkansas	38 experienced volunteer firefighters	Age: 32.25 ± 6.07 years Weight: 96.1 ± 16.4 kgs Height: 178.21 ± 7.35 cm BF%: 21.78 ± 6.22% Abdominal strength, Relative power (vertical jump), Power (vertical jump), grip strength, bench press, squat, Sit and reach, Relative power (step test), Power (step test), Push-ups, Sit-ups	1. Stair climb, 2. Rolled hose lift, and move, 3. Keiser sled, 4. Hose pull and hydrant hookup, 5. Rescue mannequin drag, 6. Charged hose advance	Full PPE and SCBA gear Sequential tasks 22.68 kgs	Upper body muscular endurance (push-ups to exhaustion) and upper body strength (1-RM bench press) were significantly inversely related with the total completion time the test (AT score; $p < 0.01$). In addition, there were significant positive associations ($p < 0.01$) between %BF and RHR variables and time to complete the AT. Flexibility, $t(36) = 2.71$, $p < 0.05$, %BF, $t(36) = 3.11$, $p < 0.05$, 1-RM bench press, $t(36) = -2.24$, $p < 0.05$, and 1-RM squat, $t(36) = -2.06$, $p < 0.05$, fitness parameters contributed significantly to the predictive power of firefighters' AT performance.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
Michaelides et al. [57]	Cross-sectional study USA, Arkansas	90 full-time male firefighters	Age: 32.25 ± 6.07 years Height: 181.16 ± 6.62 cm Body weight: 97.04 ± 15.51 kgs Age: 33 ± 67years Body fat: 23.05 ± 5.58% BMI: 29.55 ± 3.67 kg·m^{-2} Waist circumference: 97.33 ± 10.96 cm Abdominal strength, Relative power (vertical jump), Power (vertical jump), grip strength, bench press, squat, Sit and reach, Relative power (step test), Power (step test), Push-ups, Sit-ups	1. Stair climb 2. Rolled hose lift, and move 3. Keiser sled 4. Hose pull and hydrant hookup 5. Rescue mannequin drag 6. Charged hose advance	Full PPE and SCBA gear Sequential tasks 22.68 kgs	Negative correlations indicated that higher performance on the fitness variables were associated with faster completion of the AT test, thus higher firefighting performance. Poor performance on the AT was significantly correlated (positive correlations) with high resting heart rate, body mass index (BMI), BF%, age, and waist size. Results showed that abdominal strength (t [53] = 22.94, p = 0.01); power, step test (t [53] = 22.37, p = 0.05); push-ups (t [53] = 1.97, p = 0.05); resting Hr (t [53] = 2.64, p = 0.05); and BF% (t [53] = 4.29, p = 0.01) contributed significantly to the predictive power of firefighters' AT performance
Misner et al. [76]	Cross-sectional study USA, Chicago	150 female firefighter applicants	Age: 27.1 ± 4.5 years Height: 164.9 ± 5.6 cm Body mass: 63.4 ± 7.9 kgs BF%: 19.0 ± 5.9% LBM: 50.8 ± 4.3 kgs Leg press, bicycle ergometer, vertical jump, Wingate anaerobic test.	Stair climb test	Harness containing air pack 13.1 kgs	Stair climb performance was significantly correlated with age, lean body mass, vertical jump and peak power
Myhre et al. [65]	Cross-sectional study USA	222 male and female firefighters	Age: 30.4 ± 9.3 years Height: 178.6 ± 7.6 cm Weight: 83.5 ± 13.1 kgs BF%: 20.1 ± 6.9% Cycle ergometer test, bench press, upright forearm curl, upright row, barbell raise and lower.	1. "crash" aircrew rescue 2. Search and rescue	Full PPE and SCBA gear Sequential tasks 22.2 kgs	Recue time was positively correlated to age (r = 0.38), and BF% (r = 0.36) and negatively correlated to v· O2max (r = −0.36), bench press (r = −0.18) and abdominal curl (r = −0.25).

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
Nazari et al. [31]	Cross-sectional study Canada, Ontario	46 males and 3 females firefighters	Age: 33.66 ± 9.19 years Height: 1.81 ± 0.08 cm Weight: 90.35 ± 13.22 kgs BMI: 27.53 ± 3.56 kg·m^{-2} v̇O2max: 40.30 ± 6.25 mL·kg·min Cardiorespiratory fitness NIOSH lower limb strength combined grip strength	1. Stair climb, 2. Hose drag	Full PPE and SCBA gear Discrete tasks 22.7 kgs	A negative correlation was present and indicated that higher v̇O2max and/or strength levels were associated with faster completion of tasks Grip strength (r = −0.30) and CRF (r = −0.25) was negatively correlated to hose drag task. CRF was negatively correlated to the stair climb (r = −0.31). In predicting hose drag completion times, firefighters' age and right grip strength scores were shown to be the most statistically significant.
Perroni et al. [85]	Cross-sectional study Italy, Rome	20 full-time male firefighters	Height: 177 ± 6 cm Weight: 77.2 ± 8.7 kgs BMI: 24.7 ± 2.1 kg·m^{-2} HR_{max}: 90 ± 5% (176 ± 9 bmp) v̇O2peak: 43.1 ± 4.9 mL·kg·min. Treadmill test	1. Incremental treadmill test, 2. child rescue, 250m run, 3. find an exit, 4. 250 m run 2	Discrete testing 23 kgs	There was a significant correlation between v̇O2peak and time to job completion of the simulated intervention (r = 0.09, *p* = 0.72). Correlation coefficients ranging from 0.09 to 0.53 existed between v̇O2peak and time to complete the different tasks.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
Phillips et al. [79]	longitudinal study, cohort and cross-sectional study design Canada, Alberta	414 male firefighter applicants	Age: 27 ± 5 years Height: 180 ± 6 cm Mass: 89.0 ± 17.0 kgs BMI: 26.9 ± 4.2 kg·m^{-2} Treadmill: 15.9 ± 2.7 min Treadmill test	1. Hose drag, 2. Weighted sled pull 3. Forcible entry, 4. Victim rescue, 5. Ladder climb	PPE only Sequential testing 23.3 kgs	There was a significant correlation between body mass and treadmill test duration and a stronger correlation (r = 0.76) between test duration and $\dot{v}$ O2peak relative to total mass. The less than 70.0 and 70.0 to 79.9 kg mass categories were significantly slower compared with the others during the charged hose drag. For the weighted sled pull, forcible entry and victim rescue tasks, the less than 70 kg group was significantly slower. The more than 110.0 kg group was significantly slower than all the other groups on the ladder climb test. There were modest correlations ($p < 0.05$) between body mass and task completion time for the charged hose drag and weighted sled pull tests (r = 0.44, r = 0.36, respectively. There were weak correlations between task completion time and body mass for the forcible entry, victim rescue, and ladder climb tests.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
Rhea et al. [42]	Cross-sectional study USA, Phoenix	20 male firefighters	Age: 34.5 ± 6.1 years Professional service: 6.1 ± 5.2 years BF%: 16.6 ± 3.9% 12-min run, bench press 5 rm(kg) squat 5 rm (kg), hand grip strength (kg), row endurance, bench press endurance, shoulder press endurance (reps), bicep curl endurance, squat endurance, ab curls, hand grip endurance, 400-m run, body fat %:	1. Hose pull 2. Dummy drag 3. Stair climb 4. Hoist	Full SCBA gear Discrete testing 25 kg	Significant correlations ($p < 0.05$) between job performance and the following variables: total fitness (r = −0.62), bench press strength (r = −0.66), hand grip strength (r = −0.71), bent-over row endurance (r = −0.61), bench press endurance (r = −0.73), shoulder press endurance (r = −0.71), bicep endurance (r = −0.69), squat endurance (r = −0.47), and 400-m sprint time (r = 0.79). Significant correlations were also identified for each of the individual job performance tests.
Ryan et al. [69]	Cross-sectional study USA, North Carolina	41 full-time male firefighters	Age: 32.3 ± 2.5 years Stature: 178.3 ± 2.4 cm Body mass: 92.3 ± 5.7 kgs BMI: 29.0 ± 1.6 $kg \cdot m^{-2}$ BF%: 24.1 ± 2.4%	Stair climb time	Fitted with weighted vest to simulate weight of PPE. 22.73 kgs	Faster firefighter Stair Climb times (lower scores) were significantly associated with greater Peak Torque (r = −0.421; $p = 0.007$), greater PP (r = −0.530; $p = 0.001$), less fatigability (r = −0.389; $p = 0.014$), younger age (r = 0.441; $p = 0.004$), lower %BF (r = 0.629; $p < 0.001$).

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
Saari et al. [74]	Cross-sectional study USA, Ohio	74 full-time male firefighters	Younger vs. Older Age: 31.80 ± 3.42 vs. 44.65 ± 5.18 years Height: 179.85 ± 6.32 vs. 182.23 ± 5.57 cm Body mass: 92.61 ± 8.73 vs. 89.77 ± 23.06 kgs BF%: 15.94 ± 4.31 vs. 19.49 ± 4.58% Fat mass: 14.95 ± 4.84 vs. 17.71 ± 7.52 kgs Fat-free mass: 77.65 ± 6.32 vs. 72.06 ± 17.12 kgs Waist circumference: 88.67 ± 6.56 vs. 72.06 ± 17.12 cm Hip circumference: 102.47 ± 4.70 vs. 105.14 ± 6.57 cm	1. High-rise pack carry (stair climb) 2. Hose hoist 3. Forcible entry 4. Hose advance 5. Victim recue	Full PPE and SCBA gear. Sequential testing Not specified	On average, it took older firefighters 8.8% longer to complete the course compared with younger firefighters (p = 0.029). Age was positively correlated with course time (r = 0.297, p = 0.017)
Schonfeld et al. [60]	Cross-sectional study USA	20 male volunteer firefighters	Age: 38.6 ± 2.5 years Height: 175.7 ± 1.1 cm Weight: 75.4 ± 1.9 kgs v˙O2max: 48.5 ± 2.1 mL·kg·min BF%: 22.4 ± 0.9% Treadmill test	1. Stair climb 2. Chopping simulation 3. Victim drag	Full PPE and SCBA gear Sequential testing 24 kg	v˙O2max (r = −0.628) and BF% (r = 0.467) were correlated with total performance time. BF% was only correlated individually to stair climb (r = 0.535), whereas v˙O2max was correlated to all stair climb, chopping and victim drag (r = −0.627, −0.324 and −0.447)
Sheaff et al. [72]	Cross-sectional study USA, Baltimore–Washington	33 Career and volunteer firefighters	Age: 28 ± 1 years Height: 179.2 ± 1.6 cm Weight: 87.6 ± 3.8 kgs BMI: 27.1 ± 0.9 kg·m^{-2} BF%: 22.2 ± 1.1% v˙O2$_{max}$: 41.5 ± 1.4 mL·kg·min Cycle ergometer, treadmill test, chest press, leg press, knee extension.	1. Stair climb 2. Hose drag 3. Equipment carry 4. Ladder raise and extension 5. Forcible entry 6. Search 7. Rescue 8. Ceiling breach and pull	Full SCBA gear Sequential testing CPAT 22.7 kgs	v˙O2max (r = 20.602; p = 0.001), 4-finger isometric grip strength (r = 20.504; p = 0.009), and upper body strength (r = 20.485; p = 0.001) were also significantly related to CPAT performance. Furthermore, maximal HR response to stair climbing was significantly related to performance time (r = 0.523; p = 0.01), and percent of maximal HR during the stair climb (r = 0.488; p = 0.012).

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
Siddall et al. [28]	Cross-sectional study United Kingdom, London	68 (63 male; 5 female) full-time firefighters	Age: 41 ± 8 years Mass: 85.7 ± 12.9 kgs Height: 1.78 ± 0.06 m BF%: 19.7 ± 5.6% Fat mass: 17.3 ± 7.0 kgs absolute v· O2max: 4.0 ± 0.7 mL·kg·min relative v· O2max: 47.7 ± 9.0 mL·kg·min Treadmill test	1. The equipment carry: 2. The casualty evacuation 3. The 'hose run'	Full PPE and SCBA gear Sequential testing 20.3 kgs	Relative v· O2 had a stronger inverse correlation with FFST performance time (R = −0.711; R2 = 0.506, SEE = ±56 s) than absolute v· O2 (R = −0.577; R2 = 0.332; SEE = ±65 s), explaining ~18% more of the variance in FFST performance. The combination of variables that produced the strongest prediction of FFST time was the absolute v· O2 and fat mass, which explained 26% and 8% of the variance.
Sothmann et al. [39]	Cross-sectional study USA, Chicago	153 full-time male and female firefighters	Age: 36 ± 6 years Years as firefighter: 8 ± 5 years Height: 172 ± 7.6 cm Weight: 84 ± 13 kgs	1. Hose drag and high rise pack carry 2. Dummy drag	Discrete testing Not disclosed	Women completed the simulation approximately 35% slower than men which when tested by ANOVA proved to be a statistically significant difference (F 1151 = 5.70, *p* = 0.01). There was a significant age effect (F 3149 = 5.76, *p* < 0.01) on the performance times of the simulation protocol. Firefighters aged 50 years and over performed the protocol significantly slower than each of the three younger age classifications.
Stevenson et al. [64]	Cross-sectional study United Kingdom, London	69 full-time male and female firefighters	Age: 40 ± 8 years Mass: 85.8 ± 12.8 kgs Height: 178 ± 6 cm BMI: 27.0 ± 3.6 kg·m^{-2} BF%: 19.7 ± 5.5% v˙ O2max: 47.8 ± 9.0 mL·kg·min Treadmill test	1. Equipment carry 2. Casualty evacuation 3. Hose run	Full PPE and SCBA gear Sequential testing 20.2 kgs	The time to complete the firefighting simulation test (FFST) was highly inversely correlated with cardiorespiratory fitness (r = −0.73, *p* = 0.01).

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
Skinner et al. [30]	Cross-sectional study Australia	42 full-time male Aviation Rescue Firefighters	Age: 38.4 ± 7.6 years Height: 180.2 ± 6.6 cm Body mass: 81.9 kgs BMI: 26.2 ± 2.2 kg·m^{-2} Fat mass: 18.3 ± 5.6 kgs Lean mass: 62.7 ± 6.5 kgs BF%: 21.5 ± 4.6% v˙O2max: 49.5 ± 6.9 mL·kg·min Treadmill test, 3rm bench press, 3rm leg press (kg), total grip strength (kg), anaerobic step test (max), sit and reach, abdominal curl, push ups.	*Simulated aircraft rescue and firefighting (ARFF) tasks* 1. Hose drag (s) 2. Dummy drag (s) 3. Stihl saw hold (min) 4. Stair climb (s)	Full SCBA gear Sequential testing 16.5 kgs	Older age, and longer arm length had small-to-moderate correlations with slower time to complete the dummy drag and hose drag tasks respectively. A strong inverse correlation was observed between time to complete the simulated ARFF emergency protocol for speed at lactate threshold, anaerobic step test performance and v˙O2max. 3RM bench press presented a moderate to strong inverse correlation to hose drag performance time. The muscular endurance measure of maximal push-ups was significantly inversely correlated (r = −0.3) with hose drag performance time. A strong inverse correlation was observed between time to complete the simulated ARFF emergency protocol for speed at lactate threshold, anaerobic step test performance and v˙O2max

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
von Heimburg et al. [71]	Cross-sectional study Norway, Trondheim	14 Part-time male firefighters	Age: 38 ± 9 years Height: 1.79 ± 0.07 m Weight: 83 ± 11 kgs BMI: 26 ± 2 kg·m^{-2} Waist circumference: 94 ± 7 cm Hip circumference: 102 ± 5 cm Waist-to-hip ratio: 0.92 ± 0.04 v˙O2max: 4.4 ± 0.3 L·min v˙O2max: 53 ± 5 mL·kg·min Treadmill test, leg press, bench press, press behind the neck.	1. Stair climb 2. Six patient Victim drag	Full PPE and SCBA gear Sequential testing	The peak oxygen uptake in absolute terms was 18% higher in the faster subjects than in the slower ones during the rescue. The accumulated oxygen uptake obtained by integrating the oxygen uptake over the whole operation was less in the faster subjects, both in absolute terms (17%) and relative to body mass (25%). The faster firefighters had an 8% higher v˙ O2max expressed in absolute terms, but there was no difference between the two groups when the v˙O2max was expressed relative to body mass. The eight faster subjects were stronger (13%) than the six slower ones in terms of the pooled strength index.
von Heimburg et al. [58]	Cross-sectional study Norway, Trondheim	22 full-time firefighters	23 Males/1 female Age: 42 ± 9 vs. 26 years Height: 1.82 ± 0.05 vs. 1.69 cm Body mass: 85 ± 9 vs. 58 kgs BF%: 23 ± 6% vs. 16% Lean body mass: 66 ± 6 kgs vs. 49 kgs BMI: 26 ± 2 kg·m^{-2} vs. 20.3 kg·m^{-2} NLIA treadmill test	Part 1: 1. Puzzle 2. Balance 3. Hose drag 4. Hose connection and disconnect 5. Carrying heavy cans 6. Tunnel crawling Part 2: 1. Heat chamber Part 3: 1. Retreat	Full PPE and SCBA gear Sequential testing 28 kgs	Firefighters with high v˙ O2max completed the test faster than firefighters with lower v˙ O2max. Performance on the Trondheim test correlated with the measured strength on all three strength tests and with the pooled strength index; the stronger participants were the fastest

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
von Heimburg et al. [70]	Cross-sectional study Norway, Trondheim	43 experienced and inexperienced male and female firefighters	Age: 41.4 ± 4.2 years Body mass: 84 ± 9.9 kgs Height: 1.81 ± 0.06 cm BMI: 25.5 ± 2.6 kg·m^{-2} BF%: 21.6 ± 5.8% LBM: 65.8 ± 5.9 kgs NLIA Tests	Trondheim test Part 1: 1. Puzzle 2. Balance 3. Hose dragging 4. Hose connection and disconnect 5. Carrying heavy cans 6. Tunnel crawling Part 2: 1. Heat chamber Part 3: 1. Retreat	Full PPE and SCBA gear Sequential testing 23 kgs	The young men performed the skill and agility tasks faster than the senior firefighters and the female applicants.
Williford et al. [77]	Cross-sectional study USA, Alabama	91 full-time male firefighters	Age: 31.69 ± 7.39 years Height: 177.29 ± 6.38 cm Weight: 83.97 ± 10.86 kgs BF%: 13.78 ± 4.31% v˙O2 peak relative: 45.0 ± 6.0 mL·kg·min v˙O2 peak absolute: 3.75 ± 0.43 L·min 1.5 mile run (s), Pull-ups, Push-ups Sit and reach(cm), Sit ups, Total grip strength (kg)	1. Victim rescue: 48.10 ± 29.36 2. Forcible entry: 30.44 ± 18.62 3. Hoist: 32.11 ± 21.87 4. Hose advance: 19.38 ± 18.88 5. Stair climb: 53.53 ± 13.68	Full PPE and SCBA gear Sequential testing 23 kgs	Significant correlations ($p < 0.01$) were found between the total obstacle course time and the following: total grip strength (r = −0.54), FFW (r = −0.47), height (r = −0.40), pull-ups (r = −0.38), push-ups (r = −0.38), 1.5 mile run (r = −0.38), sit-ups (r = −0.32), weight (r = −0.30) and BF% (r = 0.30). FFW and 1.5 mile run times to predict total obstacle course time (r = 0.71, r2 = 0.50, SE = 99.18 s).

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Table 3. *Cont.*

References	Study Design, Setting and Sample	Sample	Participant Information and Physical Fitness Measures	Occupational Performance Measures	Testing Procedure Details	Outcome
Windisch, et al. [75]	Cross-sectional study Germany, Munich	41 full-time male firefighters	Age: 39 ± 9 years Height: 179.6 ± 2.3 cm Weight: 84.4 ± 9.2 kgs BMI: 26.1 ± 2.8 kg·m^{-2} v̇O2max: 45.0 ± 6.0 mL·kg·min Treadmill test, leg press, hand grip, partial-curl ups, push-ups, shoulder press, rowing, standing long jump, sit and reach.	1. Ladder climb: 85 ± 15 s 2. Hoist: 35 ± 8 s 3. Crawling: 412 ± 96 s	Full PPE with SCBA gear and without SCBA gear Sequential tasks	It can be noted that outstanding performers had significantly higher v̇O2 peak (p = 0.001) and significantly lower mean heart rates during REPE (p = 0.001) while completing the exercise faster (p = 0.001) compared to average, below average and poor performers. Aerobic fitness was a significant predictor of the speed a firefighter can perform the tasks
Xu et al. [63]	Cross-sectional study China, South East	20 full-time firefighters	Age: 25.65 ± 2.97 years; Height: 172.4 ± 4.8 cm; Body mass: 69.0 ± 8.9 kgs v̇O2: 46.85 mL·kg·min BF%: 14.65% upper body muscular power: 675.35 watts lower body muscular power: 1705 watts Cycle ergometer, chest press, sitting leg power.	1. Rope climb 2. Run 200 m round trip with load 3. Run 60 m carrying a ladder 4. Climb stairs with load 5. Evacuation of 400 m with supplies 6. Run 5 km with an air respirator and 7. Run 100 m with a water hose		An increase in v̇O2max decreased the time to complete firefighting tasks. Increased BF% increased the time to complete each task. Increased upper body strength the time to complete each task decreased. Increased lower body strength decreased the time to complete each task.

Note: Units of measurements: m—meters; cm—centimeters; kgs—kilograms; FFW—fat free weight; v̇O2—oxygen consumption; v̇O2max—maximum oxygen consumption; BF%—bodyfat percentage; kg·m^{-2}—kilograms per meter squared; mL·kg·min.—milliliters per kilogram per minute; L·min—liters per minute; min—minutes; s—seconds; bmp—beats per minute. PPE—personal protective equipment; SCBA—self-contained breathing apparatus.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

3.6. The Effect of Aging, Obesity, Heart Rate and Gender on Occupational Performance in Firefighters

Figure 2 shows the effects of age and obesity on occupational performance in firefighters. Due to the different methods used to determine firefighters' performance on occupational performance tasks, the standardized mean difference (SMD) was used to determine overall effect size. Age had a moderate significant pooled random effect on occupational performance [SMD = 0.66, 95%CI (0.41, 0.91), Z = 5.15, $p < 0.001$] [39,58,74,77]. The level of heterogeneity was low ($I^2 = 4\%$) and there was no evidence of publication bias (Egger test $p = 0.397$). For obesity, there was a large random effect size, that was not statistically significant [SMD = 1.89, 95%CI (−2.25, 6.03), Z = 0.90, $p = 0.37$; $I^2 = 93\%$] [57,79] (Figure 3).

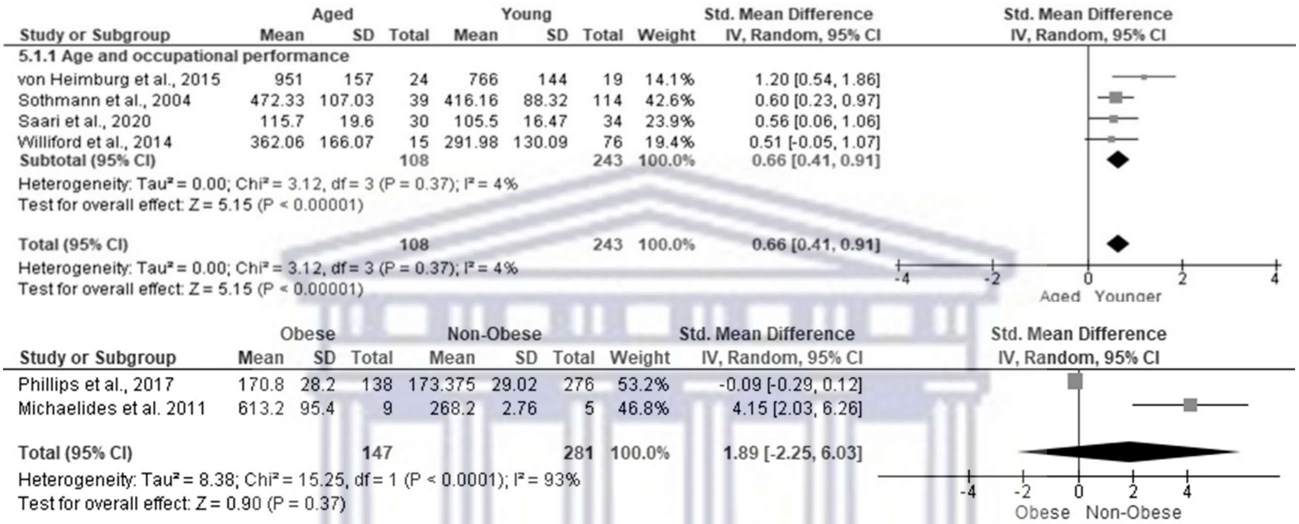


Figure 2. The effect of age and obesity on occupational performance in firefighters [39,57,70,74,77,79].

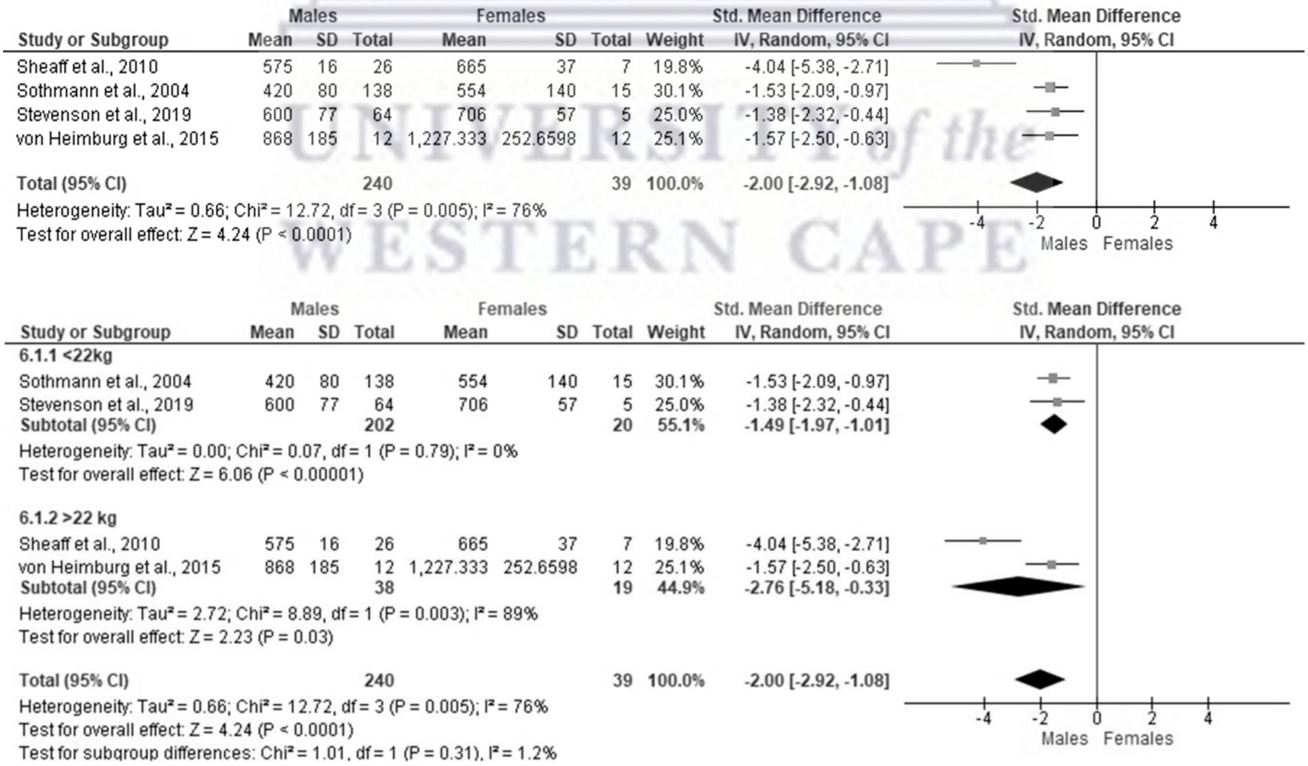


Figure 3. The effect of gender on occupational performance in firefighters. Subgroup analysis on the weight of PPE.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Gender had a large effect size on occupational performance, indicating that males performed significantly better, which was statistically significant [SMD = −2.00, 95%CI (−2.50, −0.63), Z = 4.24, $p < 0.001$] [39,64,70,72,86] (Figure 3); with considerable heterogeneity between the studies, and no evidence of publication bias ($p = 0.217$ for the Egger test). In subgroup analysis according to the weight of PPE, there was no heterogeneity between studies that used equipment weighing less than 22 kgs in total ($I^2 = 0\%$); while the total effect decreased, the overall effect remained large [SMD = −1.49, 95%CI (−1.97, −1.01), Z = 6.06, $p < 0.001$].

3.7. Correlation between Obesity, Aging and Resting Heart Rate on Occupational Performance

In Table 4, there was a low positive correlation between BF% and occupational time (R = 0.316, $p < 0.001$) [30,42,57,60,65,73,74,77,80]. There was moderate heterogeneity between studies ($I^2 = 54.51\%$). In subgroups analyses, the correlation between BF% and completion time increased for all subgroups and was highest for the subgroups of males only (R = 0.413, $p < 0.001$) and full-time firefighters only (R = 0.388, $p < 0.001$). In addition, these subgroups had the least heterogeneity present ($I^2 \leq 16.4\%$). There was a modest positive correlation between age and occupational performance (R = 0.224, $p < 0.001$) [30,57,65,66,69,74,77,80]. There was moderate-to-substantial heterogeneity present between studies ($I^2 = 74.1\%$). The correlation coefficient increased in studies that included either only male firefighters (R = 0.282, $p < 0.001$) or full-time firefighters (R = 0.323, $p < 0.001$) for the association between age and occupational performance. In addition, heterogeneity significantly decreased to 32.5% in male only studies and 0% in full-time firefighters' studies. There was a low positive correlation between heart rate and occupational performance in firefighters (R = 0.387, $p < 0.001$), with no evidence of heterogeneity [57,73].

3.8. Correlation between Fitness Parameters and Occupational Performance

In Table 5, there was a significant moderate negative correlation between cardiorespiratory fitness and completion times (R = −0.584, $p < 0.001$) [28,30,58,60,64–66,68,70,72,80]; with substantial heterogeneity between the five studies ($I^2 = 72.9\%$). In subgroup analysis, studies where cardiorespiratory fitness was determined through gas analysis, and studies that only included male firefighters were more homogenous ($I^2 = 0.0\%$ and $I^2 < 9.9\%$). However, the strongest correlation was present between studies that included only gas analysis to determine cardiorespiratory fitness (R = −0.672, $p < 0.001$). Upper body endurance had a significant low negative correlation with completion times (R = −0.344, $p < 0.001$; $I^2 = 0\%$) [30,57,66,70,73,77,80]. After subgroup analysis the highest correlation (R = −0.363, $p < 0.001$) [30,57,66,70,73,77] was present between upper body endurance and completion times studies where the weight of PPE was over 22 kgs. There was a significant low negative correlation between abdominal endurance and completion times (R = −0.308, $p < 0.001$; $I^2 = 0\%$) [30,42,57,65,66,73,77,80].

For strength, there was a significant low negative correlation between grip strength and completion times (R = −0.421, $p < 0.001$; $I^2 = 68.6\%$) [30,42,57,72,77,80]. Subgroup analysis did not explain the heterogeneity between studies; however, the highest correlation between grip strength and completion times when the weight of PPE was above 22 kgs (R = −0.473, $p < 0.001$). There was a significant low correlation between upper body strength and completion times (R = −0.318, $p < 0.001$; $I^2 = 57.7\%$) [30,42,57,66,72,73,80]. In subgroup analysis studies that included five or more tasks that were sequential were more homogenous ($I^2 = 5.1\%$). The highest correlation was found between upper body strength and occupational performance where studies only included male firefighters (R = −0.374, $p < 0.001$). Lower body strength had a significant negligible negative correlation with completion times (R = −0.216, $p = 0.020$; $I^2 = 0\%$) [42,57,73].

http://etd.uwc.ac.za/

Table 4. The correlation between age, obesity and heart rate and occupational task performance in firefighters.

Outcome	No. of Studies	No. of Participants	R (95% CI)	Z Score	*p* (Overall Effect)	Heterogeneity I^2; Cohen's Q; *p*	Egger's Test Intercept (95%CI); *p*	Begg's Test (τ; *p*)
Age	8	944	0.224 (0.162 to 0.284)	3.834	<0.001 **	74.1%; 27.0136; <0.001	2.33 (−2.36–7.02); 0.269	0.18; 0.529
Five or more tasks	5	639	0.199 (0.0425 to 0.346)	2.484	0.004 **	71.1%; 13.85; 0.008	4.18 (−2.14–10.48); 0.126	0.53; 0.197
Males only	6	416	0.282 (0.167 to 0.390)	4.675	<0.001 **	32.5%; 7.41; 0.191	2.82 (−5.30–10.95); 0.389	0.41; 0.243
Weight	5	749	0.286 (0.0968 to 0.455)	2.927	0.003 **	83.9%; 24.90; <0.001	3.69 (−6.39–13.77); 0.329	0.20; 0.624
Full-time only	5	327	0.323 (0.220 to 0.418)	5.912	<0.001 **	0.0%; 3.68; 0.452	1.47 (−0.70–9.95); 0.621	0.40; 0.327
Obesity	9	876	0.316 (0.254 to 0.375)	6.432	<0.001 **	54.5%; 17.59; 0.025	1.79 (−0.49–4.07); 0.106	0.14; 0.597
Five or more tasks	5	572	0.350 (0.184 to 0.496)	4.007	<0.001 **	71.8%; 14.18; 0.007	3.48 (−1.66–8.62); 0.120	0.60; 0.142
Males only	6	348	0.413 (0.319 to 0.498)	7.933	<0.001 **	0.0%; 5.65; 0.463	0.19 (−3.53–3.91); 0.901	0.09; 0.758
Sequential testing	6	614	0.368 (0.218 to 0.501)	4.601	<0.001 **	69.1%; 16.19; 0.006	3.43 (−0.01–6.88); 0.051	0.47; 0.189
Weight of PPE	7	770	0.354 (0.228 to 0.468)	5.253	<0.001 **	62.4%; 15.94; 0.014	1.72 (−1.44–4.89); 0.220	0.19; 0.538
Full-time only	6	512	0.388 (0.310 to 0.460)	9.095	<0.001 **	16.4%; 5.98; 0.308	0.54 (−3.21–4.28); 0.712	0.33; 0.348
Heart rate	2	110	0.398 (0.226 to 0.547)	4.301	<0.001 **	0.0%; 0.41; 0.521	2.74 (–); <0.001	1.00; 0.317

Note: ** indicates statistical significance <0.01. (–)—indicates insufficient studies to calculate Egger's test result. PPE—personal protective equipment.; italics—indicates subgroup analysis.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

3.9. Correlation between Obesity and Age on Individual Task Performance in Firefighters

In Table 6, there was a significant low positive correlation between BF% and stair climb times (R = 0.489, $p < 0.001$; $I^2 = 39.2\%$) [30,42,57,60,76,77]. In subgroup analysis there was no heterogeneity between studies where the weight of PPE was above 22 kgs and where five or more tasks were performed. In addition, there was a moderate positive correlation between BF% and stair climb times (R = 0.514, $p < 0.001$) [42,57,60,76,77] when the weight of PPE was more than 22 kgs, and when five or more tasks were performed (R = 0.537, $p < 0.001$) [57,77]. There was a significant low positive correlation between BF% and hose drag time (R = 0.241, $p < 0.001$) [30,42,57,60,77], between BF% and victim rescue (R = 0.254, $p < 0.001$) [30,42,57,60,77], BF% and forcible entry (R = 0.285, $p < 0.001$) [77,86], and between BF% and equipment hoist (R = 0.197, $p = 0.041$) times [42,77]. There was no heterogeneity for the studies included in the meta-analysis for the hose drag, victim rescue and equipment hoist. The highest correlation was present between BF% and hose drag when the weight of PPE was 22 kgs or above (R = 0.255, $p < 0.001$) [42,57,60,77]. For forcible entry, moderate heterogeneity was present between studies. There was a significant low correlation between age and stair climb time (R = 0.345, $p < 0.001$; $I^2 = 62.3\%$) [30,69,76,77]. After subgroup analysis on studies including only full-time firefighters there was 0.0% heterogeneity present.

For age, there was a low positive correlation between age and stair climb times (R = 0.345, $p < 0.001$; $I^2 = 62.3\%$) [30,69,76,77]. After subgroup analysis, 0.0% heterogeneity was present when studies that analysed full-time male firefighters only were included. In addition, the correlation was strongest between age and stair climb times when studies that included only full-time male firefighters were analysed (R = 0.434, $p < 0.001$) [30,69,77].

3.10. Correlation between Physical Fitness and Individual Task Performance

In Table 7, there was a significant low negative correlation between cardiorespiratory fitness and stair climb times (R = −0.421, $p = 0.004$; $I^2 = 82.9\%$) [30,31,61,65]. After subgroup analysis, there was a significant moderate negative correlation between cardiorespiratory fitness and stair climb times (R = −0.513, $p < 0.001$) [31,61,65], but considerable heterogeneity remained. There was a significant negative correlation between cardiorespiratory fitness and victim rescue (R = −0.320, $p = 0.003$; $I^2 = 57.1\%$) [30,61,65,66] and between cardiorespiratory fitness and hose drag times (R = −0.197, $p = 0.046$; $I^2 = 38.1\%$) [30,31,66]. In subgroup analysis, there was no heterogeneity between studies where the weight of PPE was above 22 kgs for victim rescue and hose drag.

There was a significant low negative correlation between upper body endurance and stair climb times (R = −0.408, $p < 0.001$; $I^2 = 0.0\%$) [30,57,77] (Table 7). Subgroup analysis was performed on equipment weighing over 22 kgs, which increased the strength of the correlation between studies (R = −0.436, $p < 0.001$) [57,77]. There were significant low negative correlations between upper body endurance and hose drag times (R = −0.260, $p < 0.001$; $I^2 = 0.0\%$) [30,57,66,77], victim rescue times (R = −0.200, $p = 0.026$; $I^2 = 55.2\%$) [30,57,66,77] and forcible entry times (R = −0.247, $p = 0.006$; $I^2 = 51.1\%$) [57,66,77]. There was homogeneity between studies investigating upper body endurance and hose drag times, and moderate heterogeneity present between upper body endurance and victim rescue and forcible entry times ($I^2 = 55.2\%$ and $I^2 = 51.1\%$, respectively). Subgroup analysis did not explain the heterogeneity between studies. However, there was no evidence of publication bias present for victim rescue (Egger's test $p = 0.536$) or forcible entry (Egger's test $p = 0.109$).

http://etd.uwc.ac.za/

Table 5. The correlation between physical fitness and occupational performance in firefighters.

Outcome	No. of Studies	No. of Participants	R (95% CI)	Z Score	*p* (Overall Effect)	Heterogeneity I²; Cohen's Q; *p*	Egger's Test Intercept (95%CI); *p*	Begg's Test (τ; *p*)
Cardiorespiratory fitness	11	946	−0.584 (−0.671 to −0.482)	−9.132	<0.001 **	72.9%; 36.96; <0.001	−2.52 (−4.80 to 0.23); 0.034	−0.18; 0.432
Gas analysis	5	207	−0.672 (−0.743 to −0.587)	−11.295	<0.001	0.0%; 3.98; 0.407	1.17 (−3.72 to 6.07); 0.501	0.40; 0.327
Sequential tasks	8	635	−0.589 (−0.682 to −0.476)	−8.390	<0.001 **	64.1%; 19.49; 0.007	−2.05 (−4.65 to 0.53); 0.099	−0.29; 0.322
Five or more tasks	6	525	−0.571 (−0.680 to −0.438)	−7.074	<0.001 **	61.9%; 13.11; 0.022	−1.99 (−4.88 to 0.91); 0.129	−0.33; 0.348
Males	7	281	−0.596 (−0.675 to −0.505)	−10.260	<0.001 **	9.9%; 6.66; 0.353	−0.72 (−4.04 to 2.59); 0.599	−0.19; 0.538
Males and females	4	665	−0.566 (−0.709 to −0.378)	−5.161	<0.001 **	88.2%; 25.46; <0.001	−7.31 (−15.92 to 1.29); 0.067	−0.33; 0.497
Weight of PPE	7	678	−0.551 (−0.660 to −0.419)	−7.005	<0.001 **	68.3%; 18.94; 0.004	−2.15 (−4.61 to 0.31); 0.075	−0.09; 0.758
Full-time only	7	449	−0.605 (−0.729 to −0.443)	−6.094	<0.001 **	75.0%; 24.0390; <0.001	−2.39 (−0.60 to 1.25); 0.152	0.00; 1.000
Upper body endurance	6	387	−0.344 (−0.430 to −0.251)	−6.886	<0.001 **	0.0%; 3.49; 0.624	1.13 (−4.07 to 6.33); 0.579	0.33; 0.348
Weight of PPE	4	256	−0.363 (−0.467 to −0.250)	−5.949	<0.002 **	0.0%; 1.3; 0.770	−7.6 (−8.63 to 7.11); 0.717	−0.33; 0.497
Full−time only	4	268	−0.324 (−0.430 to −0.209)	−5.318	<0.001 **	1.9%; 3.06; 0.383	4.30 (−9.22 to 17.82); 0.305	0.33; 0.497
Abdominal endurance	8	871	−0.308 (−0.367 to −0.246)	−9.256	<0.001 **	0.0%; 3.62; 0.822	−0.05 (−1.65 to 1.54); 0.939	0.14; 0.621
Five or more tasks	5	587	−0.333 (−0.403 to −0.258)	−8.267	<0.001 **	0.0%; 2.22; 0.696	−0.9 (−3.33 to 3.13); 0.929	0.00; 1.000
Sequential tasks	5	254	−0.320 (−0.428 to −0.202)	−5.121	<0.001 **	0.0%; 1.60; 0.808	1.38 (−1.35 to 4.11); 0.206	0.60; 0.142
Males only	5	323	−0.349 (−0.443 to −0.247)	−6.391	<0.001 **	0.0%; 2.01; 0.733	2.24 (−1.36 to 5.8); 0.142	0.60; 0.142
Weight of PPE	5	740	−0.296 (−0.361 to −0.229)	−8.212	<0.001 **	0.0%; 2.38; 0.795	0.09 (−1.89 to 2.09); 0.089	0.07; 0.851
Full-time only	5	446	−0.294 (−0.377 to −0.205)	−6.284	<0.001 **	0.0%; 1.82; 0.768	−0.52 (−3.22 to 2.18); 0.584	0.00; 1.000
Grip strength	6	258	−0.421 (−0.602 to −0.198)	−5.086	<0.001 **	68.6%; 15.92; 0.007	0.59 (−4.30 to 5.48); 0.754	−0.07; 0.851
Five or more tasks	4	502	−0.439 (−0.578 to −0.274)	−4.882	<0.001 **	68.9%; 9.67; 0.022	1.39 (−9.64 to 12.42); 0.642	0.67; 0.174
Males only	5	258	−0.421 (−0.602 to −0.198)	−3.542	<0.001 **	71.1%; 13.84; 0.008	0.59 (−430 to 5.48); 0.754	−0.07; 0.851
Weight of PPE	5	522	−0.473 (−0.604 to −0.317)	−5.420	<0.001 **	66.9%; 12.07; 0.017	−0.11 (−6.30 to 6.09); 0.959	−0.20; 0.624
Full-time only	4	225	−0.406 (−0.625 to −0.127)	−2.790	0.005 **	77.5; 13.31; 0.004	−1.38 (−21.05 to 18.29); 0.791	0.00; 1.000
Upper body strength	8	814	−0.318 (−0.380 to −0.254)	−5.756	<0.001 **	57.7%; 16.53; 0.207	−1.51 (−4.29 to 1.27); 0.232	−0.29; 0.320
Five or more tasks	5	530	−0.374 (−0.446 to −0.298)	−8.931	<0.001 **	5.1; 4.21; 0.378	−1.26 (−4.36 to 1.85); 0.288	−0.20; 0.624
Sequential tasks	6	572	−0.357 (−0.428 to −0.283)	−8.802	<0.001 **	28.7; 7.01; 0.219	−0.42 (−3.82 to 2.98); 0.750	−0.06; 0.851
Males only	6	286	−0.421 (−0.540 to −0.266)	−5.183	<0.001 **	42.4%; 8.68; 0.122	−0.83 (−6.93 to 5.28); 0.726	−0.20; 0.573
Weight of PPE	6	683	−0.339 (−0.449 to −0.219)	−5.321	<0.001 **	50.2; 10.04; 0.074	−1.89 (−4.52 to 0.74); 0.116	−0.60; 0.091
Full-time only	5	389	−0.313 (−0.470 to −0.137)	−3.409	0.001 **	57.5%; 9.40; 0.052	−2.40 (−6.17 to 1.37); 0.136	−0.80; 0.050
Lower body strength	3	122	−0.216 (−0.383 to −0.0349)	−2.331	0.020 *	0.0%; 0.27; 0.876	−0.22 (−12.99 to 12.55); 0.863	−0.33; 0.602
Five or more tasks	2	102	−0.201 (−0.383 to −0.003)	−1.992	0.046 *	0.0%; 0.10; 0.749	1.01 (–); <0.001	1.00; 0.317
Full-time only	2	92	−0.236 (−0.424 to −0.029)	−2.232	0.026 *	0.0%; 0.10; 0.751	−0.70 (–); <0.001	−1.00; 0.317
Flexibility	4	233	−0.099 (−0.227 to 0.032)	−1.479	0.139	0.0%; 2.05; 0.560	−2.58 (−8.81 to 3.64); 0.216	−0.67; 0.174

Note: * indicates statistical significance <0.05; ** indicates statistical significance <0.01. (–)—indicated insufficient studies present to perform Egger's test. PPE—personal protective equipment; italics – indicates subgroup analysis.

http://etd.uwc.ac.za/

Table 6. The correlation between obesity and age, and individual task performance.

Outcome	No. of Studies	No. of Participants	R (95% CI)	Z Score	*p* (Overall Effect)	Heterogeneity I^2; Cohen's Q; *p*	Egger's test Intercept (95%CI); *p*	Begg's Test (τ; *p*)
Obesity								
Stair climb	6	304	0.489 (0.361 to 0.599)	6.696	<0.001 **	39.2%; 8.23; 0.144	−1.98 (−6.92 to 2.97); 0.33	−0.28; 0.44
Five or more tasks	2	160	0.537 (0.416 to 0.640)	7.453	<0.001 **	0.0%; 0.12; 0.729	3.43 (–); <0.001	1.00; 0.317
Sequential tasks	4	222	0.485 (0.375 to 0.581)	7.670	<0.001 **	36.8%; 4.75; 0.191	−1.26 (−12.73 to 10.21); 0.682	−0.33; 0.497
Males only	5	242	0.468 (0.308 to 0.577)	7.654	<0.001 **	33.6%; 6.02; 0.197	−1.78 (−7.33 to 3.78); 0.383	−0.32; 0.439
Weight of PPE	4	200	0.514 (0.401 to 0.611)	7.789	<0.001 **	0.0%; 2.07; 0.557	−1.29 (−6.31 to 3.73); 0.385	−0.18; 0.709
Full-time only	4	222	0.435 (0.259 to 0.583)	4.543	<0.001 **	48.9%; 5.8771; 0.118	−3.45 (−11.86 to 4.96); 0.219	−0.33; 0.497
Hose drag	5	242	0.241 (0.095 to 0.378)	3.580	<0.001 **	19.5%; 4.97; 0.290	1.54 (−3.59 to 6.66); 0.411	0.53; 0.197
Five or more tasks	2	160	0.231 (−0.004 to 0.442)	1.926	0.054	55.8%; 2.26; 0.133	14.85 (–); <0.001	1.00; 0.317
Sequential tasks	4	222	0.249 (0.0702 to 0.412)	2.710	0.007 **	39.6%; 4.97; 0.174	2.46 (−7.39 to 12.31); 0.395	0.67; 0.174
Weight of PPE	4	200	0.255 (0.117 to 0.383)	3.577	<0.001 **	31.5%; 4.38; 0.223	1.81 (−5.65 to 9.26); 0.407	0.55; 0.264
Full-time only	4	222	0.206 (0.073 to 0.3310	3.022	0.003 **	0.0%; 2.59; 0.458	0.27 (−8.63 to 9.18); 0.908	0.33; 0.497
Victim drag	5	242	0.254 (0.129 to 0.371)	3.915	<0.001 **	0.0%; 1.51; 0.825	−0.35 (−3.51 to 2.81); 0.746	−0.11; 0.796
Five or more tasks	2	160	0.280 (0.129 to 0.419)	3.575	<0.001 **	0.0%; 0.22; 0.639	4.52 (–); <0.001	1.00; 0.317
Sequential tasks	4	222	0.244 (0.113 to 0.366)	3.601	<0.001 **	0.0%; 1.15; 0.765	−1.45 (−5.45 to 2.56); 0.261	−0.33; 0.497
Males only	5	242	0.254 (0.129 to 0.371)	3.915	<0.001 **	0.0%; 1.51; 0.825	−0.35 (−3.51 to 2.81); 0.746	−0.11; 0.796
Weight of PPE	4	200	0.275 (0.138 to 0.401)	3.864	<0.001 **	0.0%; 0.99; 0.805	−0.16 (−4.53 to 4.2); 0.886	0.18; 0.709
Full-time only	4	222	0.266 (0.136 to 0.386)	3.946	<0.001 **	0.0%; 1.08; 0.782	0.38 (−5.27 to 6.03); 0.801	0.00; 1.000
Forcible entry	2	160	0.285 (0.135 to 0.423)	3.639	<0.001 **	24.1%; 0.1.32; 0.251	11.51 (–); <0.001	1.00; 0.317
Equipment hoist	2	111	0.197 (0.008 to 0.372)	2.044	0.041 *	0.0%; 0.65; 0.419	−1.58 (–); <0.001	−1.00; 0.317
Age								
Stair climb	4	324	0.345 (0.166 to 0.502)	3.669	<0.001 **	62.3%; 7.74; 0.052	2.72 (−9.94 to 15.38); 0.453	0.33; 0.497
Sequential tasks	2	133	0.431 (0.280 to 0.562	5.201	<0.001 **	7.7; 1.08; 0.298	−3.74 (–); <0.001	−1.00; 0.317
Full-time male firefighters	3	174	0.434 (0.302 to 0.549)	5.963	<0.001 **	0.0%; 1.09; 0.581	−2.26 (−27.04 to 22.53); 0.454	−0.33; 0.602
Hose drag	3	222	0.0403 (0.094 to 0.173)	0.589	0.556	0.0%; 0.26; 0.889	0.46 (−19.37 to 20.29); 0.817	−0.33; 0.602
Victim rescue	3	222	0.147 (−0.079 to 0.359)	1.280	0.200	62.8%; 5.37; 0.068	6.62 (−44.75 to 57.99); 0.349	0.33; 0.602
Forcible entry	2	180	0.0318 (−0.116 to 0.178)	0.419	0.675	0.0%; 0.08; 0.771	35.74 (–); <0.001	1.00; 0.317

Note: * indicates statistical significance <0.05; ** indicates statistical significance <0.01. (–)—indicates insufficient studies to calculate Egger's test result. PPE—personal protective equipment.; italics—indicates subgroup analysis.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

There was a significant low negative correlation between abdominal endurance and stair climb times (R = −0.415, $p < 0.001$; $I^2 = 25.7\%$) [30,42,57,61,77] (Table 6). After subgroup analysis there was no heterogeneity present where the weight of PPE over 22 kgs ($I^2 = 0.0\%$) and five or more tasks were performed ($I^2 = 0.0\%$). In addition, the correlation was highest for the studies where the weight of PPE was above 22 kgs (R = −0.452, $p < 0.001$) [42,57,61,77] and five or more tasks were performed (R = −0.472, $p < 0.001$) [57,61,77]. There were significant negligible negative correlations between abdominal endurance and hose drag times (R = −0.230, $p < 0.001$; $I^2 = 17.3\%$) [30,42,57,66,77], between abdominal endurance and victim rescue times (R = −0.119, $p = 0.039$; $I^2 = 41.4\%$) [30,42,57,61,66,77] and between abdominal endurance and forcible entry times (R = −0.195, $p = 0.002$; $I^2 = 0.0\%$) [57,66,77]. After subgroup analysis, heterogeneity was reduced ($I^2 = 0.0\%$ and $I^2 = 29.1\%$, respectively), for hose drag and victim drag times when controlling for studies that used five or more tasks and tasks that were performed sequentially.

There was a significant low negative correlation between grip strength and hose drag times (R = −0.378, $p = 0.005$) [30,31,42,57,61,77]. There was substantial heterogene- ity present between studies ($I^2 = 78.9\%$), without evidence of publication bias (Eggar's test $p = 0.379$). After subgroup analysis where five or more tasks were performed, heterogeneity was reduced ($I^2 = 42.5\%$) [57,77], but moderate heterogeneity remained. The highest correlation (R = −0.442, $p = 0.005$) [31,42,57,77] was present between grip strength and hose drag time where the weight of PPE was more than 22 kgs. There was a significant moderate negative correlation between grip strength and victim rescue time (R = −0.578, $p < 0.001$) [30,31,42,57,77], with substantial heterogeneity between studies ($I^2 = 68.2\%$). After subgroup analysis, heterogeneity was reduced ($I^2 = 35.5\%$) when full-time male firefighters only were included [30,42,57,77]. In addition, after subgroup analysis, there was a moderate negative corelation between grip strength and victim rescue (R = −0.609, $p = 0.049$) [42,57,61,77] when equipment weighed more than 22 kgs. There were significant low negative correlations between grip strength and forcible entry times (R = −0.426, $p = 0.001$; $I^2 = 67.2\%$) [57,77] and between grip strength and equipment hoist times (R = −0.420, $p = 0.039$; $I^2 = 64.8\%$) [57,77].

There was a significant moderate negative correlation between upper body strength and hose drag times (R = −0.544, $p = 0.001$) [30,31,42,57], with substantial heterogene- ity present ($I^2 = 71.9\%$). After subgroup analysis there was no heterogeneity present ($I^2 = 0.0\%$) [30,57], where five or more sequential tasks were performed. In addition, af- ter subgroup analysis, performed there was a moderate negative correlation between upper body strength and victim rescue times (R = −0.609, $p = 0.049$) [42,57] when the weight of PPE was more than 22 kgs. However, considerable heterogeneity was present ($I^2 = 85.9\%$). There was a significant low negative correlation between upper body strength and victim rescue times (R = −0.350, $p = 0.012$; $I^2 = 56.1\%$) [30,42,57]. After subgroup analysis, no heterogeneity was present ($I^2 = 0.0\%$) [30,57], when five or more sequential tasks were performed.

There were significant low negative correlations between lower body strength and hose drag times (R = −0.244, $p = 0.001$) [30,31,42,57], and between lower body strength and victim rescue times (R = −0.254, $p = 0.004$) [30,42,57], with studies being homogenous. There was a significant negligible negative correlation between flexibility and stair climb times (R = −0.190, $p = 0.030$) [30,77], with low heterogeneity present between studies ($I^2 = 11.4\%$).

http://etd.uwc.ac.za/

Table 7. The correlation between physical fitness and individual task performance.

Outcome	No. of Studies	No. of Participants	R (95% CI)	Z Score	*p* (Overall Effect)	Heterogeneity I^2; Cohen's Q; *p*-Value	Egger's test Intercept (95%CI); *p*	Begg's Test (τ; *p*)
Cardiorespiratory fitness								
Stair climb	4	351	−0.421 (−0.639 to −0.140	−2.856	0.004 **	82.9%; 17.55;<0.001	4.39 (−4.24 to 13.03); 0.159	0.33; 0.497
Sequential testing	3	302	−0.451 (−0.702 to −0.100)	−2.472	0.013 *	85.4%; 13.69; 0.001	−8.39 (−254.21 to 237.44); 0.739	−0.33; 0.602
Weight of PPE	3	309	−0.513 (−0.680 to −0.296)	−4.244	<0.001 **	70.7%; 6.81; 0.033	3.13 (−23.58 to 29.83); 0.377	0.33; 0.602
Full-time only	2	91	−0.214 (−0.406 to −0.005)	−2.007	0.045 *	5.8%; 1.06; 0.303	17.68 (–); <0.001	1.00; 0.317
Hose drag	3	180	−0.197 (−0.376 to −0.004)	−1.997	0.046 *	38.1%; 3.23; 0.198	3.64 (−55.99 to 63.26); 0.580	1.00; 0.117
Five or more and Sequential	2	131	−0.138 (−0.415 to 0.163)	−0.897	0.370	61.9%; 2.62; 0.105	5.98 (–); <0.001	1.00; 0.317
Weight of PPE	2	138	−0.278 (−0.427 to −0.114)	−3.279	0.001 **	0.0%; 0.04; 0.839	0.93 (–); <0.001	−1.00; 0.317
Victim drag	4	391	−0.356 (−0.500 to −0.194)	−4.146	<0.001 **	57.1; 6.99; 0.072	2.09 (−6.87 to 11.05); 0.421	0.33; 0.497
Five or more tasks	2	127	−0.384 (−0.525 to −0.223)	−4.450	<0.001	0.0%; 0.69; 0.406	−2.72 (–); <0.001	−1.00; 0.317
Sequential tasks	3	169	−0.300 (−0.504 to −0.066)	−2.488	0.013 *	55.6%; 4.50; 0.105	0.88 (−73.51 to 75.27); 0.905	−0.33; 0.602
Males only	2	131	−0.220 (−0.482 to 0.079)	−1.449	0.147	61.6%; 2.60; 0.107	5.95 (–); <0.001	1.00; 0.317
Weight of PPE	2	260	−0.452 (−0.544 to −0.349)	−7.757	<0.001 **	0.0%; 0.05; 0.817	−4.41 (–); <0.001	−1.00; 0.317
Full-time only	3	353	−0.320 (−0.501 to −0.113)	−2.977	0.003 **	69.3%; 6.61; 0.039	4.37 (−6.36 to 15.14); 0.122	1.00; 0.117
Saw hold	2	80	0.301 (−0.601 to 0.074)	−1.580	0.114	64.8%; 2.84; 0.092	−44.09 (–); <0.001	−1.00; 0.317
Upper body endurance								
Stair climb	3	205	−0.408 (−0.518 to −0.285)	−6.061	<0.001 **	0.0%; 1.28; 0.527	3.93 (−9.22 to 17.07); 0.164	1.00; 0.1172
Weight of PPE	2	163	−0.436 (−0.553 to −0.301)	−5.850	<0.001 **	0.0%; 0.37; 0.541	7.13 (–); <0.001	1.00; 0.3173
Hose drag	4	294	−0.290 (−0.393 to −0.180)	−5.010	<0.001 **	0.0%; 0.56; 0.905	−2.15 (−6.03 to 1.72); 0.139	−0.33; 0.497
Weight of PPE	2	205	−0.290 (−0.413 to −0.157)	−4.183	<0.001 **	0.0%; 0.56; 0.754	0.78 (–); <0.001	1.00; 0.317
Full-time only	3	163	−0.266 (−0.404 to −0.115)	−3.410	0.001 **	0.0%; 0.00; 0.947	−2.48 (−15.86 to 10.89); 0.256	−0.33; 0.602
Victim rescue	4	294	−0.200 (−0.363 to −0.025)	−2.23	0.026 *	55.2%; 6.69; 0.083	4.01 (−19.23 to 27.24); 0.536	0.67; 0.174
Weight of PPE	2	163	−0.197 (−0.537 to 0.197)	−0.980	0.327	84.5%; 6.44; 0.011	29.60 (–); <0.001	1.00; 0.317
Full-time only	3	205	−0.183 (−0.420 to 0.077)	−1.383	0.167	69.9; 6.63; 0.036	4.30 (−99.57 to 108.17); 0.692	0.33; 0.602
Forcible entry	3	252	−0.247 (−0.407 to −0.072)	−2.743	0.006 **	51.1%; 4.09; 0.129	21.43 (−25.53 to 68.39); 0.109	1.00; 0.117
Weight of PPE and full-time	2	163	−0.220 (−0.488 to 0.086)	−1.411	0.158	74.3%; 3.88; 0.049	22.98 (–); <0.001	1.00; 0.317
Abdominal endurance								
Stair climb	5	262	−0.415 (−0.512 to −0.306)	−6.933	<0.001 **	25.7%; 5.38; 0.250	1.51 (−5.21 to 8.22); 0.526	0.00; 1.00
Five or more tasks and sequential	3	200	−0.472 (−0.574 to −0.354)	−7.079	<0.001 **	0.0%; 1.12; 0.572	−3.07 (−21.12 to 14.99); 0.276	−1.00; 0.117
Full-time Males firefighters	3	224	−0.388 (−0.496 to −0.268)	−5.962	<0.001 **	22.8%; 3.88; 0.274	2.53 (−5.17 to 10.23); 0.293	0.33; 0.497
Weight of PPE	4	220	−0.452 (−0.554 to −0.338)	−7.035	<0.001 **	0.0%; 2.52; 0.473	4.73 (−49.98 to 59.44); 0.470	0.33; 0.602

http://etd.uwc.ac.za/

Table 7. *Cont.*

Outcome	No. of Studies	No. of Participants	R (95% CI)	Z Score	*p* (Overall Effect)	Heterogeneity I^2; Cohen's Q; *p*-Value	Egger's test Intercept (95%CI); *p*	Begg's Test (τ; *p*)
Hose drag	5	313	−0.230 (−0.334 to −0.120)	−4.034	<0.001 **	17.3%; 4.83; 0.305	2.61 (−2.40 to 7.62); 0.196	0.40; 0.327
Five or more tasks	3	251	−0.253 (−0.367 to −0.132)	−4.029	<0.001 **	0.0%; 1.05; 1.000	−5.72 (−116.29 to 104.85); 0.629	−0.33; 0.602
Sequential tasks	4	293	−0.256 (−0.361 to −0.143)	−4.381	<0.001 **	0.0%; 1.06; 0.786	−0.92 (−10.99 to 9.14); 0.732	0.00; 1.00
Weight of PPE	2	182	−0.157 (−0.367 to 0.068)	−1.374	0.169	48.8%; 3.91; 0.142	3.11 (25.36 to 31.59); 0.397	0.33; 0.602
Full-time firefighters	4	224	−0.201 (−0.326 to −0.069)	−2.961	0.003 **	27.9%; 4.16; 0.245	2.41 (−6.16 to 10.97); 0.350	0.33; 0.497
Victim drag	6	351	−0.151 (−0.290 to −0.006)	−2.044	0.041 *	41.4%; 8.52; 0.129	1.01 (−5.24 to 7.27); 0.677	0.33; 0348
Five or more Tasks	4	289	−0.189 (−0.342 to −0.027)	−2.276	0.023	46.6%; 5.62; 0.132	−3.96 (−21.81 to 13.89); 0.441	0.00; 1.00
Sequential tasks	5	331	−0.176 (−0.281 to −0.068)	−3.165	0.002 **	29.1%; 5.64; 0.228	−2.37 (−11.97 to 7.22); 0.489	0.00; 1.00
Males only	4	271	−0.113 (−0.231 to 0.008)	−1.834	0.067	34.3%; 4.57; 0.206	3.33 (-.345 to 10.12); 0.169	1.00; 0.042
Weight of PPE	4	220	−0.137 (−0.366 to 0.108)	−1.098	0.272	64.7%; 8.50; 0.037	1.16 (−14.11 to 16.44)	0.33; 0.497
Full-time	4	224	−0.0845 (−0.248 to 0.084)	−0.984	0.325	30.4%; 4.31; 0.230	2.58 (−5.77 to 10.93); 0.315	0.67; 0.174
Forcible entry	3	251	−0.195 (−0.313 to −0.072)	−3.081	0.002 **	0.0%; 1.39; 0.499	11.35 (−35.85 to 58.56); 0.201	0.33; 0.602
Weight of PPE	2	162	−0.160 (−0.308 to −0.004)	−2.012	0.044 *	0.0%; 0.79; 0.374	9.78 (–); <0.001	1.00; 0.317
Equipment hoist	2	111	−0.168 (−0.400 to 0.167)	−0.844	0.399	37.1%; 1.59; 0.207	2.48 (–); <0.001	1.00; 0.317
Saw hold	2	80	0.252 (−0.300 to −0.677)	−0.891	0.373	83.8%; 6.17; 0.013	64.96 (–); <0.001	1.00; 0.317
Grip strength								
Stair climb	6	312	−0.200 (−0.502 to 0.071)	−1.510	0.131	85.5%; 34.49;<0.0001	−2.29 (−15.69 to 11.10); 0.348	−0.33; 0.348
Hose drag	5	274	−0.378 (−0.589 to −0.119)	−2.806	0.005 **	78.9%; 19.00;<0.001	−3.97 (−16.26 to 8.33); 0.379	0.00; 1.00
Five or more tasks	2	163	−0.325 (−0.496 to −0.129)	−3.188	0.001 **	42.5%; 1.74; 0.188	15.38 (–); <0.001	1.00; 0.317
Males only	4	225	−0.429 (−0.668 to −0.108)	−2.566	0.010 *	83.3%; 17.92; <0.001	−3.69 (−24.39 to 17.01); 0.524	0.00; 1.00
Weight of PPE	4	232	−0.442 (−0.666 to −0.145)	−2.834	0.005 **	81.8%; 16.45;<0.001	−5.37 (−21.79 to 11.06); 0.295	−0.33; 0.497
Victim rescue	5	263	−0.578 (−0.713 to −0.402)	−5.545	<0.001 **	68.2%; 12.56; 0.014	−2.11 (−12.47 to 8.25); 0.563	−0.40; 0.327
Five or more tasks	3	201	−0.610 (−0.773 to −0.372)	−4.366	<0.001 **	78.8%; 9.43; 0.009	−6.89 (−95.23 to 81.44); 0.503	−0.33; 0.602
Sequential tasks	4	243	−0.561 (−0.716 to −0.353)	−4.697	<0.001 **	74.7%; 11.84; 0.008	−2.44 (−29.09 to 24.22); 0.732	−0.33; 0.497
Full-time male firefighters	4	225	−0.507 (−0.600 to −0.401)	−8.152	<0.001 **	35.5; 4.65; 0.199	−0.51 (−12.29 to 11.27); 0.869	0.00; 1.00
Weight of PPE	4	221	−0.621 (−0.758 to −0.432)	−5.388	<0.001 **	69.6%; 9.86; 0.019	−3.07 (−17.08 to 10.93); 0.445	−0.33; 0.497
Forcible entry	2	163	−0.426 (−0.623 to −0.179)	−3.248	0.001 **	67.2; 3.05; 0.081	20.36 (–); <0.001	1.00; 0.317
Equipment hoist	2	111	−0.420 (−0.703 to −0.023)	−2.066	0.039 *	64.8%; 2.84; 0.092	3.29 (–); <0.001	1.00; 0.317
Saw hold	2	80	0.468 (−0.0836 to 0.800)	1.682	0.093	85.1%; 6.70; 0.009	67.71 (–); <0.001	1.00; 0.317
Upper body strength								
Stair climb	3	134	−0.140 (−0.306 to 0.035)	−1.571	0.116	0.0%; 1.45; 0.484	−2.33 (−17.66 to 12.99); 0.304	−1.00; 0.117
Hose drag	3	134	−0.544 (−0.748 to −0.247)	−3.337	0.001 **	71.9%; 7.11; 0.029	−5.71 (19.89 to 8.48); 0.123	−1.00; 0.117
Five or more tasks	2	114	−0.402 (−0.547 to −0.233)	−4.421	<0.001 **	0.0%; 0.45; 0.502	−3.38 (–); <0.001	−1.00; 0.317
Weight of PPE	2	92	−0.609 (−0.888 to −0.002)	−1.966	0.049 *	85.9%; 7.10; 0.008	−5.91 (–); <0.001	−1.00; 0.317

http://etd.uwc.ac.za/

Table 7. *Cont.*

Outcome	No. of Studies	No. of Participants	R (95% CI)	Z Score	*p* (Overall Effect)	Heterogeneity I^2; Cohen's Q; *p*-Value	Egger's test Intercept (95%CI); *p*	Begg's Test (τ; *p*)
Victim rescue	3	134	−0.350 (−0.573 to −0.080)	−2.512	0.012 *	56.1%; 4.55; 0.103	−3.10 (−47,24 to 41.04); 0.536	−0.33; 0.602
Five or more tasks	2	114	−0.255 (−0.422 to −0.073)	−2.715	0.007 **	0.0%; 0.67; 0.412	4.13 (–); <0.001	1.00; 0.317
Weight of PPE	2	92	−0.461 (−0.733 to −0.064)	−2.248	0.025 *	64.6%; 2.82; 0.093	−3.72 (–); <0.001	−1.00; 0.317
Lower body strength								
Stair climb	5	329	−0.0460 (−0.155 to 0.064)	−0.817	0.414	0.0%; 1.54; 0.819	−0.64 (−3.45 to 2.17); 0.522	−0.20; 0.624
Hose drag	4	179	−0.244 (−0.381 to −0.097)	−3.223	0.01 **	0.0%; 1.72; 0.632	−1.92 (−8.87 to 5.03); 0.357	0.00; 1.00
five or more tasks	2	110	−0.222 (−0.395 to −0.033)	−2.298	0022 *	0.0%; 0.29; 0.591	2.71 (–); <0.001	1.00; 0.317
Weight of PPE	3	137	−0.271 (−0.422 to −0.104)	−3.139	0.02 **	0.0%; 1.29; 0.525	−2.19 (−20.28 to 15.90); 0.367	−0.33; 0.602
Victim rescue	3	130	−0.254 (−0.411 to −0.081)	−2.851	0.004 **	0.0%; 0.29; 0.862	−0.93 (−11.45 to 9.60); 0.462	−0.33; 0.602
five or more tasks	2	110	−0.246 (−0.416 to −0.059)	−2.559	0.010 *	0.0%; 0.25; 0.619	−2.79 (–); <0.001	−1.00; 0.317
Weight of PPE	2	88	−0.229 (−0.422 to −0.017)	−2.111	0.035 *	0.0%; 0.13; 0.724	−0.81 (–); <0.001	−1.00; 0.317
Flexibility								
Stair climb	2	133	−0.190 (−0.351 to −0.019)	−1.959	0.030 *	11.4%; 1.13; 0.288	3.82 (–); <0.001	1.00; 0.317
Hose drag	3	222	−0.130 (−0.259 to 0.004)	−1.908	0.056	0.0%; 0.94; 0.626	−2.55 (−28.08 to 22.98); 0.425	−1.00; 0.012
Victim rescue	3	222	−0.0792 (−0.210 to 0.055)	−1.159	0.247	0.0%; 1.67; 0.434	−4.09 (−22.07 to 13.89); 0.212	−1.00; 0.117
Forcible entry	2	180	−0.0700 (−0.215 to 0.078)	−0.924	0.355	0.0%; 0.66; 0.418	99.59 (–); <0.001	1.00; 0.317

Note: * indicates statistical significance <0.05; ** indicates statistical significance <0.01. (–)—indicates insufficient studies to calculate Egger's test result. PPE—personal protective equipment.; italics—indicates subgroup analysis.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

4. Discussion

4.1. Summary of Evidence

The results of this systematic review and meta-analysis indicated that the effect of cardiovascular risk status and musculoskeletal health status on occupational performance are understudied, and large gaps exist in the literature. Only two cardiovascular disease risk factors were frequently studied, namely age and obesity, and both had a significant effect on occupational performance. The results indicated that as firefighters aged and accumulated more adipose tissue, their completion times increased, which was consistent for all tasks investigated. In addition, we found a significant effect of physical fitness on occupational performance with cardiorespiratory fitness, muscular endurance, and upper body strength, all related to all individual tasks performance. These results are consistent with two systematic reviews, one on firefighters and the other on military personnel, that also found that aerobic capacity, muscular endurance and muscular strength are related to completion times in emergency occupations [87,88]. In addition, the current study results indicated that the weight of PPE worn significantly influenced the performance of all tasks. Moreover, the weight of PPE was related to overall occupational performance and individual task performance according to age, obesity and all physical fitness measures. This may be due to the weight of the equipment placing an extra burden on firefighters' abilities to perform their tasks efficiently, especially when compounded with excessive adipose accumulation and older age. The weight of PPE may become particularly important when conducting occupational performance tasks, as using full PPE may represent the truest simulation of the burden firefighters face physiologically while on active duty. These results are supported by a systematic review that indicated that the weight of PPE and SCBA gear elicit a significant physiological response in firefighters [32].

Globally, firefighting is regarded as one of the most physically demanding occupations that require high levels of physical fitness in order for them to perform their jobs effectively [88]. Moreover, firefighters are expected to remain in peak physical conditioning, especially as they age, to ensure they do not become a liability as they remain in the fire services [88,89]. The results of the current review supported this standpoint, as less physically fit firefighters that had increased fat mass were the most likely to perform poorly on the occupational performance tasks. Firefighting induces significant physiological responses [9,33] and, therefore, fitter firefighters perform significantly better than unfit firefighters, even as they age.

4.2. The Effect of Age, Obesity, Blood Pressure, Heart Rate and Gender on Occupational Performance

The results indicated that age had a significant moderate effect on occupational performance in the current study. In addition, a significant correlation existed between aging and overall occupational performance, particularly among full-time career firefighters. Ageing is considered a CAD risk factor, particularly in men 45 years and older and woman 55 years and older, due to the progressive reduction in arterial elasticity, increased inflammatory responses and reduction in key growth factors responsible for maintenance of arterial health [90–93]. Moreover, diastolic blood pressure was shown to significantly affect occupational performance in firefighter, however, the literature on this is limited, and more research should be conducted to allow for meta-analysis. Previous research indicated that blood pressure significantly affected work capacity in athletes [94] and job performance in emergency personnel [95] alike, which supports the results of the current study. Regular physical activity maintains cardiovascular health, however, firefighters generally become less physically active as they age [96–99], particularly in firefighters in the City of Cape Town Fire and Rescue Service [15,22]. Firefighters that are older, especially those aged 45 years or older, should engage in regular physical activity to maintain their work performance to acceptable standards [96,97,99,100]. There was a significant positive correlation between age and stair climb performance. Older firefighters performed significantly worse compared to younger firefighters and showed the strongest correlation when occupational

http://etd.uwc.ac.za/

performance simulation protocols included five or more sequential tasks. Age did not correlate with hose drag, victim rescue and forcible entry performance. The results suggest that muscular endurance and strength are of greater significance in performing the hose drag, victim rescue and forcible entry tasks successfully. Aging had a much larger effect on cardiorespiratory fitness as opposed to muscular endurance and strength, which may explain why aged firefighters performed worse on the stair climb [37,38,96,99–101]. The present results indicated that cardiorespiratory fitness was the most significant factor in optimal performance in firefighters, and that older firefighters with lower cardiorespiratory fitness had the lowest overall occupational performance, particularly those that are obese [38,99,102–104]. A study by Von Heimburg [71] reported that firefighters that performed best on the hose drag had a better dragging technique and higher cardiorespiratory fitness, but no significant difference between age was present. The years of experience as a firefighter may, somewhat, reduce the effect of age on task performance, especially those tasks where economical and explosive technique, rather than absolute power, may prove to be most beneficial, such as hose drag, victim rescue and forcible entry.

Obesity had a significant large moderate effect on occupational performance in firefighters, indicating that non-obese firefighters performed significantly better on the occupational performance tasks. This was further strengthened by the correlation analysis which indicated that as firefighters' age increased, overall simulation performance significantly decreased, and in particular, the stair climb, and victim drag events, especially when the weight of PPE was controlled for. Obesity increases the amount of non-functional excess weight that firefighters are required to overcome while performing their duties, reducing their overall performance on simulated tasks [99,102–105]. Although research has indicated that increased body mass, to a point, may benefit certain strength or upper body stamina related tasks, overall task performance was not benefited, particularly related to the stair climb task [71,79]. Obese firefighters, generally, have a much lower cardiorespiratory fitness level, which may account for the reduced occupational performance seen in this group [26,27,103,106]. To maintain high work performance, firefighters should maintain a healthy weight throughout their careers, especially those firefighters involved in smoke diving and emergency rescues [3,6,8,107]. Although there were no studies investigating other CVD risk factors, obesity has been associated with increased risk status. Reducing obesity may not only improve overall occupational performance, but may also reduce all-cause mortality related to CVD in firefighters [2,3,6,16,108]. Increased adiposity reduced the overall performance times in stair climb, hose drag, victim rescue, forcible entry, and equipment hoist times in firefighters. Firefighters that were obese, performed significantly worse on each task. Most firefighting tasks were negatively affected by increased fat mass in firefighters, which is consistent with previous research indicating that obesity reduces performance [87].

Resting heart rate had a significant positive correlation with completion times, indicating that a higher resting heart rate resulted in worse performance on the occupational performance tasks. Resting heart rate (RHR) is closely linked to cardiorespiratory health and cardiorespiratory fitness. Higher RHRs have been linked to cardiovascular disease and poor cardiorespiratory fitness and increased cardiovascular risk [27,106,109]. Nazari et al. [33] reported that high heart rates and near maximum heart rates are reached during occupational performance tasks.

The current results indicated that gender had a significant effect on completion times in firefighters, with males performing significantly better than female firefighters. This is consistent with previous results that indicated males were stronger and fitter than their female counterparts and performed the occupational tasks faster. This may be due to many tasks being strength and endurance based, favouring male firefighters [31,86]. This is most likely due to males being taller, more muscular, and stronger than female firefighters, which has been shown to be a significant predictor of performance times [79]. Female firefighters may need to engage in more frequent off-duty strength training to maintain the minimum levels of strength needed to perform firefighting tasks optimally.

http://etd.uwc.ac.za/

4.3. The Effect of Physical Fitness on Occupational Performance

The results indicated that a moderate negative correlation existed between cardiorespiratory fitness and completion times. Fitter firefighters performed significantly better on the occupational performance tasks compared to less fit firefighters. Studies suggest that firefighting require a minimum V̇O2max of 42 mL·kg·min and, unsurprisingly, firefighters with higher cardiorespiratory fitness levels performed significantly better. This is supported by Hauschild et al. [88], where the review indicated that emergency per- sonnel that had higher cardiorespiratory fitness performed better in the simulated tasks. Although all physical fitness parameters, except flexibility, was significantly correlated to occupational performance, cardiorespiratory fitness had the highest correlation with overall performance. Maintenance of cardiorespiratory fitness may be the most important aspect in the maintenance of optimal work performance in firefighters. This is especially true when firefighters that find themselves in emergency situations and are required to work at moderate-to-vigorous levels of intensity for prolonged periods of time. Cardiorespiratory fitness was significantly and negatively correlated to stair climb and hose drag times, especially when subgroup analysis was performed on studies including heavier equipment weights (>22 kgs). The stair climb and hose drag tasks require firefighters to perform locomotive move either climbing a flight of stairs or dragging a hose, which require the use of large muscle groups that require large amounts of oxygen. Fitter firefighters are able to utilize the available oxygen more efficiently, performing better on these locomotive tasks. Heavier equipment increased the cardiorespiratory load of each firefighting task, and require a higher fitness level for adequate completion [32].

Upper body (push-up) and abdominal (sit-ups) endurance had a significant negative correlation with overall completion times, particularly when firefighters performed five or more tasks and when equipment weighed more than 22 kgs. Many of the tasks' firefighters are required to perform involve forceful repetitive upper body exertive movements. Higher levels of upper body muscular endurance allow firefighters to sustain a particular amount of force over a number of repetitions [61,62,66,77]. Such as the door breach, which require firefighters to sustain maximal force during each hit to move the tyre or sled the desired distance [57,66,110]. Significant negative correlations were present between upper body and abdominal endurance and stair climb, hose drag, victim rescue, and forcible entry performance and, in particular, when subgroup analysis was performed on studies with equipment weighing more than 22 kgs and five or more tasks. Higher levels of upper body and abdominal stamina positively affected performance in stair climb, hose drag, victim rescue and forcible entry tasks. For all tasks, firefighters are required to wear their full protective equipment and SCBA gear which places significant strain on the upper body muscular [79,111,112]. Higher levels of upper body endurance will reduce the muscular strain of wearing PPE and SCBA gear while performing the occupational tasks. As indicated by Marcel-Millet [9], there are significant physiological differences between firefighters that wore PPE and SCBA gear, compared to those without. Focussing on improving firefighter stamina may prove to be particularly important to maintain high levels of occupational performance.

Grip strength, upper body strength and lower body strength were all significantly and negatively correlated with overall simulation performance in firefighters, particularly in males, where five or more tasks were performed while wearing equipment weighing more than 22 kgs. In general, stronger firefighters completed the simulation protocols significantly quicker than weaker firefighters. As mentioned previously, stronger firefighters are capable of producing higher levels of force with each movement, as most studies indicated significant relationships existed between muscle strength and endurance in firefighters [42,57,61,62]. In addition, higher levels of strength reduce the effort required to perform each task, allowing them to sustain the minimum required level of force for longer. This allows firefighters to move the tyre or sled further with each swing of the sledgehammer, or hoisting equipment further with each pull. More specifically, grip strength correlated negatively to hose drag, victim rescue, forcible entry and equipment hoist times,

http://etd.uwc.ac.za/

upper and lower body strength was negatively correlated to hose drag and victim rescue times, only, and in particular, when heavier equipment was used. Surprisingly, lower body strength was not correlated with better performance in the stair climb task. Grip strength appeared to be the most significant strength measure to maintain overall occupational performance in firefighters. This may be due to firefighting requiring firefighters to constantly grip and hold objects in place while producing high levels of force, such as sledgehammers, axes, jaws of life and fire hoses [42,61,62,77]. Higher levels of upper and lower body strength may allow firefighters to carry and drag the hose and victim with less effort [61,62,65,87]. There were insufficient studies available to analyse the effect of upper and lower body strength on forcible entry or equipment hoist times.

Flexibility was the only physical fitness parameter that was not significantly correlated to overall occupational performance, however, was negatively correlated to stair climb times in firefighters. More flexible firefighters may be able to have longer strides while climbing the stairs, as the hamstring is able to stretch further with less discomfort, improving the stair climb performance. A systematic review reported that hamstring flexibility was a key factor sprinting, jumping and agility [113]. Although the present study did not find a significant correlation between flexibility and other firefighter tasks, maintenance of flexibility may assist in maintaining high levels of occupational performance in firefighters [57,66,73]. Importantly, higher flexibility has been shown to reduce the incidence of injury in firefighters [43,44,114].

4.4. Limitations of the Study

The large number of cross-sectional studies are a limitation of the current study. Heterogeneity was introduced due to differences in weight of equipment and age ranges of the firefighters across different studies. However, this was at least partially mitigated through subgroup analysis. A limited number of studies were conducted on the relationship between cardiovascular and musculoskeletal health and occupational performance, which negatively impacted the meta-analysis on these variables. The older studies included in this systematic review, may have influenced the results, as advancements in PPE, work environments and intervention techniques, have in different physical demands, compared with previous years. Limitations in the quality of evidence are described below.

4.5. Applicability of Evidence

The results indicated that non-obese, younger male firefighters that have a high cardiorespiratory fitness level, and those that have high levels of muscular endurance and strength have the most favorable overall occupational performance. Cardiorespiratory fitness, along with upper body and abdominal endurance should be prioritized in exercise training programmes. Moreover, tasks that were performed sequentially where the weight of PPE worn was over 22 kgs significantly and negatively affected overall performance times. Taller, heavier male firefighters may have the most favorable performance outcomes when performing occupational specific duties. An inherent limitation of the evidence is that all firefighters recruited to participate in the studies are apparently healthy and injury free. More studies need to be conducted on firefighters with cardiovascular disease risk factors and underlying musculoskeletal health issues. Regular aerobic training, along with strength training may prove to be particularly beneficial for older firefighters who are smaller in stature and have a lower body mass, and in particular, female firefighters.

4.6. Quality of Evidence

Critical appraisal of the included studies for the majority of studies were acceptable; however, few studies appraised were low in overall quality. Three studies scored 15 points in the AXIS appraisal too, but was largely due to the small sample sizes of the studies. Due to the difficulty of performing occupational simulation tasks, most studies included small number of firefighters to participate. High heterogeneity was present between approximately half of the analysis, and possibly due to the difference is sample sizes,

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

which may have influenced the means, standard deviations, as well the correlation strength between the included variables. Although high heterogeneity was present, the studies provided valuable information on factors affecting occupational performance.

4.7. Gaps in the Literature

The effects of cardiovascular disease risk factors and musculoskeletal health on firefighters' occupational performance are understudied. Particularly, studies related to the effect of cardiovascular risk factors, such as hypertension, diabetes, dyslipidaemia, and cigarette smoking on occupational performance, and the effect of musculoskeletal health issues on occupation performance. More research should be conducted on cardiovascular risks and musculoskeletal health related to occupational performance in firefighters.

4.8. Implications for Future Research

More research should be conducted investigating the effect of cardiovascular disease risk factors, and overall risk status on occupational performance. The effect of musculoskeletal health on work performance is also understudied.

5. Conclusions

Age and obesity significantly affected occupational performance in firefighters, increasing task completion times across all events. Physical fitness is integral to occupational performance in firefighters, with cardiorespiratory fitness, muscular endurance and upper body strength having the most significant effect on total completion times and all individual tasks. The weight of PPE is an essential consideration, as this significantly impacts completion times, highlighted by the heterogeneity caused between studies, particularly when five or more tasks were performed sequentially while firefighters wore PPE weighing over 22 kg. Moreover, younger, stronger, and heavier male firefighters performed significantly better than older, lighter and weaker firefighters, which emphasizes the importance of maintaining a suitable body composition, and appropriate levels of muscular endurance and strength as firefighters age. Firefighting departments should adopt regular physical activity, focused on maintaining cardiorespiratory fitness, muscular endurance, and upper body strength, to maintain firefighters' physical fitness and dietary recommendations, to reduce the likelihood of overweight and obesity in firefighters, which is particularly important as they age.

6. Patents

Protocol Registration

Details of the protocol for this systematic review were registered on PROSPERO (CRD42021258898) and can be accessed at: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=258898 (accessed on 21 January 2022).

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ijerph191911946/s1, Supplementary S1: Search strategy for databases; Supplementary S2: Eligibility screening form; Supplementary S3: Data extraction form.

Author Contributions: Conceptualization, J.R. and L.L.; methodology, J.R., R.V.N. and A.P.K.; software, J.R.; validation, J.R., L.L., A.P.K., D.L.S. and E.S.S.; formal analysis, J.R.; investigation, J.R. and R.V.N.; resources, J.R.; data curation, J.R. and R.V.N.; writing—original draft preparation, J.R.; writing—review and editing, J.R., L.L., A.P.K., D.L.S. and E.S.S.; visualization, J.R., L.L., A.P.K., D.L.S. and E.S.S.; supervision, L.L., A.P.K., D.L.S. and E.S.S.; project administration, J.R., L.L., A.P.K., D.L.S. and E.S.S.; funding acquisition, J.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Research Foundation (NRF), grant number 141282 and The Ryoichi Sasakawa Young Leaders Fellowship Fund (SLYFF).

Institutional Review Board Statement: Not applicable.

http://etd.uwc.ac.za/

Informed Consent Statement: Not applicable.

Data Availability Statement: All data generated or analyzed during this study are included in the published review article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Shin, J.-H.; Lee, J.-Y.; Yang, S.-H.; Lee, M.-Y.; Chung, I.-S. Factors related to heart rate variability among firefighters. *Ann. Occup. Environ. Med.* **2016**, *28*, 25. [CrossRef] [PubMed]
2. Smith, D.L.; Barr, D.A.; Kales, S.N. Extreme sacrifice: Sudden cardiac death in the US Fire Service. *Extreme Physiol. Med.* **2013**, *2*, 6. [CrossRef] [PubMed]
3. Soteriades, E.S.; Smith, D.L.; Tsismenakis, T.; Baur, D.M.; Kales, S.N. Cardiovascular disease in US firefighters: A systematic review. *Cardiol. Rev.* **2011**, *19*, 202–215. [CrossRef] [PubMed]
4. Lima, E.D.P.; Assunção, A.; Barreto, S.M. Smoking and occupational stressors in firefighters, 2011. *Rev. Saude Publica* **2013**, *47*, 897–904. [CrossRef]
5. Navarro, K.M.; Kleinman, M.T.; Mackay, C.E.; Reinhardt, T.E.; Balmes, J.R.; Broyles, G.A.; Ottmar, R.D.; Naher, L.P.; Domitrovich, J.W. Wildland firefighter smoke exposure and risk of lung cancer and cardiovascular disease mortality. *Environ. Res.* **2019**, *173*, 462–468. [CrossRef]
6. Smith, D.L.; Deblois, J.P.; Kales, S.N.; Horn, G.P. Cardiovascular Strain of Firefighting and the Risk of Sudden Cardiac Events. *Exerc. Sport Sci. Rev.* **2016**, *44*, 90–97. [CrossRef]
7. Farioli, A.; Yang, J.; Teehan, D.; Baur, D.M.; Smith, D.L.; Kales, S.N. Duty-related risk of sudden cardiac death among young US firefighters. *Occup. Med.* **2014**, *64*, 428–435. [CrossRef]
8. Smith, D.L.; Haller, J.M.; Korre, M.; Sampani, K.; Porto, L.G.G.; Fehling, P.C.; Christophi, C.A.; Kales, S.N. The Relation of Emergency Duties to Cardiac Death among US Firefighters. *Am. J. Cardiol.* **2019**, *123*, 736–741. [CrossRef]
9. Marcel-Millet, P.; Ravier, G.; Grosprêtre, S.; Gimenez, P.; Freidig, S.; Groslambert, A. Physiological responses and parasympathetic reactivation in rescue interventions: The effect of the breathing apparatus. *Scand. J. Med. Sci. Sports* **2018**, *28*, 2710–2722. [CrossRef]
10. Feairheller, D.L. Blood pressure and heart rate responses in volunteer firefighters while wearing personal protective equipment. *Blood Press. Monit.* **2015**, *20*, 194–198. [CrossRef]
11. Rodrigues, S.; Dias, D.; Paiva, J.S.; Cunha, J.P. Psychophysiological Stress Assessment among On-Duty Firefighters. In Proceedings of the 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Honolulu, HI, USA, 18–21 July 2018; pp. 4335–4338. [CrossRef]
12. Liao, L.-M.; Al-Zaiti, S.S.; Carey, M.G. Depression and heart rate variability in firefighters. *SAGE Open Med.* **2014**, *2*, 2050312114545530. [CrossRef]
13. Hom, M.A.; Stanley, I.H.; Rogers, M.L.; Tzoneva, M.; Bernert, R.A.; Joiner, T.E. The Association between Sleep Disturbances and Depression among Firefighters: Emotion Dysregulation as an Explanatory Factor. *J. Clin. Sleep Med.* **2016**, *12*, 235–245. [CrossRef] [PubMed]
14. Gulliver, S.B.; Zimering, R.T.; Knight, J.; Morissette, S.B.; Kamholz, B.W.; Pennington, M.L.; Dobani, F.; Carpenter, T.P.; Kimbrel, N.A.; Keane, T.M.; et al. A prospective study of firefighters' PTSD and depression symptoms: The first 3 years of service. *Psychol. Trauma* **2021**, *13*, 44–55. [CrossRef] [PubMed]
15. Ras, J.; Leach, L. Prevalence of Coronary Artery Disease Risk Factors in Firefighters in the City of Cape Town Fire and Rescue Service—A Descriptive Study. *J. Public Health Res.* **2021**, *10*, 2000. [CrossRef] [PubMed]
16. Savall, A.; Charles, R.; Bertholon, A.; Gramont, B.; Trombert, B.; Barthélémy, J.-C.; Roche, F. Volunteer and career French firefighters: Cardiovascular risk factors and cardiovascular risk assessment. *Eur. J. Prev. Cardiol.* **2020**, *27*, 107–109. [CrossRef]
17. Hunter, A.L.; Shah, A.; Langrish, J.P.; Raftis, J.B.; Lucking, A.J.; Brittan, M.; Venkatasubramanian, S.; Stables, C.; Stelzle, D.; Marshall, J.; et al. Fire Simulation and Cardiovascular Health in Firefighters. *Circulation* **2017**, *135*, 1284–1295. [CrossRef]
18. Wolkow, A.; Netto, K.; Langridge, P.; Green, J.; Nichols, D.; Sergeant, M.; Aisbett, B. Cardiovascular risk screening of volunteer firefighters. In Proceedings of the Bushfire CRC & AFAC 2012 Conference Research Forum, Perth, Australia, 28 August 2012.
19. Gendron, P.; Lajoie, C.; Laurencelle, L.; Trudeau, F. Cardiovascular disease risk in female firefighters. *Occup. Med.* **2018**, *68*, 412–414. [CrossRef]
20. Azmi, N.L.A.M.; Masuri, M.G. Work-related musculoskeletal disorder (WMSDs) and functional status of firefighters in Klang Valley. *Healthscope Off. Res. Book Fac. Health Sci. UiTM* **2019**, 2. Available online: http://healthscopefsk.com/index.php/research/article/view/74 (accessed on 7 August 2021).
21. Kodom-Wiredu, J.K. The Relationship between Firefighters' Work Demand and Work-related Musculoskeletal Disorders: The Moderating Role of Task Characteristics. *Saf. Health Work* **2019**, *10*, 61–66. [CrossRef]
22. Ras, J.; Leach, L. Relationship between Physical Activity, Coronary Artery Disease Risk Factors and Musculoskeletal Injuries in the City of Cape Town Fire and Rescue Service. *Inq. J. Health Care Organ. Financ.* **2022**, *59*, 00469580221084485. [CrossRef]
23. Saremi, M.; Madvari2, R.F.; Laal, F.; Noorizadeh, N.; Rahimi, E. Assessment of Mental Workload, Workability and Musculoskeletal Disorders of Firefighters. *J. Community Health. Res.* **2019**, *8*, 139–147. [CrossRef]

http://etd.uwc.ac.za/

24. Donovan, R.; Nelson, T.; Peel, J.; Lipsey, T.; Voyles, W.; Israel, R.G. Cardiorespiratory fitness and the metabolic syndrome in firefighters. *Occup. Med.* **2009**, *59*, 487–492. [CrossRef] [PubMed]
25. Li, K.; Lipsey, T.; Leach, H.J.; Nelson, T.L. Cardiac health and fitness of Colorado male/female firefighters. *Occup. Med.* **2017**, *67*, 268–273. [CrossRef] [PubMed]
26. Baur, D.M.; Christophi, C.A.; Tsismenakis, T.; Cook, E.F.; Kales, S.N. Cardiorespiratory Fitness Predicts Cardiovascular Risk Profiles in Career Firefighters. *J. Occup. Environ. Med.* **2011**, *53*, 1155–1160. [CrossRef]
27. Seyedmehdi, S.M.; Attarchi, M.; Cherati, A.S.; Hajsadeghi, S.; Tofighi, R.; Jamaati, H. Relationship of aerobic fitness with cardiovascular risk factors in firefighters. *Work* **2016**, *55*, 155–161. [CrossRef]
28. Siddall, A.G.; Stevenson, R.D.M.; Turner, P.J.F.; Bilzon, J.L.J. Physical and Physiological Performance Determinants of a Firefighting Simulation Test. *J. Occup. Environ. Med.* **2018**, *60*, 637–643. Available online: https://journals.lww.com/joem/Fulltext/2018/07000/Physical_and_Physiological_Performance.10.aspx (accessed on 20 May 2022). [CrossRef]
29. MacDermid, J.C.; Tang, K.; Sinden, K.E.; D'Amico, R. Work Functioning among Firefighters: A Comparison between Self-Reported Limitations and Functional Task Performance. *J. Occup. Rehabil.* **2019**, *29*, 194–204. [CrossRef]
30. Skinner, T.L.; Kelly, V.G.; Boytar, A.N.; Peeters, G.; Rynne, S.B. Aviation Rescue Firefighters physical fitness and predictors of task performance. *J. Sci. Med. Sport* **2020**, *23*, 1228–1233. [CrossRef]
31. Nazari, G.; MacDermid, J.C.; Sinden, K.E.; Overend, T.J. The Relationship between Physical Fitness and Simulated Firefighting Task Performance. *Rehabil. Res. Pr.* **2018**, *2018*, 3234176. [CrossRef]
32. Li, J.; Wang, Y.; Jiang, R.; Li, J. Quantifying self-contained breathing apparatus on physiology and psychological responses during firefighting: A systematic review and meta-analysis. *Int. J. Occup. Saf. Ergon.* **2022**, 1–13. [CrossRef]
33. Nazari, G.; Lu, S.; MacDermid, J.C. Quantifying physiological responses during simulated tasks among Canadian firefighters: A systematic review and meta-analysis. *J. Mil. Veter-Fam. Health.* **2021**, *7*, 55–75. [CrossRef]
34. Soares, E.M.K.V.K.; Smith, D.; Porto, L.G.G. Worldwide prevalence of obesity among firefighters: A systematic review protocol. *BMJ Open* **2020**, *10*, e031282. [CrossRef]
35. Park, K.; Rosengren, K.S.; Horn, G.P.; Smith, D.L.; Hsiao-Wecksler, E.T. Assessing gait changes in firefighters due to fatigue and protective clothing. *Saf. Sci.* **2011**, *49*, 719–726. [CrossRef]
36. Park, K.; Sy, J.F.; Horn, G.P.; Kesler, R.M.; Petrucci, M.N.; Rosengren, K.S.; Hsiao-Wecksler, E.T. Assessing gait changes in firefighters after firefighting activities and while carrying asymmetric loads. *Appl. Ergon.* **2018**, *70*, 44–50. [CrossRef] [PubMed]
37. Magyari, P.; Fonger, T.; May, J. Upper Body Muscular Endurance among Active Duty Male and Female Firefighters. *J. Strength Cond. Res.* **2010**, *24*, 1. Available online: https://journals.lww.com/nsca-jscr/Fulltext/2010/01001/Upper_Body_Muscular_Endurance_Among_Active_Duty.99.aspx (accessed on 20 May 2022). [CrossRef]
38. Lindberg, A.-S.; Oksa, J.; Antti, H.; Malm, C. Multivariate Statistical Assessment of Predictors of Firefighters' Muscular and Aerobic Work Capacity. *PLoS ONE* **2015**, *10*, e0118945. [CrossRef]
39. Sothmann, M.S.; Gebhardt, D.L.; A Baker, T.; Kastello, G.M.; A Sheppard, V. Performance requirements of physically strenuous occupations: Validating minimum standards for muscular strength and endurance. *Ergonomics* **2004**, *47*, 864–875. [CrossRef]
40. Schmit, M.; DeBeliso, M. The Relationship between Firefighters' Physical Performance Aspects and Simulated Firefighting Demands. *Turk. J. Kinesiol.* **2019**, *5*, 63–75. [CrossRef]
41. Smith, D.L.; Haller, J.M.; Benedict, R.; Moore-Merrell, L. Firefighter Incident Rehabilitation: Interpreting Heart Rate Responses. *Prehospital Emerg. Care* **2016**, *20*, 28–36. [CrossRef]
42. Rhea, M.R.; Alvar, B.A.; Gray, R. Physical Fitness and Job Performance of Firefighters. *J. Strength Cond. Res.* **2004**, *18*, 348–352. [CrossRef]
43. Hong, O.; Phelps, S.; Feld, J.; Vogel, S. Occupational Injuries, Duty Status, and Factors Associated with Injuries among Firefighters. *Work. Health Saf.* **2012**, *60*, 517–523. [CrossRef] [PubMed]
44. Nowak, A.; Molik, B.; Wójcik, A.; Rutkowska, I.; Nowacka-Dobosz, S.; Kowalczyk, M.; Marszalek, J. Physical Activity and Injuries Relating to Physical Fitness of Professional Firefighters. *Adv. Rehabil.* **2018**, *32*, 13–22. [CrossRef]
45. Ras, J.; Leach, L. Use of Mobile Technology in Assessing Occupational Performance and Stress in Firefighters. In *Handbook of Research on New Media, Training, and Skill Development for the Modern Workforce*; Mentor, D., Ed.; IGI Global: Hershey, PA, USA, 2022; pp. 150–186. [CrossRef]
46. Walls, R.S.; Eksteen, R.; Kahanji, C.; Cicione, A. Appraisal of fire safety interventions and strategies for informal settlements in South Africa. *Disaster Prev. Manag. Int. J.* **2019**, *28*, 343–358. [CrossRef]
47. Walls, R.; Olivier, G.; Eksteen, R. Informal settlement fires in South Africa: Fire engineering overview and full-scale tests on "shacks". *Fire Saf. J.* **2017**, *91*, 997–1006. [CrossRef]
48. Ryan, A.M.; Greguras, G.J.; Ployhart, R.E. Perceived Job Relatedness of Physical Ability Testing for Firefighters: Exploring Variations in Reactions. *Hum. Perform.* **1996**, *9*, 219–240. [CrossRef]
49. McDonough, S.L.; Phillips, J.S.; Twilbeck, T.J. Determining Best Practices to Reduce Occupational Health Risks in Firefight- ers. *J. Strength Cond. Res.* **2015**, *29*, 2041–2044. Available online: https://journals.lww.com/nsca-jscr/Fulltext/2015/07000/Determining_Best_Practices_to_Reduce_Occupational.34.aspx (accessed on 20 May 2022). [CrossRef]
50. Nazari, G.; Osifeso, T.A.; MacDermid, J.C. Distribution of Number, Location of Pain and Comorbidities, and Determinants of Work Limitations among Firefighters. *Rehabil. Res. Pr.* **2020**, *2020*, 1942513. [CrossRef]

http://etd.uwc.ac.za/

51. Ras, J.; Kengne, A.P.; Smith, D.; Soteriades, E.S.; Leach, L. Effects of cardiovascular health, musculoskeletal health and physical fitness on occupational performance of firefighters: Protocol for a systematic review and meta-analysis. *BMJ Open* **2022**, *12*, e061435. [CrossRef]
52. Stroup, D.F.; Berlin, J.A.; Morton, S.C.; Olkin, I.; Williamson, G.D.; Rennie, D.; Moher, D.; Becker, B.J.; Sipe, T.A.; Thacker, S.B. Meta-analysis of Observational Studies in EpidemiologyA Proposal for Reporting. *JAMA* **2000**, *283*, 2008–2012. [CrossRef]
53. Brand, R.A. Editorial: Standards of Reporting: The CONSORT, QUORUM, and STROBE Guidelines. *Clin. Orthop. Relat. Res.* **2009**, *467*, 1393–1394. [CrossRef]
54. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef] [PubMed]
55. Ouzzani, M.; Hammady, H.; Fedorowicz, Z.; Elmagarmid, A. Rayyan—A web and mobile app for systematic reviews. *Syst. Rev.* **2016**, *5*, 210. [CrossRef] [PubMed]
56. Downes, M.J.; Brennan, M.L.; Williams, H.C.; Dean, R.S. Development of a critical appraisal tool to assess the quality of cross-sectional studies (AXIS). *BMJ Open* **2016**, *6*, e011458. [CrossRef] [PubMed]
57. Michaelides, M.A.; Parpa, K.M.; Henry, L.J.; Thompson, G.B.; Brown, B.S. Assessment of Physical Fitness Aspects and Their Relationship to Firefighters' Job Abilities. *J. Strength Cond. Res.* **2011**, *25*, 956–965. [CrossRef] [PubMed]
58. Von Heimburg, E.; Medbø, J.I. Energy Cost of the Trondheim Firefighter Test for Experienced Firefighters. *Int. J. Occup. Saf. Ergon.* **2013**, *19*, 211–225. [CrossRef] [PubMed]
59. Perroni, F.; Cignitti, L.; Cortis, C.; Capranica, L. Physical Fitness Profile of Professional Italian Firefighters: Differences among Age Groups. *Appl. Ergon.* **2014**, *45*, 456–461. [CrossRef]
60. Schonfeld, B.R.; Doerr, D.F.; Convertino, V.A. An Occupational Performance Test Validation Program for Fire Fighters at the Kennedy Space Center. *J. Occup. Environ. Med.* **1990**, *32*, 638–643. Available online: https://journals.lww.com/joem/Fulltext/1990/07000/An_Occupational_Performance_Test_Validation.16.aspx (accessed on 20 May 2022). [CrossRef]
61. Lindberg, A.-S.; Oksa, J.; Malm, C. Laboratory or Field Tests for Evaluating Firefighters' Work Capacity? *PLoS ONE* **2014**, *9*, e91215. [CrossRef]
62. Lindberg, A.-S.; Oksa, J.; Gavhed, D.; Malm, C. Field Tests for Evaluating the Aerobic Work Capacity of Firefighters. *PLoS ONE* **2013**, *8*, e68047. [CrossRef]
63. Xu, D.; Song, Y.; Meng, Y.; István, B.; Gu, Y. Relationship between Firefighter Physical Fitness and Special Ability Performance: Predictive Research Based on Machine Learning Algorithms. *Int. J. Environ. Res. Public Health.* **2020**, *17*, 7689. [CrossRef]
64. Stevenson, R.D.M.; Siddall, A.G.; Turner, P.J.F.; Bilzon, J.L.J. Validity and Reliability of Firefighting Simula-tion Test Performance. *J. Occup. Environ. Med.* **2019**, *61*, 479–483. [CrossRef] [PubMed]
65. Myhre, L.G.; Tucker, D.M.; Bauer, D.H.; Fisher, J.R., Jr.; Grimm, W.H. Relationship between Selected Measures of Physical Fitness and Performance of a Simulated Fire Fighting Emergency Task. ARMSTRONG LAB BROOKS AFB TX 1997. Available online: https://apps.dtic.mil/sti/citations/ADA319915 (accessed on 20 May 2022).
66. Chizewski, A.; Box, A.; Kesler, R.; Petruzzello, S.J. Fitness Fights Fires: Exploring the Relationship between Physical Fitness and Firefighter Ability. *Int. J. Environ. Res. Public Health.* **2021**, *18*, 11733. [CrossRef] [PubMed]
67. Kleinberg, C.R.; Ryan, E.D.; Tweedell, A.J.; Barnette, T.J.; Wagoner, C.W. Influence of Lower Extremity Muscle Size and Quality on Stair-Climb Performance in Career Firefighters. *J. Strength Cond. Res.* **2016**, *30*, 1613–1618. [CrossRef] [PubMed]
68. Elsner, K.L.; Kolkhorst, F.W. Metabolic demands of simulated firefighting tasks. *Ergonomics* **2008**, *51*, 1418–1425. [CrossRef] [PubMed]
69. Ryan, E.D.; Laffan, M.R.; Trivisonno, A.J.; Gerstner, G.R.; Mota, J.A.; Giuliani, H.K.; Pietrosimone, B.G. Neuromuscular determinants of simulated occupational performance in career firefighters. *Appl. Ergon.* **2022**, *98*, 103555. [CrossRef]
70. Von Heimburg, E.; Medbø, J.I.; Sandsund, M.; Reinertsen, R.E. Performance on a Work-Simulating Firefighter Test Versus Approved Laboratory Tests for Firefighters and Applicants. *Int. J. Occup. Saf. Ergon.* **2013**, *19*, 227–243. [CrossRef]
71. Von Heimburg, E.D.; Rasmussen, A.K.R.; Medbø, J.I. Physiological responses of firefighters and performance predictors during a simulated rescue of hospital patients. *Ergonomics* **2006**, *49*, 111–126. [CrossRef]
72. Sheaff, A.K.; Bennett, A.; Hanson, E.D.; Kim, Y.-S.; Hsu, J.; Shim, J.K.; Edwards, S.T.; Hurley, B.F. Physiological Determinants of the Candidate Physical Ability Test in Firefighters. *J. Strength Cond. Res.* **2010**, *24*, 3112–3122. [CrossRef]
73. Michaelides, M.A.; Parpa, K.M.; Thompson, J.; Brown, B. Predicting Performance on a Firefghter's Ability Test from Fitness Parameters. *Res. Q. Exerc. Sport* **2008**, *79*, 468–475. [CrossRef]
74. Saari, A.I.; Renz, G.; Davis, P.; Abel, M.G. The Influence of Age on Firefighter Combat Challenge Performance and Exercise Training Habits. *J. Strength Cond. Res.* **2020**, *34*, 2500–2506. [CrossRef]
75. Windisch, S.; Seiberl, W.; Schwirtz, A.; Hahn, D. Relationships between strength and endurance parameters and air depletion rates in professional firefighters. *Sci. Rep.* **2017**, *7*, 44590. [CrossRef]
76. Misner, J.E.; Boileau, R.A.; Plowman, S.A.; Elmore, B.G.; Gates, M.A.; Gilbert, J.A.; Horswill, C. Leg Power Characteristics of Female Firefighter Applicants. *J. Occup. Environ. Med.* **1988**, *30*, 433–437. [CrossRef]
77. Williford, H.N.; Duey, W.J.; Olson, M.S.; Howard, R.; Wang, N. Relationship between fire fighting suppression tasks and physical fitness. *Ergonomics* **1999**, *42*, 1179–1186. [CrossRef] [PubMed]
78. Davis, P.O.; Dotson, C.O.; Santa Maria, D.L. Relationship between Simulated Fire Fighting Tasks and Physical Performance Measures. *Med. Sci. Sports Exerc.* **1982**, *14*, 65–71. [CrossRef] [PubMed]

http://etd.uwc.ac.za/

79. Phillips, D.B.; Scarlett, M.P.; Petersen, S.R. The Influence of Body Mass on Physical Fitness Test Performance in Male Firefighter Applicants. *J. Occup. Environ. Med.* **2017**, *59*, 1101–1108. [CrossRef] [PubMed]
80. Henderson, N.D.; Berry, M.W.; Matic, T. Field Measures of Strength and Fitness Predict Firefighter Performance on Physically Demanding Tasks. *Pers. Psychol.* **2007**, *60*, 431–473. [CrossRef]
81. Haidich, A.B. Meta-analysis in medical research. *Hippokratia* **2010**, *14*, 29–37. Available online: https://pubmed.ncbi.nlm.nih.gov/21487488 (accessed on 20 May 2022). [PubMed]
82. Akkaya-Hocagil, T. Meta-analysis: Methods for health and experimental studies: ShahjahanKhanSpringerNature Singapore Pte. Ltd. 2020. pp. 293. *Biometrics* **2022**, *78*, 414. [CrossRef]
83. Lin, L. Comparison of four heterogeneity measures for meta-analysis. *J. Eval. Clin. Pr.* **2020**, *26*, 376–384. [CrossRef]
84. Davis, S.C.; Jankovitz, K.Z.; Rein, S. Physical Fitness and Cardiac Risk Factors of Professional Firefighters across the Career Span. *Res. Q. Exerc. Sport* **2002**, *73*, 363–370. [CrossRef]
85. Perroni, F.; Tessitore, A.; Cortis, C.; Lupo, C.; D'artibale, E.; Cignitti, L.; Capranica, L. Energy Cost and Energy Sources During a Simulated Firefighting Activity. *J. Strength Cond. Res.* **2010**, *24*, 3457–3463. Available online: https://journals.lww.com/nsca-jscr/Fulltext/2010/12000/Energy_Cost_and_Energy_Sources_During_a_Simulated.34.aspx (accessed on 20 May 2022). [CrossRef] [PubMed]
86. Misner, J.E.; A Plowman, S.; A Boileau, R. Performance differences between males and females on simulated firefighting tasks. *J. Occup. Med. Off. Publ. Ind. Med Assoc.* **1987**, *29*, 801–805.
87. Fyock-Martin, M.B.; Erickson, E.K.; Hautz, A.H.; Sell, K.M.; Turnbaugh, B.L.; Caswell, S.V.; Martin, J.R. What do Firefighting Ability Tests Tell Us about Firefighter Physical Fitness? A Systematic Review of the Current Evidence. *J. Strength Cond. Res.* **2020**, *34*, 2093–2103. [CrossRef]
88. Hauschild, V.D.; DeGroot, D.W.; Hall, S.M.; Grier, T.L.; Deaver, K.D.; Hauret, K.G.; Jones, B.H. Fitness tests and occupational tasks of military interest: A systematic review of correlations. *Occup. Environ. Med.* **2017**, *74*, 144–153. [CrossRef] [PubMed]
89. Lentz, L.; Randall, J.R.; Gross, D.P.; Senthilselvan, A.; Voaklander, D. The Relationship between Physical Fit-ness and Occupational Injury in Emergency Responders: A Systematic Review. *Am. J. Ind. Med.* **2019**, *62*, 3–13. [CrossRef] [PubMed]
90. Lakatta, E.G. Age-associated Cardiovascular Changes in Health: Impact on Cardiovascular Disease in Older Persons. *Heart Fail. Rev.* **2002**, *7*, 29–49. [CrossRef]
91. Costantino, S.; Paneni, F.; Cosentino, F. Ageing, metabolism and cardiovascular disease. *J. Physiol.* **2016**, *594*, 2061–20733. [CrossRef]
92. Ferrucci, L.; Fabbri, E. Inflammageing: Chronic inflammation in ageing, cardiovascular disease, and frailty. *Nat. Rev. Cardiol.* **2018**, *15*, 505–522. [CrossRef]
93. Arnett, D.K.; Blumenthal, R.S.; Albert, M.A.; Buroker, A.B.; Goldberger, Z.D.; Hahn, E.J.; Himmelfarb, C.D.; Khera, A.; Lloyd-Jones, D.; McEvoy, J.W.; et al. 2019 ACC/AHA Guideline on the primary prevention of cardiovascular disease: A report of the american college of cardiology/American heart association task force on clinical practice guidelines. *Circulation* **2019**, *140*, e596–e646. [CrossRef]
94. Mazic, S.; Lazic, J.S.; Dekleva, M.; Antic, M.; Soldatovic, I.; Djelic, M.; Nesic, D.; Acimovic, T.; Lazic, M.; Lazovic, B.; et al. The impact of elevated blood pressure on exercise capacity in elite athletes. *Int. J. Cardiol.* **2015**, *180*, 171–177. [CrossRef]
95. Hawkins, S.A.; Vie, L.L.; Wolf, P.S.A.; Lester, P.B.; Whittaker, K.S.; Hawkins, J.N.; Perez, A.L. Measuring Job Performance in the Army: Insights from Evidence on Civilian Stress and Health. In *Occupational Stress and Well-Being in Military Contexts*; Harms, P.D., Perrewé, P.L., Eds.; Emerald Publishing Limited: Bingley, UK, 2018; Volume 16, pp. 49–68, ISBN 978-1-78756-184-7.
96. Durand, G.; Tsismenakis, A.J.; Jahnke, S.A.; Baur, D.M.; Christophi, C.A.; Kales, S.N. Firefighters' physical activity: Relation to fitness and cardiovascular disease risk. *Med. Sci. Sports Exerc.* **2011**, *43*, 1752–1759. [CrossRef] [PubMed]
97. Yu, C.C.; Au, C.T.; Lee, F.Y.; So, R.C.; Wong, J.P.; Mak, G.Y.; Chien, E.P.; McManus, A.M. Association between Leisure Time Physical Activity, Cardiopulmonary Fitness, Cardiovascular Risk Factors, and Cardiovascular Workload at Work in Firefighters. *Saf. Health. Work* **2015**, *6*, 192–199. [CrossRef] [PubMed]
98. Alves, A.J.; Viana, J.; Cavalcante, S.L.; Oliveira, N.L.; Duarte, J.A.; Mota, J.; Oliveira, J.; Ribeiro, F. Physical activity in primary and secondary prevention of cardiovascular disease: Overview updated. *World J. Cardiol.* **2016**, *8*, 575. [CrossRef] [PubMed]
99. Baur, D.M.; Christophi, C.A.; Cook, E.F.; Kales, S.N. Age-Related Decline in Cardiorespiratory Fitness among Career Firefighters: Modification by Physical Activity and Adiposity. *J. Obes.* **2012**, *2012*, 710903. [CrossRef] [PubMed]
100. Barry, A.M.; Lyman, K.J.; Dicks, N.D.; Landin, K.D.; McGeorge, C.R.; Hackney, K.J.; Walch, T.J. Firefighters' Physical Activity and Waist Circumference as Predictors of VO2max. *J. Occup. Environ. Med.* **2019**, *61*, 849–853. [CrossRef] [PubMed]
101. Kirlin, L.K.; Nichols, J.F.; Rusk, K.; A Parker, R.; Rauh, M.J. The effect of age on fitness among female firefighters. *Occup. Med.* **2017**, *67*, 528–533. [CrossRef]
102. Mayer, J.M.; Nuzzo, J.L.; Chen, R.; Quillen, W.S.; Verna, J.L.; Miro, R.; Dagenais, S. The Impact of Obesity on Back and Core Muscular Endurance in Firefighters. *J. Obes.* **2012**, *2012*, 729283. [CrossRef]
103. Poston, W.S.C.; Haddock, C.K.; Jahnke, S.A.; Jitnarin, N.; Tuley, B.C.; Kales, S.N. The Prevalence of Overweight, Obesity, and Substandard Fitness in a Population-Based Firefighter Cohort. *J. Occup. Environ. Med.* **2011**, *53*, 266–273. [CrossRef]
104. Nikolakaros, G.; Vahlberg, T.; Auranen, K.; Sillanmäki, L.; Venetoklis, T.; Sourander, A. Obesity, Underweight, and Smoking Are Associated with Worse Cardiorespiratory Fitness in Finnish Healthy Young Men: A Population-Based Study. *Front. Public Health* **2017**, *5*, 206. Available online: https://www.frontiersin.org/article/10.3389/fpubh.2017.00206 (accessed on 20 May 2022). [CrossRef]
105. Mehta, R.K. Impacts of obesity and stress on neuromuscular fatigue development and associated heart rate variability. *Int. J. Obes.* **2015**, *39*, 208–213. [CrossRef]

http://etd.uwc.ac.za/

106. Strauss, M.; Foshag, P.; Jehn, U.; Brzęk, A.; Littwitz, H.; Leischik, R. Higher cardiorespiratory fitness is strongly associated with lower cardiovascular risk factors in firefighters: A cross-sectional study in a German fire brigade. *Sci. Rep.* **2021**, *11*, 2445. [CrossRef] [PubMed]
107. Smith, D.L.; Haller, J.M.; Benedict, R.; Moore-Merrell, L. Cardiac Strain Associated with High-rise Firefighting. *J. Occup. Environ. Hyg.* **2015**, *12*, 213–221. [CrossRef]
108. Berryman, P.; Lukes, E.; Drew-Nord, D.C.; Hong, O.; Froelicher, E.S. Cardiovascular Risk Factors among Career Firefighters. *AAOHN J.* **2009**, *57*, 415–422. [CrossRef]
109. Choi, B.; Ko, S.; Kojaku, S. Resting heart rate, heart rate reserve, and metabolic syndrome in professional firefighters: A cross-sectional study. *Am. J. Ind. Med.* **2017**, *60*, 900–910. [CrossRef] [PubMed]
110. Williams-Bell, F.M.; Villar, R.; Sharratt, M.T.; Hughson, R.L. Physiological Demands of the Firefighter Candidate Physical Ability Test. *Med. Sci. Sports Exerc.* **2009**, *41*, 653–662. [CrossRef]
111. Lyons, J.; Allsopp, A.; Bilzon, J. Influences of body composition upon the relative metabolic and cardiovascular demands of load-carriage. *Occup. Med.* **2005**, *55*, 380–384. [CrossRef]
112. Lali, H.; Bukmir, L.; Ferhatovi, M. Simulation of Working Conditions by Maximum Work Load on Firefighters. *Coll. Antropol.* **2007**, *31*, 153–158.
113. García-Pinillos, F.; Ruiz-Ariza, A.; Del Castillo, R.M.; Latorre-Román, P.Á. Impact of limited hamstring flexibility on vertical jump, kicking speed, sprint, and agility in young football players. *J. Sports Sci.* **2015**, *33*, 1293–1297. [CrossRef]
114. Butler, R.J.; Contreras, M.; Burton, L.C.; Plisky, P.J.; Goode, A.; Kiesel, K. Modifiable risk factors predict injuries in firefighters during training academies. *Work* **2013**, *46*, 11–17. [CrossRef]

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

CHAPTER FIVE: PUBLICATION FOUR − SYSTEMATIC REVIEW TWO

Association between Cardiovascular Disease Risk Factors and Cardiorespiratory Fitness in Firefighters: A Systematic Review and Meta-Analysis

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

International Journal of
Environmental Research and Public Health

MDPI

Systematic Review

Association between Cardiovascular Disease Risk Factors and Cardiorespiratory Fitness in Firefighters: A Systematic Review and Meta-Analysis

Jaron Ras [1,*], Andre P. Kengne [2], Denise L. Smith [3], Elpidoforos S. Soteriades [4,5] and Lloyd Leach [1]

1 Department of Sport, Recreation and Exercise Science, Faculty of Community and Health Sciences, University of the Western Cape, Cape Town 7535, South Africa
2 Non-Communicable Diseases Research Unit, South African Medical Research Council, Cape Town 7505, South Africa
3 Health and Human Physiological Sciences, Skidmore College, Saratoga Springs, NY 12866, USA
4 Healthcare Management Program, School of Economics and Management, Open University of Cyprus, Nicosia 2220, Cyprus
5 Department of Environmental Health, Environmental and Occupational Medicine and Epidemiology (EOME), Harvard T.H. Chan School of Public Health, Boston, MA 02115, USA
* Correspondence: 3405618@myuwc.ac.za

Abstract: Approximately 45% of on-duty related mortalities were due to sudden cardiac death, with many of these fatalities related to cardiovascular disease and overexertion, while performing emergency duties. Therefore, the aim of this systematic review was to determine the association between cardiovascular disease risk factors and cardiorespiratory fitness in firefighters. A literature search of PubMed, SCOPUS, Web of Science, Embase, EBSCOHost, and ScienceDirect was conducted; the Rayyan® intelligent systematic review tool was used to screen and select studies for inclusion. The appraisal tool for cross-sectional studies and the Critical Appraisal Skills Programme toolkit were used for methodological assessment of included studies. Data were analyzed using the Review Manager 5.3 and MedCalc® statistical softwares to determine the effects of obesity ($Z = 10.29$, $p < 0.001$) and aging ($Z = 4.72$, $p < 0.001$) on cardiorespiratory fitness. Furthermore, there was a significant effect for cardiorespiratory fitness level on systolic blood pressure ($Z = 5.94$, $p < 0.001$), diastolic blood pressure ($Z = 2.45$, $p < 0.001$), total cholesterol levels ($Z = 3.80$, $p < 0.001$), low-density lipoprotein cholesterol ($Z = 4.44$, $p < 0.001$), triglycerides ($Z = 3.76$, $p < 0.001$) and blood glucose concentration ($Z = 4.78$, $p < 0.001$). Cardiovascular disease risk factors and cardiorespiratory fitness were significantly and inversely associated in firefighters. Fire service departments should adopt behavioral intervention strategies to maintain optimum cardiovascular disease risk factor profiles and cardiorespiratory fitness among firefighters to ensure their occupational well-being.

Keywords: firefighters; cardiovascular disease risk factors; cardiorespiratory fitness; aging; obesity; hypertension; dyslipidemia; diabetes; systematic review

check for updates

Citation: Ras, J.; Kengne, A.P.; Smith, D.L.; Soteriades, E.S.; Leach, L. Association between Cardiovascular Disease Risk Factors and Cardiorespiratory Fitness in Firefighters: A Systematic Review and Meta-Analysis. *Int. J. Environ. Res. Public Health* **2023**, *20*, 2816. https://doi.org/10.3390/ijerph20042816

Academic Editors: Marta Ferreiro-González, Gerardo Fernández Barbero and Maria Jose Aliaño-González

Received: 19 December 2022
Revised: 26 January 2023
Accepted: 2 February 2023
Published: 5 February 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Firefighting is an extremely hazardous occupation, where firefighters not only are required to contend with severe temperatures but are also required to perform emergency rescues and are routinely exposed to hazardous chemicals and fumes [1–4]. The hazardous nature of the profession requires firefighters to wear personal protective equipment (PPE), and in some departments, PPE can weigh up to 29.3 kg [5], which places significant strain on firefighters [6–8]. In addition, many firefighters have been reported to have underlying cardiovascular disease (CVD) risk factors, which significantly predispose them to cardiovascular events while on duty [9–12]. This translates into an excessively high mortality rate of nearly 50% related to on-duty sudden cardiac death (SCD) [1–3,13]. This is largely due to the physically demanding nature of their occupation, which requires

http://etd.uwc.ac.za/

firefighters to sustain a high level of physical intensity for prolonged periods, particularly when involved with fire suppression [2,3]. If underlying CVD risk factors are present, this predisposes firefighters to cardiac incidents while on duty [1,4]. Therefore, firefighters are expected to maintain optimum cardiovascular conditioning to reduce the likelihood of duty-related morbidity and mortality [2,3,14,15].

The most prevalent CVD risk factors among firefighters include obesity ranging between 14% and 60% [16–19], hypertension between 10% and 44% [17,20–23], cigarette smoking ranging between 11% and 39% [24–30], dyslipidemia between 20% and 56.5% [17,27,31–33], and physical inactivity between 14.7% and 70% [10,34–39]. These risk factors have been reported to consistently lower cardiorespiratory fitness in firefighters [30,35,40–42], primarily due to reducing vascular elasticity, reducing preload, and increasing afterload, and subsequently, reducing stroke volume and oxygen transportation to working muscles [43–47]. Firefighters, by maintaining their cardiorespiratory fitness through regular physical activity, can reduce their likelihood of CVD events, especially as they age [35,48,49]. Moreover, maintaining a healthy diet can assist in reducing the likelihood of CVD [50–53]. Previous systematic reviews have focused on the impact of firefighting tasks and the physiological responses while completing those tasks [54], and the physiological responses of firefighters that wear PPE and self-contained breathing apparatus gear [8]. Two studies have reported that significant physiological responses occurred while firefighters performed occupational tasks and especially while wearing full PPE and breathing apparatuses [8,54]. We are not aware of systematic reviews conducted on the effect of CVD risk factors on cardiorespiratory fitness in firefighters. The relatively low number of studies published on the effect of CVD risk factors on cardiorespiratory fitness is a concern, given the high number of CVD-related fatalities in firefighters [2,4,13,55]. Crucial new knowledge on the effect of CVD risk factors and which risk factors have the most significant effect on cardiorespiratory fitness is needed to assist in the formulation of policies to assist in maintaining firefighters' cardiovascular health and fitness.

Therefore, this systematic review aimed at determining the association between CVD risk factors and cardiorespiratory fitness in firefighters. The research question guiding this study was: What is the association between CVD risk factors and cardiorespiratory fitness in firefighters?

2. Materials and Methods

Each phase of the screening procedure was completed in accordance with the PRISMA standards for systematic reviews, which are illustrated in a flow diagram [56] (Figure 1). The guidelines for Meta-analysis of Observational Studies in Epidemiology (MOOSE) and Quality of Reporting of Meta-analysis (QUOROM) were utilized to complete the methodology of the current review [56,57].

2.1. Summary of Methods

The exposures assessed included CVD risk factors in relation to cardiorespiratory fitness in firefighters. There were no limitations to the publication year when considering studies for this review.

The inclusion criteria were as follows:

(i) Studies that included full-time, part-time, and volunteer adult male and female firefighters between the ages of 18 and 65 years;
(ii) Cross-sectional, observational, and experimental (intervention) study designs;
(iii) Studies that investigated the association between CVD risk factors or health metrics and cardiorespiratory fitness in firefighters;
(iv) Studies that were available in full text or that could be acquired through a request from the authors.

http://etd.uwc.ac.za/

The exclusion criteria were as follows:

(i) Studies that failed to mention exposure and outcome measures, such as cardiorespiratory fitness and risk factors for cardiovascular disease;
(ii) Various forms of reviews, such as systematic reviews, literature reviews, scoping reviews, etc.;
(iii) Non-English language articles.

The comprehensive systematic review protocol can be found on PROPERO (CRD-42022330510).

2.2. Study Selection, Screening, and Data Management

To find all pertinent papers, the two primary reviewers (J.R. and R.N.) conducted a thorough literature search of Web of Science, SCOPUS, PubMed/Medline, ScienceDirect, and EBSCOHost, using a combination of search terms (Supplementary File S1). Search outputs were compiled into the Zotero™ reference software, where duplicates were then removed. The remaining entries were imported into Rayyan Systems Inc. [58] where the titles and abstracts were screened for eligibility, using the categories of included, excluded, and unsure. Reasons for exclusion were provided as comments for each excluded study. The two principal reviewers used an initial rudimentary data extraction form (Supplementary File S2) to obtain the primary characteristics of each study, which comprised general study information, including authors and affiliations, publication date, study title, design, and country, as well as the exposure evaluated and outcome measures. Then, using a thorough data extraction form, study parameters were retrieved, including the sampling strategy, sample size, and participant's information that included age, height, weight, body mass index (BMI), percentage of body fat, and maximum oxygen consumption (VO_2max) (Supplementary File S3). Lastly, the details of the main exposures and outcomes for the current review were extracted and included CVD risk factors and cardiorespiratory fitness measures. Studies that qualified for the meta-analysis were entered into the Review Manager 5.3 [59] (The Cochrane Collaboration, London, UK) and MedCalc® statistical software Ltd. (Ostend, Belgium, version 20.104).

2.3. Critical Appraisal of Included Studies

The methodological evaluation of the included studies was carried out using the appraisal tool for cross-sectional studies (AXIS checklist) (Table S1, Supplementary File S4) [60] and The Critical Appraisal Skills Programme (CASP) toolkit (Middle Way, Oxford, UK) (Table S2 Supplementary File S4) ((https://casp-uk.net/casp-tools-checklists/) (accessed on 1 September 2021)). For evaluating the quality of cross-sectional studies, it has been demonstrated that the CASP toolkit (Middle Way, Oxford, UK) and the AXIS toolkit are relevant and dependable resources [60,61]. According to the AXIS checklist, each study that was given a score, between 15 and 17 points was considered to be "good" quality and a score from 18 to 19 points was considered to be "high" quality. For the CASP toolkit, all studies were considered to be high quality, as all boxes were ticked.

2.4. Study Selection

The database searches yielded a total of 1881 entries (Figure 1). Of these, 1205 duplicates were removed. Of the remaining 677 studies screened via titles and abstracts, 56 studies met the inclusion criteria, and full texts were screened for final inclusion in the review. Reasons for exclusion included not investigating either the exploratory or outcome variables; studies that were qualitative in design, the main focus of the manuscript not being aligned with the current study, studies that were reviews, and studies that were not available in full-text. Following the full-text screening, 31 papers, in total, were eliminated, leaving 25 studies eligible to move forward with the data extraction and narrative synthesis. The reasons for exclusion included the association between the exploratory variable and the outcome variable not being analyzed. From this, 16 studies were suitable for inclusion in the meta-analysis after data extraction. Nine studies were excluded from the meta-analysis due to

http://etd.uwc.ac.za/

the data not being suitable for the analysis. The reasons for exclusion were, firstly, that studies did not include the means and standard deviation for both the CVD risk factors and the cardiorespiratory fitness measures. Secondly, there were no comparisons made between healthy firefighters and those with CVD risk factors and firefighters with good or poor cardiorespiratory fitness.

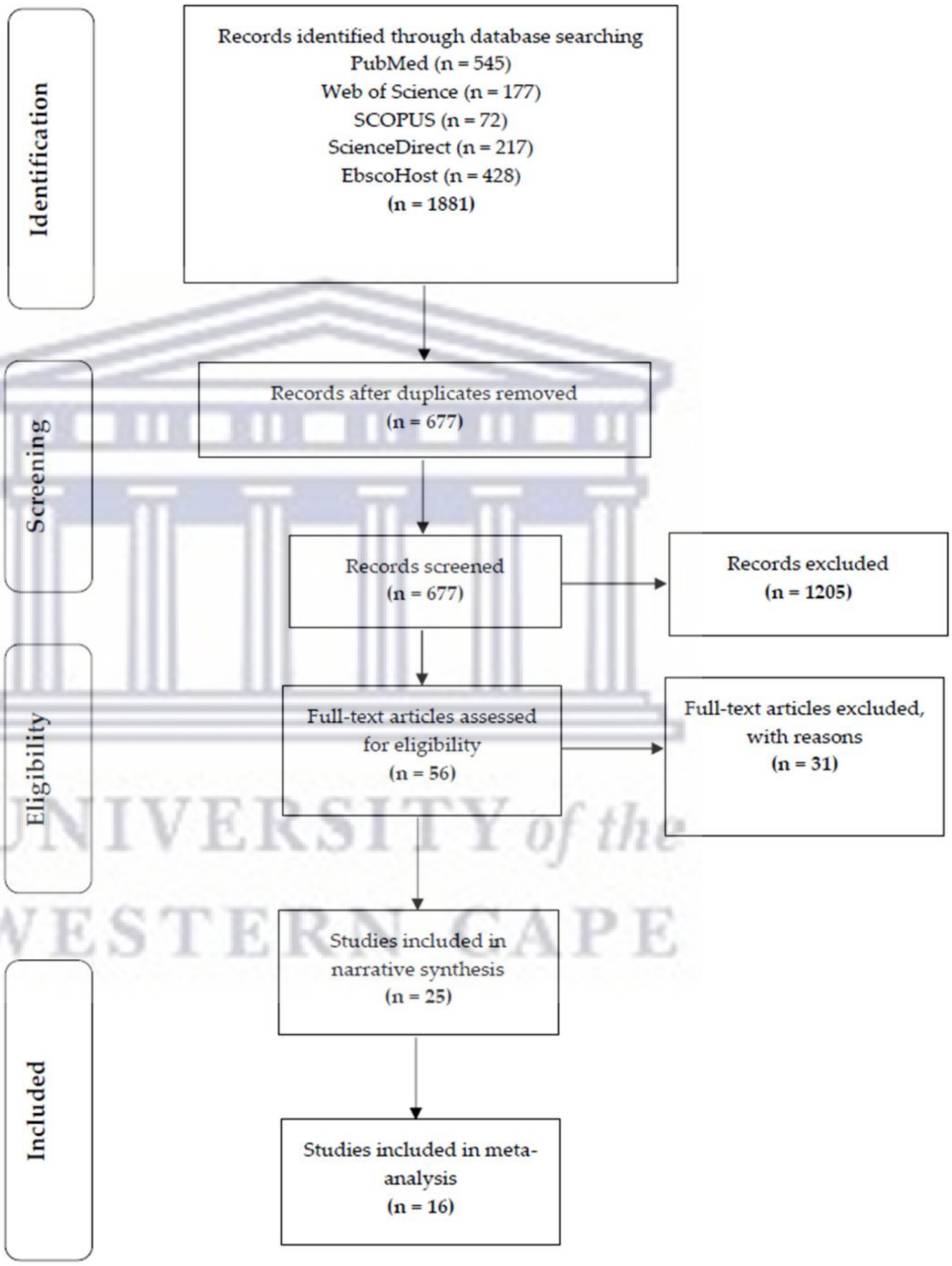


Figure 1. Flow chart of study selection in narrative review [62].

http://etd.uwc.ac.za/

2.5. Data Analysis

2.5.1. Assessment of Overall Effect Size

The data were imported and analyzed using Review Manager 5.3 [59,63–65]. The outcome measure (cardiorespiratory fitness) was analyzed as a continuous variable and dichotomous variable. The mean difference (MD), with a 95% confidence interval (CI) of estimation was used as effect estimates of the association between cardiovascular disease risk factors and cardiorespiratory fitness in firefighters [64]. For cardiorespiratory fitness measures that were dichotomous, the measure of 12 METS or greater was used to classify firefighters as being fit, and less than 12 METS as unfit. A meta-analysis of correlations was conducted using the MedCalc® statistical software Ltd. (Ostend, Belgium, version 20.104). Using the inverse variance approach, the R values from the pooled studies were grouped based on correlation coefficients of similar exposures and outcomes and aggregated into a single, exemplary effect estimate [66]. The following formula was used to convert the original R values to a general test measure using Fisher's "R" to "Z" transformation [66]:

$$Z_{ri} = \frac{1}{2}\ln\left(\frac{1+ri}{1-ri}\right) \quad s\frac{2}{z} = \frac{1}{n-3}$$

To ascertain the correlation between the exposure and the outcome variables, the Fisher's Z values from the original studies were pooled using the random effect model [67].

Interpretation of correlation coefficient strength [67]:

Very high correlation, from 0.90 to 1.00 (−0.90 to −1.00);
High correlation, from 0.70 to 0.90 (−0.70 to −0.90);
Moderate correlation, from 0.50 to 0.70 (−0.50 to −0.70);
Low correlation, from 0.30 to 0.50 (−0.30 to −0.50);
Negligible correlation, from 0.00 to 0.30 (−0.00 to −0.30).

2.5.2. Classification of Cardiovascular Disease Risk Factors and Cardiorespiratory Fitness

Across studies, similar criteria were used to classify CVD risk factors. Age, as a risk factor, was classified as an age ≥45 years for males and ≥55 years for females. Obesity was classified as a body mass index (BMI) ≥30 kg·m^{-2}. Hypertension was classified as a systolic blood pressure ≥140 mm Hg, or a diastolic blood pressure ≥90 mm Hg, or having been previously diagnosed with hypertension by a medical professional. Cigarette smoking was classified as being a current cigarette smoker or having quit within 6 months. Physical inactivity was classified as not exercising at a moderate intensity for at least 30 min, for at least three times a week. Dyslipidemia was classified as a total cholesterol concentration ≥5.18 mmol·L and a low-density lipoprotein ≥3.34 mmol·L or having been diagnosed by a medical professional. Diabetes was classified as a fasting blood glucose concentration ≥7.0 mmol·L or having a diagnosis by a medical professional. Firefighters were classified as being fit by meeting the minimum required cardiorespiratory fitness levels of 12 metabolic equivalents (METS), which is an oxygen consumption (VO_2) of 42 mL·kg·min, that has been accepted as the minimum required cardiorespiratory fitness level needed for the profession. Firefighters that did not meet the 12 METS cut-off were categorized as not meeting the minimum required cardiorespiratory fitness level. Studies using the 12 METs cut-off were categorized as dichotomous variables and the CVD risk factors were continuous. Studies using relative VO_2 were used as a continuous variable and CVD risk factors were used as dichotomous variables.

http://etd.uwc.ac.za/

2.5.3. Assessment of Heterogeneity and Publication Bias

The I^2 and chi-square tests were employed as the two techniques to determine the degree of heterogeneity amongst the included studies [60]. These techniques have been used in previous meta-analyses to evaluate the effect of heterogeneity of the meta-analysis [60].

The following criteria were used to interpret I^2 statistics:

(i) From 0% to 30%, indicated heterogeneity may not be important;
(ii) From 31% to 60%, indicated that there was moderate heterogeneity;
(iii) From 61% to 80%, indicated that there was substantial heterogeneity;
(iv) From 81% to 100%, indicated that there was considerable heterogeneity.

2.5.4. Risk of Bias

The Begg's test and Egger's test were run using the Statistical Package for the Social Sciences (SPSS®, Chicago, IL, USA) version 28 to evaluate the risk of bias in the studies included in the meta-analysis.

2.5.5. Subgroup Analysis and Investigation of Heterogeneity

To account for the presence of heterogeneity, a subgroup analysis was performed to explore the possible sources of the heterogeneity within studies [61]. The subgroup analysis was conducted on studies that used either a treadmill testing protocol, bicycle ergometer protocol, field tests, non-exercise measures, and direct VO_{2max} estimation using gas analysis.

3. Results

3.1. Study Characteristics

The included studies encompassed 21 cross-sectional studies, three cohort studies, and one case-controlled study, conducted between 1991 and 2021, and included a total of 7822 firefighters. Studies were conducted on fire departments located in various regions globally, where multiple variations of cardiorespiratory fitness tests were used to estimate cardiorespiratory fitness. A summary of the included studies is found in Table 1. The detailed critical appraisal of the studies may be found in Supplementary File S4.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Table 1. Characteristics of included studies in the narrative synthesis and quantitative meta-analysis.

References	Study Design and Setting	Sample	Cardiovascular Disease Risk Factors	Cardiorespiratory Fitness	Performance Measures	Outcome
Atikah et al. [67]	Cross-sectional study Malaysia, Kebangsaan	385 Male firefighters	Age: N/A BMI: N/A	VO_2max: 26.49 ± 5.14 mL·kg·min	20 m shuttle run test	The cardiorespiratory fitness of firefighters aged between 20 and 28 years old was significantly higher as compared with firefighters aged between 29 and 37 years old and between 38 and 46 years old.
Baur et al. [68]	Cross-sectional study USA, Massachusetts	957 Male firefighters	Age: 39.6 ± 8.5 years BMI: 29.4 ± 4.3 BF%: 21.6 ± 6.0	MaxMETs: 12.0 ± 1.9 METs	Maximal treadmill exercise stress test	The number of metabolic syndrome risk factors was significantly different between maximum MET groups (<0.00001). Metabolic syndrome was a significant predictor of cardiorespiratory fitness (CRF).
Baur et al. [69]	Cross-sectional study USA, Massachusetts	968 Male firefighters	Age: 39.5 ± 8.6 years BMI: 29.3 ± 4.3 kg·m^{-2} BF%: 21.0 ± 5.6% Cigarette smokers: 23.9% SBP: 122.6 ± 12.0 mmHg DBP: 78.6 ± 8.6 mmHg TC: 5.02 ± 0.96 mmol·L LDL-C: 3.22 ± 0.83 mmol·L HDL-C: 1.13 ± 0.30 mmol·L TG: 1.5 ± 1.3 mmol·L	METs: 12.0 ± 1.9 METs	Maximal treadmill exercise stress test	There were significant associations between max METs and age, BMI, systolic blood pressure (SBP), diastolic blood pressure (DBP), triglycerides, total cholesterol, low-density lipoprotein cholesterol (LDL-C), and blood glucose.
Baur et al. [70]	Cross-sectional study USA	804 Male firefighters	Age: 37.4 ± 8.4 years BMI: 29.3 ± 4.4 kg·m^{-2}	MaxMETs: 10.7 ± 2.0	Maximal treadmill stress test	Cardiorespiratory was significantly related to age, physical activity, and BMI in firefighters.
Barry et al. [49]	Cross-sectional study USA	30 Male firefighters	Age: 34.45 ± 7.15 years Height: 180.74 ± 6.80 cm Body mass: 94.70 ± 10.65 kgs BMI: 28.97 ± 2.52 kg·m^{-2} WC: 96.48 ± 7.95 cm	VO_2max: 40.82 ± 6.95 mL·kg·min	Treadmill graded exercise stress test	There were significant correlations between sedentary time (r = −0.62, $p < 0.001$), vigorous physical activity time (r = −0.48, $p < 0.001$), waist circumference (WC) (r = −0.55, $p < 0.01$), and BMI (r = −0.53, $p < 0.01$) and VO_2max.

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

Table 1. *Cont.*

References	Study Design and Setting	Sample	Cardiovascular Disease Risk Factors	Cardiorespiratory Fitness	Performance Measures	Outcome
Cameron et al. [71]	Cross-sectional study USA, San Diego	1169 Male firefighters	Age: 38.1 ± 0.3 years Height: 178.79 ± 6.65 cm Weight: 88.42 ± 13.36 kgs BMI: 27.65 ± 3.79 kg·m^{-2}	METs: 13.96 ± 2.43 METs	Maximal treadmill graded exercise stress test	Cardiorespiratory fitness was significantly different between age groups in firefighters ($p < 0.001$).
Delisle et al. [72]	Cross-sectional study USA, Florida	30 Male and female firefighters	Age: 31.9 ± 6.4 years BF%: 26.0 ± 6.4% BMI: 27.2 ± 3.8 kg·m^{-2}	VO_2max: 44.6 ± 3.9 mL·kg·min	Bruce treadmill protocol	Cardiorespiratory fitness was significantly and moderately associated with percentage body fat (r = −0.7353, p = 0.0001), DBP (r = −0.541, p = 0.0035), BMI (r = −0.5445, p = 0.003), 1-min recovery HR (r = 0.537, p = 0.0038), and body composition (r = −0.5178; p = 0.008).
Donovan et al. [41]	Cross-sectional study USA, Colorado	214 Male firefighters	Age: 39 ± 9 Height: 179 ± 6 cm Weight: 88 ± 15 kg BMI: 28 ± 4 kg·m^{-2} BF%: 21 ± 7% WC: 94 ± 11 cm SBP: 129 ± 12 mmHg DBP: 83 ± 8 mmHg TG: 1.4 ± 0.9 mmol·L HDL-C: 1.2 ± 0.3 mmol·L FGL: 4.8 ± 0.5 mmol·L CS: 3.7%	VO_2max: 46.3 ± 6.1 mL·kg·min	Bruce treadmill protocol	After controlling for age, cardiorespiratory fitness was inversely associated with increasing metabolic abnormalities ($p < 0.001$). Estimated VO_2max values for firefighters with 0, 1, 2, and 3 metabolic abnormalities were 47.8 mL·kg·min, 47.7 mL·kg·min, 45.2 mL·kg·min, and 43.6 mL·kg·min, respectively. The estimated VO_{2max} for subjects with two, three, or more metabolic abnormalities were found to be significantly lower than that of subjects with zero or one metabolic abnormality.

http://etd.uwc.ac.za/

Table 1. *Cont.*

References	Study Design and Setting	Sample	Cardiovascular Disease Risk Factors	Cardiorespiratory Fitness	Performance Measures	Outcome
Durand et al. [35]	Cross-sectional cohort study USA, Kansas and Missouri	527 Full-time male firefighters	Age: 37.2 ± 8.6 years BMI: 29.3 ± 4.5 kg·m^{-2}	METs: 12.7 ± 1.6 METs	Bruce or modified Bruce protocols	Among the four CRF outcome variables, max-METs was significantly different among the three PA categories after adjusting for age, BMI, and smoking status ($p < 0.001$). The association with CRF was strong across all three measures of PA dimensions, as well as with total weekly aerobic exercise.
Espinoza et al. [73]	Cross-sectional study Chile., South America	76 Volunteer male firefighters	Age: 27.5 years Height: 172 cm BMI: 27.7 kg·m^{-2} SBP: 120 mmHg DBP: 73 mmHg FGL: 5.4 mmol·L	VO_2max: 44 mL·kg·min	Leger test	CRF was negatively correlated with age, BMI, WC, BF%, SBP, DBP, and blood glucose. CRF was significantly different among normal-weight and obese firefighters.
Kirlin et al. [74]	Cross-sectional study USA, San Diego	96 Full-time female firefighters	Age group: 25–34 vs. 35–44 vs. 45–54 vs. 55+ years Height: 170.7 ± 4.9 vs. 169.4 ± 5.4 168.4 ± 5.7 vs. 167.9 ± 4.3 cm Weight: 72.2 ± 10.2 vs. 74.2 ± 13.4 vs. 73.6 ± 13.4 vs. 68.7 ± 9.3 kgs BMI: 24.7 ± 3.3 vs. 25.8 ± 4.4 vs. 25.9 ± 4.4 vs. 24.4 ± 3.8 kg·m^{-2} BF%: 22.9 ± 7.0 vs. 25.1 ± 8.2 vs. 26.7 ± 7.7 vs. 24.0 ± 6.4%	VO_2max: 50.9 ± 7.4 vs. 45.0 ± 7.1 vs. 42.8 ± 6.4 vs. 45.2 ± 5.1 METs: 14.6 ± 2.1 vs. 12.9 ± 2.0 vs. 12.2 ± 1.8 vs. 12.9 ± 1.5 METs	Graded exercise test	CRF decreased significantly across the age groups. Post hoc analysis showed a significantly lower relative VO_2max in the 35–44 age group as compared with the 25–34 age group and in the 45–54 age group as compared with the 25–34 age group. Post hoc analysis of absolute VO_2max revealed a significantly higher CRF in the 25–34 age group as compared with the 35–44 group, the 45–54 age group, and the 55+ group.
Kiss et al. [75]	Cross-sectional study Belgium, Ghent	1249 Firefighters	Age: 38 ± 10 years BF%: 24.6 ± 7.0% BMI: 26.0 ± 3.8 kg·m^{-2}	VO_2max: 46.5 ± 8.8 mL·kg·min	Maximal treadmill exercise stress test	Cardiorespiratory fitness was significantly different between age groups, BF% categories, and BMI categories in firefighters. In addition, age, BF%, and BMI were significant predictors of cardiorespiratory fitness.

http://etd.uwc.ac.za/

Table 1. *Cont.*

References	Study Design and Setting	Sample	Cardiovascular Disease Risk Factors	Cardiorespiratory Fitness	Performance Measures	Outcome
Houck et al. [76]	Cross-sectional study USA, New Mexico	80 Male and female firefighters	Age: 34.9 ± 7.9 years Height: 178.2 ± 6.2 cm Weight: 85.0 ± 12.0 kgs BMI: 26.7 ± 3.0 kg·m^{-2} BF%: 18.7 ± 6.3% SBP: 122.0 ± 8.4 mmHg DBP: 78.3 ± 7.2 mmHg	VO_2max: 38.4 ± 6.8 mL·kg·min	Graded exercise test Bicycle ergometer test	Cardiorespiratory fitness was significantly and negatively associated with BF% (r = −0.597), BMI (r = −0.497), maximal SBP (r = −0.305), maximal DBP (r = 0.262), and resting HR (r = 0.320). Lean body mass was significantly positively correlated with cardiorespiratory fitness (r = 0.576). Results of bivariate logistic regression show that %BF (odds ratio [OR] = 1.24, $p < 0.01$), estimated VO_2 max (OR = 0.90, $p < 0.05$), and metabolic syndrome (OR = 2.66, $p < 0.05$).
Li et al. [77]	Cross-sectional study USA, Colorado	294 Full-time male and female firefighters	Age: 46.88 ± 5.67 years Height: 1.78 ± 0.10 m Weight: 89.2 ± 17.3 kgs BMI: 28.6 ± 10.1 kg·m^{-2} BF%: 23.8 ± 7.01%	VO_2 max: 44.5 ± 5.94 mL·kg·min	Maximal exercise test	The age group ($p < 0.001$) was significantly related to 10-year ASCVD risk. BMI and sex were not significantly associated with 10-year ASCVD risk. No significant association was found between VO_2 max and 10-year ASCVD risk. In total, 49% of firefighters did not meet the minimum cardiorespiratory fitness level of 42.0 mL·kg·min.
Li et al. [78]	Cross-sectional study USA, Colorado	1099 Male and female firefighters	Age: 37.2 ± 9.8 years Male: 37.1 ± 9.8; female 38.0 ± 10.1 BF%: female: 21.1 ± 7.9%; male: 18.4 ± 6.7%	VO_2max: 46.9 ± 6.8 mL·kg·min	Bruce protocol	VO_2 max, body fat values, and age group were significantly associated with the number of metabolic syndrome components among males and body fat values, but VO_2max and age group, were not significantly associated with the number of metabolic syndrome components among females. VO_2 max ($p < 0.001$) was negatively associated with the number of metabolic syndrome components.

http://etd.uwc.ac.za/

Table 1. *Cont.*

References	Study Design and Setting	Sample	Cardiovascular Disease Risk Factors	Cardiorespiratory Fitness	Performance Measures	Outcome
Seyedmedi et al. [30]	Cross-sectional study Iran, Tehran	157 Male firefighters	Age: 34.18 years BMI: 25.61 kg·m^{-2} Aerobic fitness: 33.76 mL·kg^{-1}·min^{-1} SBP: 116.93 mmHg DBP: 76.03 mmHg TC: 5.22 ± 0.72 mmol·L LDL-C: 3.11 ± 0.63 mmol·L HDL-C: 1.02 ± 0.17 mmol·L TG: 1.6 ± 0.7 mmol·L FGL: 5.0 ± 0.6 mmol·L	METs: 9.64 METs	YMCA bicycle ergometer test	Significant differences between individuals with >11 MET versus individuals with <9 MET for all factors with the exception of total cholesterol, fasting blood sugar, and SBP. The high CRF group was significantly younger with lower BMI, triglycerides, LDL, resting heart rate, DBP, and higher HDL. The frequency of subjects with CVD risk factors in the group with AF < 9 MET was significantly higher than that in the group with AF ≥ 9 MET ($p < 0.05$) for all factors except triglycerides. Individuals with low AF were more than 5 times as likely to smoke, not participate in physical activity, and have higher LDL-C levels than firefighters with high AF.
McAllister et al. [79]	Cross-sectional study USA, Texas	46 Full-time firefighters	Age: 37.2 ± 8.9 BF%: 24.1 ± 5.4 BMI: 29.5 ± 5.5 FGL: 5.1 ± 0.6 mmol·L TC: 4.79 ± 0.77 mmol·L LDL-C: 2.97 ± 0.87 mmol·L HDL-C: 1.20 ± 0.34 mmol·L TG: 1.5 ± 1.2 mmol·L	VO_2max: 35.0 ± 9.6	Bruce protocol	There were significant differences among BMI ($p < 0.01$), BF% ($p < 0.001$), cholesterol ($p < 0.05$), triglycerides ($p < 0.001$), HDL-C ($p < 0.05$), and LDL-C ($p < 0.01$) between the low fit and high fit groups.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 1. *Cont.*

References	Study Design and Setting	Sample	Cardiovascular Disease Risk Factors	Cardiorespiratory Fitness	Performance Measures	Outcome
Nogueira et al. [19]	Cross-sectional studyBrazil	4237 Full-time male firefighters	Age: 39 (22–49) years BMI: 26.6 (16.9–43.8) kg·m^{-2} WC: 90.0 cm (55.0–136.0) BAI = 24.9 (10.5–38.3) BF% = 21.7% (14.0–34.3%)	VO_2max: 42.4 mL·kg·min	12 min Cooper test	VO_2max was negatively correlated with age (r = 20.21, $p < 0.001$), WC (r = 20.50, $p < 0.001$), BMI (r = −0.45, $p < 0.001$), and BAI (r = −0.35, $p < 0.001$). The proportion of obese FF among the less fit firefighters was 5.5-fold higher than among the fittest group. Poor cardiorespiratory fitness (<12 METs) was associated with all indices of obesity, i.e., BMI ($p < 0.001$), BAI ($p < 0.001$), BF% (p <0.001), and WC ($p < 0.001$).
Perroni et al. [42]	Cross-sectional study Italy, Rome	161 Male firefighters	Age: 33 ± 7 years Height: 176 ± 6 cm Weight: 75.8 ± 8.4 kgs BMI: 24.4 ± 2.3 kg·m^{-2}	VO_2max: 51.8 ± 6.8 mL·kg·min	Queensland College step test	Age was significantly related to cardiorespiratory fitness in firefighters.
Porto et al. [80]	Cross-sectional study Brazil	38 Firefighters	Age: 41 years BMI: 26.1 kg·m^{-2}	VO_2max: 42.4 mL·kg·min	SRPA questionnaire estimated VO_2max	PNN50, rMSSD, and LHR were significantly different between cardiorespiratory fitness categories. Fitter firefighters had better heart rate variability.
Poston et al. [81]	Cross-sectional study USA, Missouri	478 Full-time and 199 volunteer firefighters	Age: 38.64 ± 10.57 years Height: 178.45 ± 6.45 cm Weight: 92.33 ± 16.47 kgs BMI: 28.86 ± 4.83 kg·m^{-2} BF%: 25.56 ± 6.95% SBP: 125.9 ± 13.2 mmHg DBP: 79.2 ± 10.6 mmHg TC: 4.06 ± 1.03 mmol·L LDL-C: 2.6 ± 0.9 mmol·L HDL-C: 0.98 ± 0.32 mmol·L TG: 1.4 ± 0.9 mmol·L	METs: 10.9 ± 2.5 VO_2max: 37.8 ± 8.1 mL·kg·min	Self-report of physical activity questionnaire	Obese firefighters had significantly lower cardiorespiratory fitness than non-obese firefighters.

http://etd.uwc.ac.za/

Table 1. *Cont.*

References	Study Design and Setting	Sample	Cardiovascular Disease Risk Factors	Cardiorespiratory Fitness	Performance Measures	Outcome
Punakallio et al. [82]	Longitudinal study Finland, Helsinki	78 Full-time male firefighters	Age group: 30–34 vs. 40–44 years Age: 32.5 ± 1.5 vs. 41.8 ± 1.4 years Height: 179.8 ± 6.0 vs. 176.6 ± 5.5 cm Weight: 83.6 ± 8.0 vs. 83.6 ± 8.4 kgs BMI: 25.9 ± 2.2 vs. 26.9 ± 2.7 $kg{\cdot}m^{-2}$ Experience: 10.4 ± 2.5 vs. 19.3 ± 2.3 years	VO_2max: 41.7 ± 6.42 vs. 36.0 ± 5.97 mL·kg·min	Incremental exercise bicycle ergometer test	Age-standardized regular smoking ($p = 0.048$) and the sum of variables related to lifestyle factors ($p = 0.034$) significantly predicted absolute VO_2max after 13 years.
Strauss et al. [40]	Cross-sectional study Germany, Westphalia	97 Full-time male firefighters	Age: 40.5 ± 9.0 years BMI: 25.9 ± 3.2 $kg{\cdot}m^{-2}$ BF%: 17.7 ± 6.2% WC: 89.8 ± 10.0 cm Experience: 16.3 ± 9.1 years SBP: 126.4 ± 9.8 mmHg DBP: 84.1 ± 7.4 mmHg TC: 5.1 ± 0.9 mmol·L LDL-C: 2.9 ± 0.8 mmol·L HDL-C: 1.4 ± 0.3 mmol·L TG: 1.6 ± 0.8 mmol·L	METs: 10.7 ± 1.8 METs	Bicycle spiroergometric exercise stress test	Higher lipid concentrations, DBP, SBP, heart rates, WC, BF%, and years of work experience were inversely related to lower cardiorespiratory fitness levels. Significant associations were present between higher cardiorespiratory fitness and lower BMI ($p < 0.0001$), WC ($p < 0.0001$), BF% ($p < 0.0001$), SBP ($p = 0.0061$), triglycerides ($p = 0.0018$), and total cholesterol levels ($p = 0.0443$).

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 1. *Cont.*

References	Study Design and Setting	Sample	Cardiovascular Disease Risk Factors	Cardiorespiratory Fitness	Performance Measures	Outcome
Vandersmissen et al. [83]	Cross-sectional study Belgium	605 Full-time male firefighters	Age: 40.4 ± 11.5 years BMI: 25.9 ± 3.4 kg·m^{-2} WC: 92.3 ± 10.3 cm HRmax: 99.7 ± 7.6 bpm	VO_2max: 43.3 ± 9.8 mL·kg·min	Maximal treadmill and bicycle ergometer exercise stress test	Cardiorespiratory capacity was significantly related to age ($p < 0.001$), BMI ($p < 0.001$), and WC ($p < 0.001$). Firefighters older than 45 years and those that were obese or had central obesity had a mean VO_2max under 42 mL·kg·min.
Vicente et al. [84]	Cross-sectional study Italy	104 Full-time male firefighters	Age: 47.1 ± 6.8 years BMI: 26.6 ± 2.5 kg·m^{-2} BF%: 22.9 ± 5.0 SBP: 125.4 ± 21 mmHg DBP: 88.9 ± 21.6 mmHg	VO_2max: 45.7.3 ± 7.0 mL·kg·min	Shuttle test	CRF was significantly different between the age group categories ($p < 0.001$). There was a significant negative correlation between CRF and age (r = −0.50, $p < 0.01$).

Note: Units of measurements: m—meters; cm—centimeters; kgs—kilograms; VO_2—oxygen consumption; VO_{2max}—maximum oxygen consumption; HR—heart rate; BMI—body mass index; WC—waist circumference; BF%—body fat percentage; BAI—body adiposity index; kg·m^{-2}—kilograms per meter squared; mL·kg·min.- milliliters per kilogram per minute; bmp—beats per minute; SBP—systolic blood pressure; DBP—diastolic blood pressure; TC—total cholesterol; LDL-C—low-density lipoprotein cholesterol; HDL-C—high-density lipoprotein cholesterol; TG—triglycerides; FBG—fasting blood glucose; PNN50—successive normal sinus (NN) intervals exceeding 50 ms, rMSSD—root mean square root of successive differences; LHR—low/high-frequency ratio; ASCVD—atherosclerotic cardiovascular disease.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

3.2. The Association between Aging and Cardiorespiratory Fitness in Firefighters

Aged firefighters had a significantly worse cardiorespiratory fitness level as compared with younger firefighters [71–75,83,84]. In addition, aged firefighters were less likely to meet the minimum cardiorespiratory requirements for firefighting. In Figure 2A, age had a significant negative pooled random effect on cardiorespiratory fitness (MD = −7.59 mL·kg·min, Z = 4.94, $p < 0.001$) [71,74,75,83,84], with substantial heterogeneity ($I^2 = 96\%$), but no indication of publication bias ($p = 0.623$) (Figure S2C: Supplementary File S5). After subgroup analysis, heterogeneity remained at a considerable level ($I^2 = 72\%$) for non-treadmill testing. Not meeting the minimum cardiorespiratory fitness level had a significant positive pooled random effect on age in firefighters (MD = 9.33 years, Z = 5.94, $p < 0.001$) [30,40,69] (Figure 2B), with considerable heterogeneity present ($I^2 = 65\%$) between studies; however, there was no evidence of publication bias (Egger's test $p = 0.263$) (Figure S2D: Supplementary File S5). After subgroup analysis, heterogeneity was reduced to 0% when a bicycle ergometer testing protocol was used.

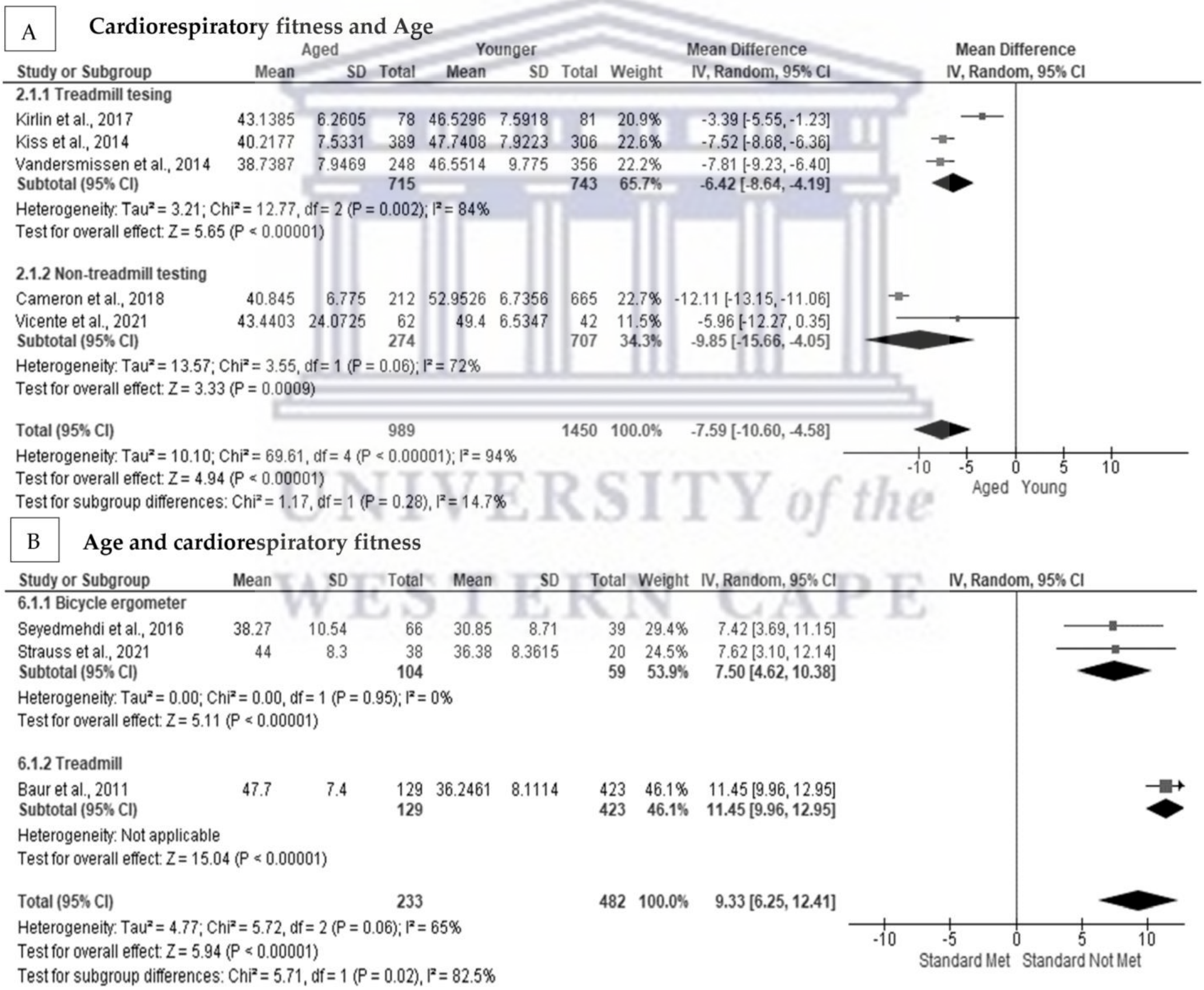


Figure 2. The association between age and cardiorespiratory fitness in firefighters: (**A**) The association between age and cardiorespiratory fitness with subgroup analysis [71,74,75,83,84]; (**B**) the association between cardiorespiratory fitness and age with subgroup analysis [30,40,69].

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

3.3. The Association between Obesity and Cardiorespiratory Fitness in Firefighters

Obese firefighters had reduced cardiorespiratory fitness, with many of them not meeting the minimum recommended requirement of 42 mL·kg·min for active duty [19,49,72,73,75,79,83–86]. In Figure 3A, we show that obesity had a significant nega- tive pooled random effect on cardiorespiratory fitness (MD = −8.24 mL·kg·min, Z = 10.29, $p < 0.001$) [19,73,75,83,85], with considerable heterogeneity between studies ($I^2 = 87\%$), and no indication of publication bias (Egger's Test $p = 0.089$) (Figure S3C: Supplementary File S5). After subgroup analysis, there was homogeneity ($I^2 = 0\%$) present between studies when cardiorespiratory fitness was assessed using a treadmill protocol. The effect remained for obese as compared with non-obese firefighters on cardiorespiratory fitness (MD = −8.09 mL·kg·min, Z = 15.64, $p < 0.001$) [73,85]. In Figure 3B, not meeting the minimum cardiorespiratory fitness level had a significant positive pooled random effect on BMI (MD = 2.72 kg·m^{-2}, Z = 5.62, $p < 0.001$) [30,40,69,79], with moderate heterogeneity between studies ($I^2 = 64\%$); however, no indication of publication bias was seen (Egger's test $p = 0.598$) (Figure S3D: Supplementary File S5). After subgroup analysis, heterogeneity was reduced ($I^2 = 31\%$) when a treadmill testing protocol was used to estimate cardiorespiratory fitness.

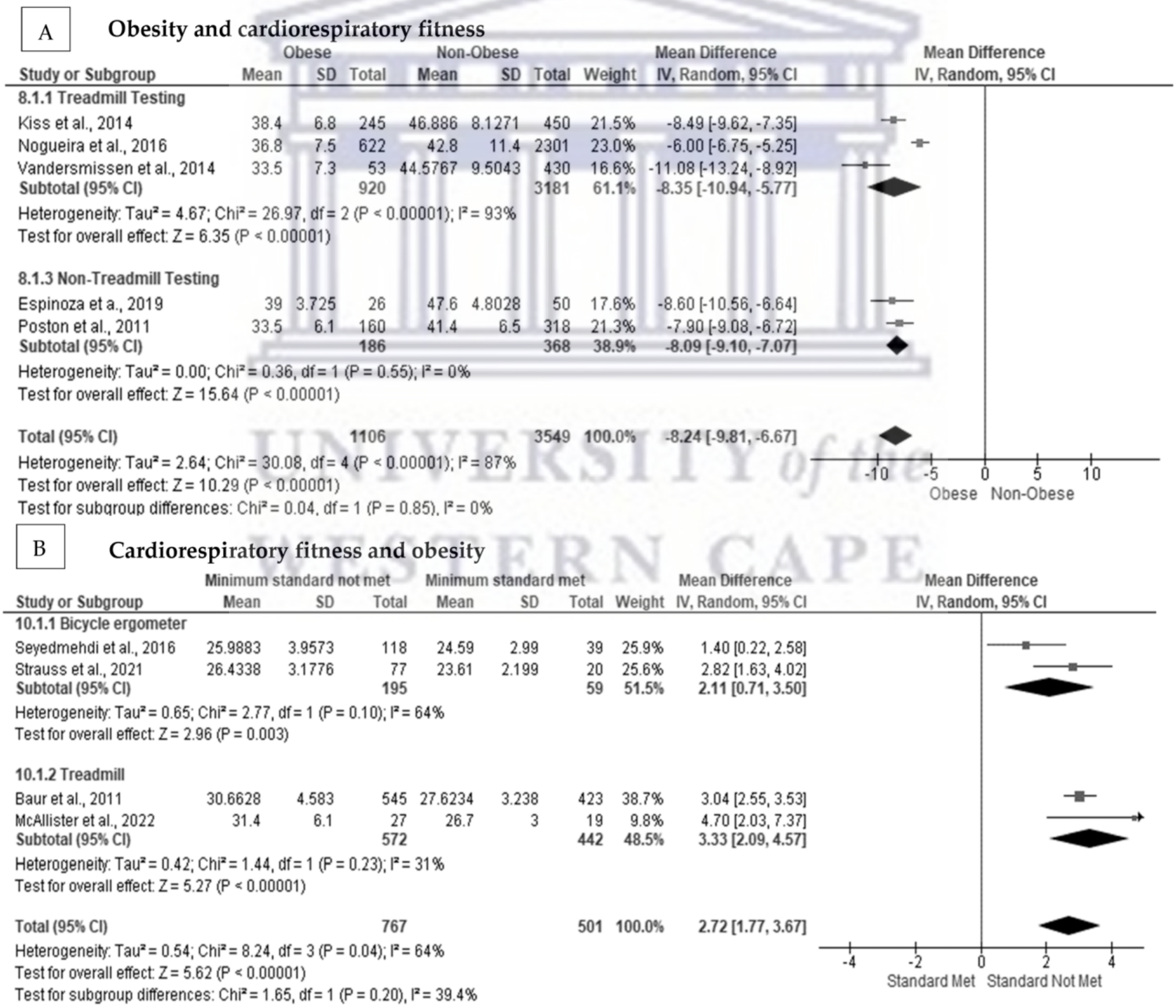


Figure 3. The association between obesity status on cardiorespiratory fitness in firefighters: (**A**) The association between obesity status and cardiorespiratory fitness with subgroup analysis [19,73,75,83,85]; (**B**) the association between cardiorespiratory fitness and BMI with subgroup analysis [30,40,69,79].

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

3.4. The Effect of Cardiorespiratory Fitness on Blood Pressure in Firefighters

Systolic and diastolic blood pressure significantly and inversely influenced the cardiorespiratory fitness in firefighters [30,40,69,72,73,79]. Furthermore, higher blood pressure measurements reduced the overall cardiorespiratory fitness in firefighters since those with higher blood pressure were less likely to meet the minimum cardiorespiratory requirements for firefighting. In Figure 4A, not meeting the minimum cardiorespiratory fitness level had a significant positive pooled random effect on systolic blood pressure (MD = 5.69 mm Hg, Z = 5.94, $p < 0.001$) [30,40,69], with no heterogeneity between studies ($I^2 = 0\%$) (Figure S4C, Supplementary File S5). Not meeting the minimum cardiorespiratory fitness level had a significant positive pooled random effect on diastolic blood pressure in firefighters (MD = 3.43 mm Hg, Z = 2.45, $p = 0.01$) (Figure 4B) [30,40,69] with considerable heterogeneity present ($I^2 = 63\%$) between studies; however, there was no evidence of publication bias (Egger's test $p = 0.269$) (Figure S4D, Supplementary File S5). After subgroup analysis, heterogeneity was reduced to 0% when a bicycle ergometer testing protocol was used. The effect remained significant for cardiorespiratory fitness levels on diastolic blood pressure after subgroup analysis (MD = 5.01 mm Hg, Z = 3.95, $p < 0.001$) [30,40].

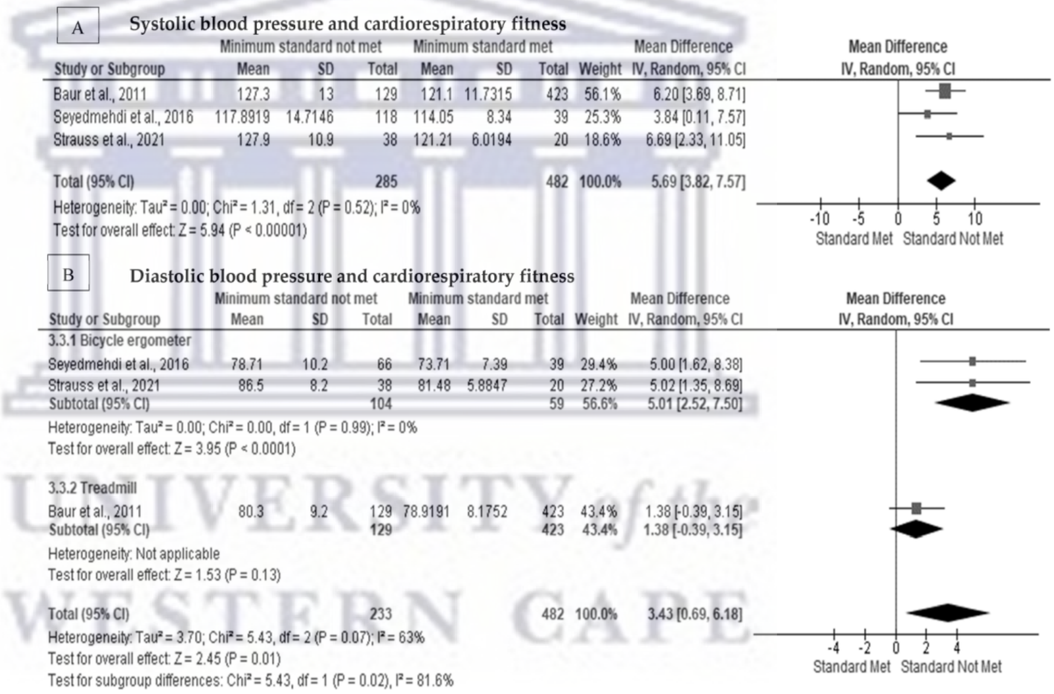


Figure 4. The association between cardiorespiratory fitness and blood pressure in firefighters: (**A**) The association between cardiorespiratory fitness and systolic blood pressure [30,40,69]; (**B**) the association between cardiorespiratory fitness and diastolic blood pressure with subgroup analysis [30,40,69].

3.5. The Effect of Cardiorespiratory Fitness on Blood Cholesterol Concentration in Firefighters

Total cholesterol was significantly related to cardiorespiratory fitness in firefi- ghters [30,40,69,79]. In addition, LDL-C [30,40,69,79] and triglycerides [30,40,69,79] were significantly and negatively related to cardiorespiratory fitness, with those firefighters being less likely to meet the minimum cardiorespiratory fitness requirements for firefighting. The meta-analysis indicated that there was a significant positive pooled random effect for not meeting the minimum cardiorespiratory fitness level on total cholesterol concentration in firefighters (MD = 0.39 mmol·L, Z = 3.80, $p < 0.001$) [30,40,69,79] (Figure 5A), with moderate heterogeneity among the studies ($I^2 = 52\%$), but there was no indication of publication bias (Egger's Test $p = 0.312$, Figure S5D, Supplementary File S5). After subgroup analysis, heterogeneity was reduced ($I^2 = 37\%$) when testing used a bicycle ergometer protocol but remained moderate. Not meeting the minimum cardiorespiratory fitness

http://etd.uwc.ac.za/

level had a significant pooled random effect on LDL-C concentration (MD = 0.30 mmol·L, Z = 4.44, p < 0.001) [30,40,69,79] (Figure 5B), with low heterogeneity among the included studies (I^2 = 12%). There was a significant pooled effect for not meeting the minimum cardiorespiratory fitness on triglyceride concentration in firefighters (MD = 0.51 mmol·L, Z = 3.76, p < 0.001] [30,40,69,79] (Figure 5C), with considerable heterogeneity (I^2 = 69%) among the studies; however, there was no evidence of publication bias (Egger's test p = 0.144) (Figure S5F, Supplementary File S5). Heterogeneity was not removed following subgroup analysis (I^2 = 75%).

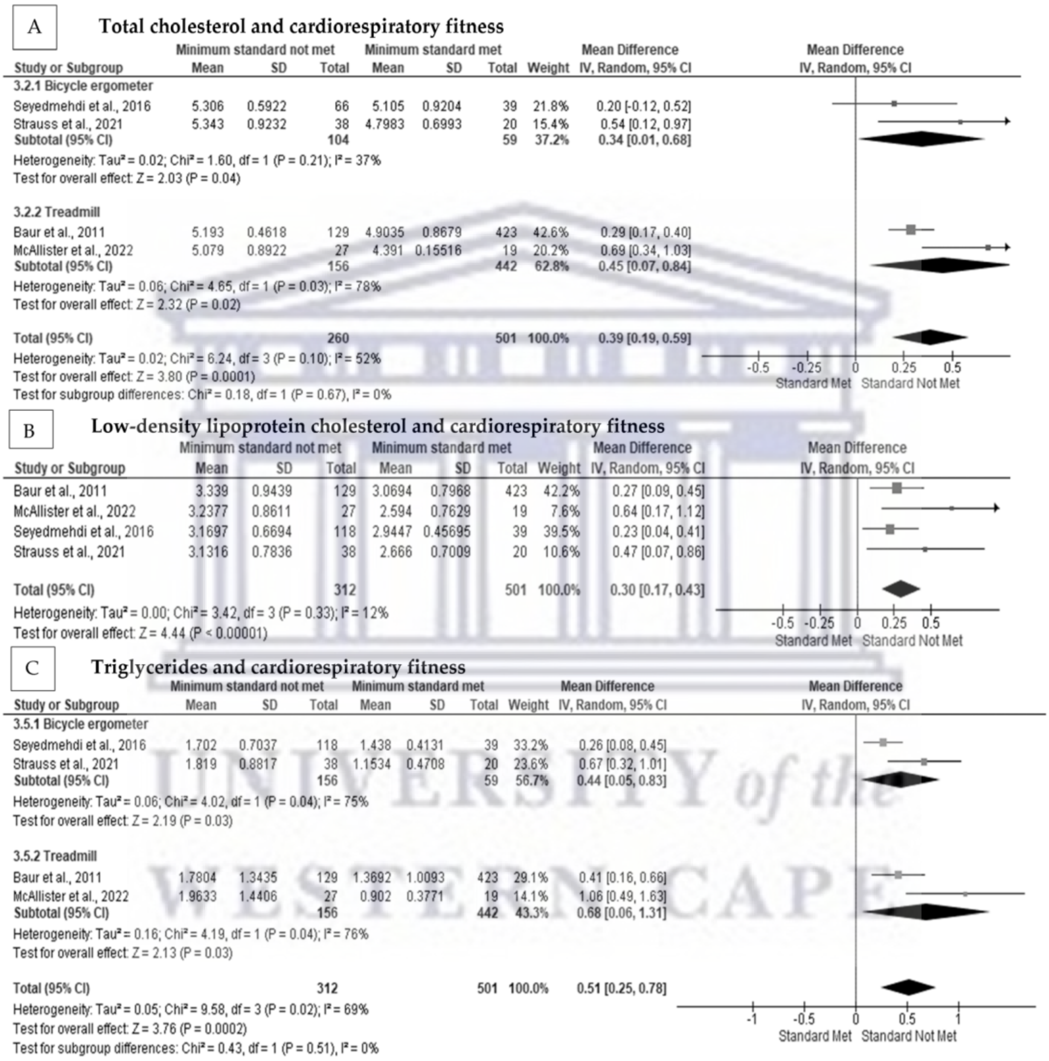


Figure 5. The association between cardiorespiratory fitness and blood lipid concentrations in firefighters: (**A**) The association between cardiorespiratory fitness and total cholesterol concentration with subgroup analysis [30,40,69,79]; (**B**) the association between cardiorespiratory fitness and low-density lipoprotein concentration with subgroup analysis [30,40,69,79]; (**C**) the association between cardiorespiratory fitness and triglyceride concentration with subgroup analysis [30,40,69,79].

3.6. The Effect of Cardiorespiratory Fitness on Blood Glucose in Firefighters

Blood glucose was significantly and negatively related to cardiorespiratory fitness in firefighters [30,69,73,79]. There was a significant positive pooled random effect for cardiorespiratory fitness on blood glucose concentration in firefighters (MD = 0.32 mmol·L, Z = 2.33, p < 0.001) [30,69,79] (Figure 6A). There was considerable heterogeneity (I^2 = 72%) present among the studies (Figure S6B, Supplementary File S5), but there was no indication

http://etd.uwc.ac.za/

of publication bias (Egger's test $p = 0.362$). After subgroup analysis, heterogeneity was not reduced ($I^2 = 81\%$).

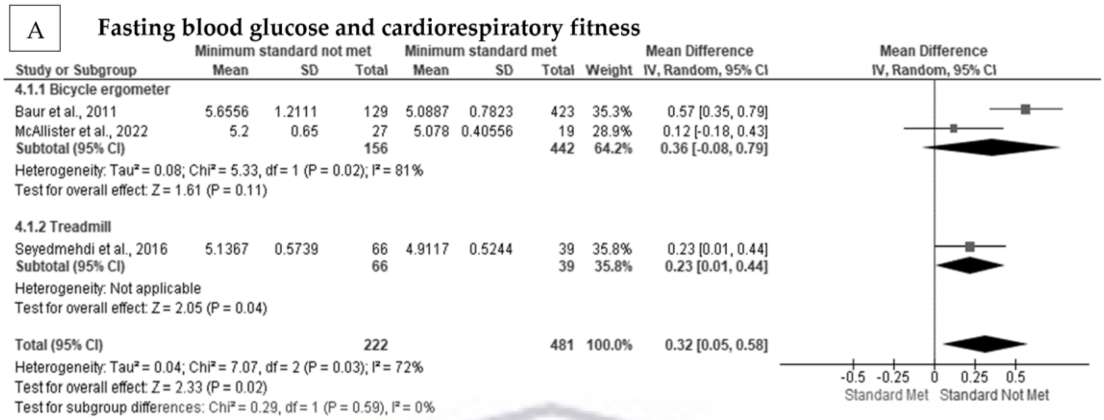


Figure 6. The association between cardiorespiratory fitness and blood glucose in firefighters: (**A**) The association between cardiorespiratory fitness and blood glucose concentration [30,69,79].

3.7. The Associations between Cigarette Smoking, Physical Inactivity, CVD Risk, and Heart Rate Variability and Cardiorespiratory Fitness in Firefighters

Punakallio et al. [82] and Durand et al. [35] reported that cigarette smoking was significantly associated with cardiorespiratory fitness in firefighters. Physical inactivity was significantly related to cardiorespiratory fitness in firefighters [35]. Li et al. [77] reported that overall, the 10-year ASCVD risk was not significantly related to cardiorespiratory fitness, after controlling for BF% in firefighters. Metabolic syndrome and an increasing number of cardiometabolic risk factors were significantly and negatively related to cardiorespiratory fitness in firefighters [41,70,78]. Porto et al. [80] reported that the number of times the change in successive normal sinus intervals exceeds 50 ms (PNN50), the root mean square of successive differences between normal heartbeats (rMSSD), and low-frequency and high-frequency ratio (LHR) were significantly different between cardiorespiratory fitness levels.

3.8. Correlations between Cardiovascular Disease Risk Factors and Cardiorespiratory Fitness

In Table 2, there was a significantly low negative correlation between age and cardiorespiratory fitness ($R = -0.471$, $p < 0.001$) [72,73,75], with moderate heterogeneity ($I^2 = 47\%$). After subgroup analysis, homogeneity ($I^2 = 0\%$) was present among the studies, when treadmill testing was used to assess cardiorespiratory fitness. There was a significantly moderate negative correlation between obesity and cardiorespiratory fitness ($R = -0.595$, $p < 0.001$) [49,72,73,75,76,84,86] with substantial heterogeneity ($I^2 = 77\%$) among the studies. In subgroup analysis, there was no heterogeneity between studies using a cycle ergometer for testing ($I^2 = 0\%$). There was a significantly high negative correlation between central obesity and cardiorespiratory fitness ($R = -0.715$, $p < 0.001$) [49,73], with considerable heterogeneity ($I^2 = 80\%$) among the studies. There was a significantly moderate nega- tive correlation between body-fat percentage and cardiorespiratory fitness ($R = -0.663$, $p < 0.001$) [72,73,76,84], moderate heterogeneity ($I^2 = 55\%$) among the studies, and no indication of publication bias (Egger's test $p = 0.455$). Heterogeneity was reduced ($I^2 = 27\%$) following subgroup analysis on testing procedures that used a cycle ergometer. There was a significantly negligible negative correlation between systolic blood pressure and cardiorespiratory fitness ($R = -0.190$, $p = 0.007$) [72,73,84], with homogeneity ($I^2 = 0\%$) present among the studies. There was a significantly low negative correlation between diastolic blood pressure and cardiorespiratory fitness ($R = -0.267$, $p = 0.028$) [72,73,84], with moderate heterogeneity ($I^2 = 47\%$) present among the studies and no indication of publication bias (Egger's test $p = 0.089$). Heterogeneity was not reduced in subgroup analysis.

http://etd.uwc.ac.za/

Table 2. The correlations between age, obesity, and blood pressure and cardiorespiratory fitness.

Outcome	No. of Studies	No. of Participants	R (95% CI)	Z Score	*p* (Overall Effect)	Heterogeneity I^2; Cohen's Q; *p*-Value	Egger's Test Intercept (95%CI); *p*	Begg's Test (τ; *p*)
Age	4	1434	−0.471 (−0.562 to −0.369)	−8.073	<0.001 **	47%; 5.66; 0.129	1.72 (−0.65 to 4.10); 0.089	0.67; 0.174
Treadmill testing	2	105	−0.334 (−0.497 to −0.150)	−3.460	0.001 **	0%; 0.24; 0.628	1.40 (–); <0.001	1.00; 0.317
Gas analysis	2	1254	−0.451 (−0.654 to −0.188)	−3.215	0.001 **	63%; 2.67; 0.102	1.93 (–); <0.001	1.00; 0.317
Obesity	7	1632	−0.595 (−0.681 to −0.493)	−9.263	<0.001 **	73%; 22.08; <0.001	−1.28 (−4.12 to 1.57); 0.301	−0.19; 0.538
Treadmill testing	3	1330	−0.645 (−0.819 to −0.362)	−3.879	<0.001 **	90%; 20.89; <0.001	−2.71 (−42.69 to 37.28); 0.548	−0.33; 0.602
Non-Treadmill testing	4	302	−0.560 (−0.634 to −0.476)	−10.769	<0.001 **	0%; 1.03; 0.793	0.59 (−6.08 to 7.27); 0.739	0.33, 0.602
Gas analysis	3	245	−0.658 (−0.808 to −0.428)	−4.652	<0.001 **	85%; 13.57; 0.001	−34.02 (−691.86 to 623.82); 0.629	−0.33; 0.602
Central obesity	2	105	−0.715 (−0.884 to −0.3810	−3.543	<0.001 **	80%; 4.96; 0.026	6.43 (–); <0.001	1.00; 0.317
Body-fat percentage	4	290	−0.663 (−0.753 to −0.550)	−8.640	<0.001 **	55%; 6.62; 0.085	−3.26 (−18.49 to 11.98); 0.455	−0.67; 0.174
Cycle ergometer testing	2	110	−0.639 (−0.739 to −0.511)	−7.715	<0.001 **	27%; 1.37; 0.241	−3.34 (–); <0.001	−1.00; 0.317
Systolic blood pressure	3	209	−0.190 (−0.319 to −0.053)	−2.716	0.007 **	0%; 0.37; 0.829	−0.49 (−17.06 to 16.08); 0.772	−0.33; 0.602
Treadmill testing	2	105	−0.230 (−0.406 to −0.0367)	−2.326	0.020 *	0%; 0.03; 0.854	0.53 (–); <0.001	1.00; 0.317
Diastolic blood pressure	3	209	−0.267 (−0.475 to −0.030)	−2.202	0.028 *	47; 1.72; 0.129	1.72 (−0.65 to 4.10); 0.089	0.67; 0.174
Treadmill testing	2	105	−0.375 (−0.622 to −0.059)	−2.310	0.021 *	57%; 2.33; 0.127	−4.41 (–); <0.001	−1.00; 0.317

Note: * indicates significant <0.05; ** indicates significant <0.01. Italics—indicates subgroup analysis.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

4. Discussion

4.1. Summary of Evidence

To the best of the authors' knowledge, this is the first systematic review and meta-analysis performed to examine the relationship between CVD risk factors and cardiorespiratory fitness in firefighters. The results indicated that CVD risk factors had a statistically significant and inverse association with cardiorespiratory fitness in firefighters. This was particularly true for age, obesity, blood pressure, and blood lipid concentration. Collectively, having a better overall cardiovascular disease risk profile may have a compounded effect on firefighters' health, significantly improving their overall cardiorespiratory fitness and reducing their on-duty risks.

4.2. Cardiovascular Disease Risk Factors and Cardiorespiratory Fitness

Aged firefighters had poorer cardiorespiratory fitness as compared with younger firefighters. In addition, firefighters that did not meet the minimum required cardiorespiratory fitness were older than those who met the minimum required cardiorespiratory fitness level. Aging causes a decrease in vascular elasticity, which may negatively affect blood flow toward muscles [87,88]. In addition, the atrial and ventricular chambers of the heart show reduced elasticity [46,89], which negatively affects stroke volume and reduces blood flow toward the working muscles [88,89]. Furthermore, aging has been shown to reduce muscle functions, particularly those related to muscular force production [46]. Research has indicated that firefighters tend to become more physically inactive as they age, which may assist in the steady decline in cardiorespiratory fitness seen in this population with time [35,48,49].

The results of our systematic review and meta-analysis indicated that obese firefighters had a significantly lower cardiorespiratory fitness level as compared with non-obese firefighters. In addition, firefighters that did not meet the minimum cardiorespiratory fitness levels had a higher BMI than those that met the requirement. Previous system- atic reviews have indicated that obesity significantly reduced cardiorespiratory fitness in sportsmen [90,91] and emergency occupations alike [8,92,93]. Moreover, obesity has been shown to increase the incidence of duty-related fatalities in firefighters [2]. Obesity increases non-functional mass in firefighters that are required to be carried. Increased peripheral resistance subsequently increases blood pressure, which reduces atrial preload, negatively affecting stroke volume and oxygen uptake to working muscles [47,94]. Increased fat mass increases the effort of respiratory muscles to expand the rib cage, reducing the available oxygen content toward working muscles [95]. Firefighters are required to carry additional weight while on duty [5], and therefore, firefighters are required to have a much higher cardiorespiratory fitness to cope with these stressors [6,83,96]. Obese firefighters who carry additional heavy protective gear may be significantly predisposed to poorer occupational performance [6,83,96] and significantly higher cardiorespiratory strain [3].

Firefighters that met the minimum cardiorespiratory standard had lower systolic and diastolic blood pressure than firefighters that did not meet the minimum requirements. Increased blood pressure, due to reduced vascular elasticity and increased total peripheral resistance, directly reduced stroke volume [97]. As mentioned previously, a reduction in stroke volume diminishes the quantity of oxygen transported to working muscles, limiting oxygen usage and energy production [43,97]. Firefighters should maintain normal and preferably optimal blood pressure levels throughout their careers to maintain adequate cardiorespiratory fitness levels, through multiple interventions.

In the present study, firefighters that did not meet the minimum cardiorespiratory fitness standard for firefighting had significantly higher concentrations for total cholesterol, LDL-C, triglycerides, and blood glucose. The current results were supported by previous literature that indicated physical fitness was significantly related to LDL-C and triglyceride concentrations [45,98,99]. Rumora et al. [100] reported that high LDL-C levels impaired mitochondrial function, by reducing oxygen uptake and subsequently reducing aerobic

http://etd.uwc.ac.za/

capacity. Physical activity was reported to improve blood lipid concentrations, specifically in reducing LDL-C and increasing HDL-C [99]. In addition, previous reviews have indicated that blood glucose and diabetes were significantly related to cardiorespiratory fitness [44,101]. The prevalence of diabetes is relatively low in firefighters; however, diabetes may have the highest overall impact on their overall cardiorespiratory fitness levels among the haematological parameters [9,12,27,30,33,69,102].

In previous studies, cigarette smoking and physical activity were investigated in relation to cardiorespiratory fitness in firefighters; however, insufficient studies were available to perform a meta-analysis. The results indicated that cigarette smoking was significantly related to declining cardiorespiratory fitness levels in firefighters over time. This was supported by the results of previous systematic reviews that indicated cigarette smoking negatively affected the cardiorespiratory fitness of healthy adult males [103]. In addition, exposure to passive smoke was also related to reduced cardiorespiratory fitness [103]. Physical inactivity, especially in obese firefighters, was significantly related to poorer cardiorespiratory fitness in firefighters. This is supported by a previous systematic review in young adults, where longer duration of physical activity sessions and higher frequency of physical activity were significantly related to cardiorespiratory fitness [104]. Only one study was found that investigated the overall effect of cardiovascular risk status on cardiorespiratory fitness in firefighters, indicating that a significant gap exists. This has been proven in previous research where higher cardiorespiratory fitness improved overall cardiovascular risk and all-cause mortality [105,106]. Similar to overall cardiovascular disease risk, only one study was found that investigated heart rate variability and cardiorespiratory fitness. The results indicated that heart rate variability increased as cardiorespiratory fitness increased, suggesting that optimal cardiovascular health was related to higher levels of cardiorespiratory fitness [80].

4.3. Strengths and Limitations

The overall quality of the studies that were included in our review was high, with most studies being above a score of eighteen. This study provided valuable evidence in an understudied research field in firefighters. An inherent weakness is that insufficient studies have investigated all the cardiovascular disease risk factors in firefighters, specifically cigarette smoking, physical inactivity, and a family history of cardiovascular disease. In addition, only one study used an overall risk score to determine cardiovascular risk on cardiorespiratory fitness. Several studies that were included did not include a selection procedure that would allow researchers to choose individuals who were representative of the intended population and the sample frame was not taken from an appropriate population base. A limited number of studies were available for many of the analyses, reducing the strength of the inferences that could be made. Lastly, cardiorespiratory fitness was not consistently measured in the same way, which likely contributed to the heterogeneity of results that could not be explained through subgroup analysis.

5. Conclusions

The current systematic review and meta-analysis support previous findings suggesting that firefighters need to maintain optimum cardiovascular health and cardiorespiratory fitness throughout their careers. As the reciprocal relationship indicated, this will re- duce the likelihood of firefighters' cardiorespiratory fitness dropping below the minimum requirements for firefighting. Decreased cardiorespiratory fitness was attributed to the development and progression of CVD risk factors, which was most notable in firefighters not meeting the minimum recommended fitness level. Given that firefighters actively maintain their cardiorespiratory fitness levels, this is expected to have a positive effect on their cardiovascular health, subsequently reducing the risk of CVD-related morbidity and mortality. Fire and Rescue departments should promote regular physical activity and behavioral medication programs designed to not only increase the cardiorespiratory fitness of firefighters but improve their overall cardiovascular health status. It is recommended

http://etd.uwc.ac.za/

that fire departments should adopt scheduled physical activity or exercise programs while firefighters are on-duty and should ensure that firefighters are regularly assessed to measure their cardiorespiratory health. Future research should focus on the collective effect that an increased CVD risk status may have on cardiorespiratory fitness in firefighters. In addition, more studies should be conducted on cardiorespiratory fitness in relation to total fitness. i.e., muscular endurance, muscular strength, flexibility, and body composition. Few studies investigated the relationship between heart rate variability and cardiorespiratory fitness, indicating a significant research gap in this particular area.

6. Patents

Protocol Registration

Details of the protocol for this systematic review were registered on PROSPERO (CRD42022330510) and can be accessed at: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42022330510 (accessed on 18 December 2022).

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ijerph20042816/s1, Supplementary File S1: Search strategy; Supplementary File S2: Data extraction form; Supplementary File S3: Data extraction form; Supplementary File S4: Table S1. critical appraisal of cross-sectional studies (adapted from the appraisal tool for cross-sectional studies checklist); Table S2: Critical Appraisal Skills Programme of cohort and case-controlled studies (adapted from the Critical Appraisal Skills Programme). Supplementary File S5: Figure S2C: Funnel plot for publication bias; Figure S2D: Funnel plot for publication bias; Figure S3C: Forest plot for publication bias; Figure S3D: Forest plot for publication bias; Figure S4C: Forest plot for publication bias; Figure S4D: Forest plot for publication bias; Figure S5D: Forest plot for publication bias; Figure S5E: Forest plot for publication bias; Figure S5F: Forest plot for publication bias; Figure S6B: Forest plot for publication bias.

Author Contributions: Conceptualization, J.R. and L.L.; methodology, J.R. and A.P.K.; software, J.R.; validation, J.R., L.L., A.P.K., D.L.S. and E.S.S.; formal analysis, J.R.; investigation, J.R.; resources, J.R.; data curation, J.R.; writing—original draft preparation, J.R.; writing—review and editing, J.R., L.L., A.P.K., D.L.S. and E.S.S.; visualization, J.R L.L., A.P.K., D.L.S. and E.S.S.; supervision, L.L., A.P.K., D.L.S. and E.S.S.; project administration, J.R., L.L., A.P.K., D.L.S. and E.S.S.; funding acquisition, J.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Research Foundation (NRF), grant number 141282 and The Ryoichi Sasakawa Young Leaders Fellowship Fund (SLYFF).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data generated or analyzed during this study are included in the published review article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Smith, D.L.; Haller, J.M.; Korre, M.; Sampani, K.; Porto, L.G.G.; Fehling, P.C.; Christophi, C.A.; Kales, S.N. The Relation of Emergency Duties to Cardiac Death Among US Firefighters. *Am. J. Cardiol.* **2019**, *123*, 736–741. [CrossRef] [PubMed]
2. Smith, D.L.; Barr, D.A.; Kales, S.N. Extreme Sacrifice: Sudden Cardiac Death in the US Fire Service. *Extrem. Physiol. Med.* **2013**, *2*, 6. [CrossRef] [PubMed]
3. Smith, D.L.; DeBlois, J.P.; Kales, S.N.; Horn, G.P. Cardiovascular Strain of Firefighting and the Risk of Sudden Cardiac Events. *Exerc. Sport Sci. Rev.* **2016**, *44*, 90–97. [CrossRef] [PubMed]
4. Soteriades, E.S.; Smith, D.L.; Tsismenakis, A.J.; Baur, D.M.; Kales, S.N. Cardiovascular Disease in US Firefighters: A Systematic Review. *Cardiol. Rev.* **2011**, *19*, 202–215. [CrossRef]
5. Henderson, N.D.; Berry, M.W. Field Measures of Strength and Fitness Predict Firefighter Performance on Physically Demanding Tasks. *Pers. Psychol.* **2007**, *60*, 431–473. [CrossRef]
6. Marcel-Millet, P.; Ravier, G.; Grospretre, S.; Gimenez, P.; Freidig, S.; Groslambert, A. Physiological Responses and Parasympathetic Reactivation in Rescue Interventions: The Effect of the Breathing Apparatus. *Scand. J. Med. Sci. Sports* **2018**, *28*, 2710–2722. [CrossRef]

http://etd.uwc.ac.za/

7. Taylor, N.A.S.; Lewis, M.C.; Notley, S.R.; Peoples, G.E. A Fractionation of the Physiological Burden of the Personal Protective Equipment Worn by Firefighters. *Eur. J. Appl. Physiol.* **2012**, *112*, 2913–2921. [CrossRef]
8. Li, J.; Wang, Y.; Jiang, R.; Li, J. Quantifying Self-Contained Breathing Apparatus on Physiology and Psychological Responses during Firefighting: A Systematic Review and Meta-Analysis. *Int. J. Occup. Saf. Ergon.* **2022**. [CrossRef]
9. Ras, J.; Leach, L. Prevalence of Coronary Artery Disease Risk Factors in Firefighters in the City of Cape Town Fire and Rescue Service–A Descriptive Study. *J. Public Health Res.* **2021**, *10*. [CrossRef]
10. Risavi, B.L.; Staszko, J. Prevalence of Risk Factors for Coronary Artery Disease in Pennsylvania (USA) Firefighters. *Prehosp. Disaster. Med.* **2015**, *31*, 102–107. [CrossRef]
11. Smith, D.L.; Graham, E.; Stewart, D.; Mathias, K.C. Cardiovascular Disease Risk Factor Changes Over 5 Years Among Male and Female US Firefighters. *J. Occup. Environ. Med.* **2020**, *62*, 398–402. [CrossRef] [PubMed]
12. Drew-Nord, D.C.; Hong, O.S.; Froelicher, E.S. Cardiovascular Risk Factors among Career Firefighters. *AAOHN J.* **2009**, *57*, 415–424. [CrossRef] [PubMed]
13. Farioli, A.; Yang, J.; Teehan, D.; Baur, D.M.; Smith, D.L.; Kales, S.N. Duty-Related Risk of Sudden Cardiac Death among Young US Firefighters. *Occup. Med. (Chic Ill)* **2014**, *64*, 428–435. [CrossRef] [PubMed]
14. Smith, D.L. Firefighter Fitness: Improving Performance and Preventing Injuries and Fatalities. *Curr. Sports Med. Rep.* **2011**, *10*, 167–172. [CrossRef]
15. Smith, D.L.; Haller, J.M.; Benedict, R.; Moore-merrell, L. Cardiac Strain Associated with High-Rise Firefighting. *J. Occup. Environ. Hyg.* **2015**, *12*, 213–221. [CrossRef]
16. Soares, E.M.K.V.K.; Smith, D.; Grossi Porto, L.G. Worldwide Prevalence of Obesity among Firefighters: A Systematic Review Protocol. *BMJ Open* **2020**, *10*, e031282. [CrossRef]
17. Choi, B.K.; Steiss, D.; Garcia-Rivas, J.; Kojaku, S.; Schnall, P.; Dobson, M.; Baker, D. Comparison of Body Mass Index with Waist Circumference and Skinfold-Based Percent Body Fat in Firefighters: Adiposity Classification and Associations with Cardiovascular Disease Risk Factors. *Int. Arch. Occup Environ. Health* **2016**, *89*, 435–448. [CrossRef]
18. Damacena, F.C.; Batista, T.J.; Ayres, L.R.; Zandonade, E.; Sampaio, K.N. Obesity Prevalence in Brazilian Firefighters and the Association of Central Obesity with Personal, Occupational and Cardiovascular Risk Factors: A Cross-Sectional Study. *BMJ Open* **2020**, *10*, e032933. [CrossRef]
19. Nogueira, E.C.; Porto, L.G.G.; Nogueira, R.M.; Martins, W.R.; Fonseca, R.M.C.; Lunardi, C.C.; de Oliveira, R.J. Body Composition Is Strongly Associated with Cardiorespiratory Fitness in a Large Brazilian Military Firefighter Cohort: The Brazilian Firefighters Study. *J. Strength Cond. Res.* **2016**, *30*, 33–38. [CrossRef]
20. Choi, B.K.; Schnall, P.; Dobson, M. Twenty-Four-Hour Work Shifts, Increased Job Demands, and Elevated Blood Pressure in Professional Firefighters. *Int. Arch. Occup. Environ. Health* **2016**, *89*, 1111–1125. [CrossRef]
21. Choi, B.; Dobson, M.; Schnall, P.; Garcia-Rivas, J. 24-Hour Work Shifts, Sedentary Work, and Obesity in Male Firefighters. *Am. J. Ind. Med.* **2016**, *59*, 486–500. [CrossRef] [PubMed]
22. Soteriades, E.S.; Hauser, R.; Kawachi, I.; Christiani, D.C.; Kales, S.N. Obesity and Risk of Job Disability in Male Firefighters. *Occup. Med. (Chic Ill)* **2008**, *58*, 245–250. [CrossRef] [PubMed]
23. Nor, N.; Lee, C.J.; Park, K.S.; Chang, S.-J.; Kim, C.; Park, S. The Risk of Mortality and Cardiovascular Disease is Increased in Firefighters with Elevated Blood Pressure Compared to the General Population. *J. Hypertens* **2019**, *37*, e11. [CrossRef]
24. Jitnarin, N.; Haddock, C.K.; Poston, W.S.C.; Jahnke, S. Smokeless Tobacco and Dual Use among Firefighters in the Central United States. *J. Environ. Public Health* **2013**, *2013*, 675426. [CrossRef]
25. Haddock, C.K.; Jitnarin, N.; Poston, W.S.C.; Tuley, B.; Jahnke, S.A. Tobacco Use among Firefighters in the Central United States. *Am. J. Ind. Med.* **2011**, *54*, 697–706. [CrossRef] [PubMed]
26. Planinc, N.; Kokalj-Kokot, M.; Pajk, A.; Zupet, P. P-100 Analysis of Voluntary Firefighters' Health Status in Slovenia. *Br. J. Sports Med.* **2016**, *50*, A88–A89. [CrossRef]
27. Martin, Z.T.; Schlaff, R.A.; Hemenway, J.K.; Coulter, J.R.; Knous, J.L.; Lowry, J.E.; Ode, J.J. Cardiovascular Disease Risk Factors and Physical Fitness in Volunteer Firefighters. *Int. J. Exerc. Sci.* **2019**, *12*, 764–776.
28. Noh, J.; Lee, C.J.; Hyun, D.S.; Kim, W.; Kim, M.J.; Park, K.S.; Koh, S.; Chang, S.J.; Kim, C.; Park, S. Blood Pressure and the Risk of Major Adverse Cardiovascular Events among Firefighters. *J. Hypertens* **2020**, *38*, 850–857. [CrossRef]
29. Leary, D.B.; Takazawa, M.; Kannan, K.; Khalil, N. Perfluoroalkyl Substances and Metabolic Syndrome in Firefighters: A Pilot Study. *J. Occup. Environ. Med.* **2020**, *62*, 52–57. [CrossRef]
30. Seyedmehdi, S.M.; Attarchi, M.; Cherati, A.S.; Hajsadeghi, S.; Tofighi, R.; Jamaati, H. Relationship of Aerobic Fitness with Cardiovascular Risk Factors in Firefighters. *Work* **2016**, *55*, 155–161. [CrossRef]
31. Byczek, L.; Walton, S.M.; Conrad, K.M.; Reichelt, P.A.; Samo, D.G. Implications for Occupational Health Nurse Practice. *Aaohn* **2004**, *52*, 66–77. [CrossRef]
32. Cohen, H.W.; Zeig-Owens, R.; Joe, C.; Hall, C.B.; Webber, M.P.; Weiden, M.D.; Cleven, K.L.; Jaber, N.; Skerker, M.; Yip, J.; et al. Long-Term Cardiovascular Disease Risk Among Firefighters After the World Trade Center Disaster. *JAMA Netw. Open* **2019**, *2*, e199775. [CrossRef]
33. Smith, D.L.; Fehling, P.C.; Frisch, A.; Haller, J.M.; Winke, M.; Dailey, M.W. The Prevalence of Cardiovascular Disease Risk Factors and Obesity in Firefighters. *J. Obes.* **2012**, *2012*, 908267. [CrossRef]

http://etd.uwc.ac.za/

34. Mehrdad, R.; Movasatian, F.; Momenzadeh, A.S. Fitness for Work Evaluation of Firefighters in Tehran. *Acta Med. Iran.* **2013**, *51*, 265–269.
35. Durand, G.; Tsismenakis, A.J.; Jahnke, S.A.; Baur, D.M.; Christophi, C.A.; Kales, S.N. Firefighters' Physical Activity: Relation to Fitness and Cardiovascular Disease Risk. *Med. Sci. Sports Exerc.* **2011**, *43*, 1752–1759. [CrossRef] [PubMed]
36. Cavalcante Neto, J.L.; Calheiros, D.d.S.; Calheiros, D. dos S.; Neto, T. dos S.; Pinto, M.P.; da Rocha, D.F. Levels of Physical Activity and Associated Factors between Military Policemen and Firemen. *Work* **2019**, *62*, 515–521. [CrossRef] [PubMed]
37. Eastlake, A.C.; Knipper, B.S.; He, X.; Alexander, B.M.; Davis, K.G. Lifestyle and Safety Practices of Firefighters and Their Relation to Cardiovascular Risk Factors. *Work* **2015**, *50*, 285–294. [CrossRef] [PubMed]
38. Amodeo, K.L.; Nickelson, J. Predicting Intention to Be Physically Active among Volunteer Firefighters. *Am. J. Health Educ.* **2020**, *51*, 1–13. [CrossRef]
39. Soteriades, E.S.; Psalta, L.; Leka, S.; Spanoudis, G. Occupational Stress and Musculoskeletal Symptoms in Firefighters. *Int. J. Occup. Med. Environ Health* **2019**, *32*, 341–352. [CrossRef]
40. Strauss, M.; Foshag, P.; Jehn, U.; Brzęk, A.; Littwitz, H.; Leischik, R. Higher Cardiorespiratory Fitness Is Strongly Associated with Lower Cardiovascular Risk Factors in Firefighters: A Cross-Sectional Study in a German Fire Brigade. *Sci. Rep.* **2021**, *11*, 2445. [CrossRef]
41. Donovan, R.; Nelson, T.; Peel, J.; Lipsey, T.; Voyles, W.; Israel, R.G. Cardiorespiratory Fitness and the Metabolic Syndrome in Firefighters. *Occup. Med. (Chic Ill)* **2009**, *59*, 487–492. [CrossRef] [PubMed]
42. Perroni, F.; Cignitti, L.; Cortis, C.; Capranica, L. Physical Fitness Profile of Professional Italian Firefighters: Differences among Age Groups. *Appl. Ergon.* **2014**, *45*, 456–461. [CrossRef] [PubMed]
43. McArdle, W.D.; Katch, F.I.; Katch, V.L. *Exercise Physiology: Nutrition, Energy, and Human Performance*; Lippincott Williams & Wilkins: Phillidelphia, PH, USA, 2010; ISBN 0781797810.
44. Carbone, S.; del Buono, M.G.; Ozemek, C.; Lavie, C.J. Obesity, Risk of Diabetes and Role of Physical Activity, Exercise Training and Cardiorespiratory Fitness. *Prog. Cardiovasc. Dis.* **2019**, *62*, 327–333. [CrossRef]
45. Karelis, A.D.; Pasternyk, S.M.; Messier, L.; St-Pierre, D.H.; Lavoie, J.-M.; Garrel, D.; Rabasa-Lhoret, R. Relationship between Insulin Sensitivity and the Triglyceride–HDL-C Ratio in Overweight and Obese Postmenopausal Women: A MONET Study. *Appl. Physiol. Nutr. Metab.* **2007**, *32*, 1089–1096. [CrossRef]
46. Kajuluri, L.P.; Singh, K.; Morgan, K.G. Vascular Aging, the Vascular Cytoskeleton and Aortic Stiffness. *Explor. Med.* **2021**, *2*, 186–197. [CrossRef] [PubMed]
47. Alpert, M.A.; Lavie, C.J.; Agrawal, H.; Kumar, A.; Kumar, S.A. Cardiac Effects of Obesity: Cardiac Effects of Obesity: Pathophysiologic, clinical, and prognostic consequences—A review. *J. Cardiopulm Rehabil. Prev.* **2016**, *36*, 1–11. [CrossRef]
48. Yu, C.C.W.; Au, C.T.; Lee, F.Y.F.; So, R.C.H.; Wong, J.P.S.; Mak, G.Y.K.; Chien, E.P.; McManus, A.M. Association between Leisure Time Physical Activity, Cardiopulmonary Fitness, Cardiovascular Risk Factors, and Cardiovascular Workload at Work in Firefighters. *Saf. Health Work* **2015**, *6*, 192–199. [CrossRef]
49. Barry, A.M.; Lyman, K.J.; Dicks, N.D.; Landin, K.D.; McGeorge, C.R.; Hackney, K.J.; Walch, T.J. Firefighters' Physical Activity and Waist Circumference as Predictors of VO_{2max}. *J. Occup. Environ. Med.* **2019**, *61*, 849–853. [CrossRef]
50. Yang, J.; Farioli, A.; Korre, M.; Kales, S.N. Dietary Preferences and Nutritional Information Needs among Career Firefighters in the United States. *Glob. Adv. Health Med.* **2015**, *4*, 16–23. [CrossRef]
51. Christodoulou, A.; Sotos-Prieto, M.; Kales, S.N.; Christophi, C.A. Dietary Patterns and Their Association with Cardio-Metabolic Outcomes in US Firefighters. *Eur. J. Public Health* **2020**, *30*, ckaa165-717. [CrossRef]
52. Bucala, M.; Sweet, E. Obesity in the Fire Service: An inside Look at the Perceptions of Firefighters towards Obesity and Other Health Issues. *Res. Sq.* **2019**. [CrossRef]
53. Dobson, M.; Choi, B.; Schnall, P.L.; Wigger, E.; Garcia-Rivas, J.; Israel, L.; Baker, D.B. Exploring Occupational and Health Behavioral Causes of Firefighter Obesity: A Qualitative Study. *Am. J. Ind. Med.* **2013**, *56*, 776–790. [CrossRef] [PubMed]
54. Nazari, G.; Lu, S.; MacDermid, J.C. Quantifying Physiological Responses during Simulated Tasks among Canadian Firefighters: A Systematic Review and Meta-Analysis. *J. Mil. Veteran. Fam. Health* **2021**, *7*, 55–75. [CrossRef]
55. Yang, J.; Teehan, D.; Farioli, A.; Baur, D.M.; Smith, D.; Kales, S.N. Sudden Cardiac Death among Firefighters ≤45 Years of Age in the United States. *Am. J. Cardiol.* **2013**, *112*, 1962–1967. [CrossRef]
56. Stroup, D.F.; Berlin, J.A.; Morton, S.C.; Olkin, I.; Williamson, G.D.; Rennie, D.; Moher, D.; Becker, B.J.; Sipe, T.A.; Thacker, S.B.; et al. Meta-Analysis of Observational Studies in EpidemiologyA Proposal for Reporting. *JAMA* **2000**, *283*, 2008–2012. [CrossRef]
57. Brand, R.A. Editorial: Standards of Reporting: The CONSORT, QUORUM, and STROBE Guidelines. *Clin. Orthop Relat. Res.* **2009**, *467*, 1393–1394. [CrossRef]
58. Ouzzani, M.; Hammady, H.; Fedorowicz, Z.; Elmagarmid, A. Rayyan-a Web and Mobile App for Systematic Reviews. *Syst. Rev.* **2016**, *5*, 210. [CrossRef]
59. Collaboration, C. *Review Manager (RevMan)*; Version 5.3; The Nordic Cochrane Centre: Copenhagen, Denmark, 2014.
60. Downes, M.J.; Brennan, M.L.; Williams, H.C.; Dean, R.S. Development of a Critical Appraisal Tool to Assess the Quality of Cross-Sectional Studies (AXIS). *BMJ Open* **2016**, *6*, e011458. [CrossRef]
61. Sanderson, S.; Tatt, I.D.; Higgins, J.P.T. Tools for Assessing Quality and Susceptibility to Bias in Observational Studies in Epidemiology: A Systematic Review and Annotated Bibliography. *Int. J. Epidemiol.* **2007**, *36*, 666–676. [CrossRef]

http://etd.uwc.ac.za/

62. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; Group, T.P. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef]
63. Haidich, A.B. Meta-Analysis in Medical Research. *Hippokratia* **2010**, *14*, 29–37.
64. Gurevitch, J.; Koricheva, J.; Nakagawa, S.; Stewart, G. Meta-Analysis and the Science of Research Synthesis. *Nature* **2018**, *555*, 175–182. [CrossRef]
65. Lin, L. Comparison of Four Heterogeneity Measures for Meta-Analysis. *J. Eval. Clin. Pract.* **2020**, *26*, 376–384. [CrossRef]
66. Akkaya-Hocagil, T. *Meta-Analysis: Methods for Health and Experimental Studies*; Springer Nature Pte. Ltd.: Berlin/Heidelberg, Germany, 2020; p. 293.
67. Atikah, C.W.; Nihayah, M.; Leonard, J.H.; Omar, B.; Noor Ibrahim, M.S.; Zurkarnain, M.K.; Jamri, M.; Wan Mohd Noor, I. A Cross-Sectional Evaluation on Physical Fitness of Malaysian Firefighters. *Sains Malays.* **2015**, *44*, 1461–1466. [CrossRef]
68. Baur, D.M.; Leiba, A.; Christophi, C.A.; Kales, S.N. Low Fitness Is Associated with Exercise Abnormalities among Asymptomatic Firefighters. *Occup. Med.* **2012**, *62*, 566–569. [CrossRef] [PubMed]
69. Baur, D.M.; Christophi, C.A.; Tsismenakis, A.J.; Cook, E.F.; Kales, S.N. Cardiorespiratory Fitness Predicts Cardiovascular Risk Profiles in Career Firefighters. *J. Occup. Environ. Med.* **2011**, *53*, 1155–1160. [CrossRef] [PubMed]
70. Baur, D.M.; Christophi, C.A.; Kales, S.N. Metabolic syndrome is inversely related to cardiorespiratory fitness in male career firefighters. *J. Strength Cond. Res.* **2012**, *26*, 2331–2337. [CrossRef]
71. Cameron, N.A.; Shen, J.; Rusk, K.; Parker, R.; Godino, J.G.; Nichols, J.F. Longitudinal Decline in Cardiorespiratory Fitness with Age among Male Firefighters in San Diego, California, 2005-2015. *Am. J. Public Health* **2018**, *108*, 1388–1393. [CrossRef]
72. Delisle, A.T.; Piazza-Gardner, A.K.; Cowen, T.L.; Sayedul Huq, M.B.; Delisle, A.D.; Stopka, C.B.; Tillman, M.D. Validation of a cardiorespiratory fitness assessment for firefighters. *J. Strength Cond. Res.* **2014**, *28*, 2717–2723. [CrossRef]
73. Espinoza, F.; Delgado-Floody, P.; Martínez-Salazar, C.; Jerez-Mayorga, D.; Guzmán-Guzmán, I.P.; Caamaño-Navarrete, F.; Ramirez-Campillo, R.; Chamorro, C.; Campos-Jara, C. The Influence of Cardiometabolic Risk Factors on Cardiorespiratory Fitness in Volunteer Chilean Firefighters. *Am. J. Hum. Biol.* **2019**, *31*, e23280. [CrossRef]
74. Kirlin, L.K.; Nichols, J.F.; Rusk, K.; Parker, R.A.; Rauh, M.J. The Effect of Age on Fitness among Female Firefighters. *Occup. Med.* **2017**, *67*, 528–533. [CrossRef]
75. Kiss, P.; de Meester, M.; Maes, C.; de Vriese, S.; Kruse, A.; Braeckman, L. Cardiorespiratory Fitness in a Representative Sample of Belgian Firefighters. *Occup. Med.* **2014**, *64*, 589–594. [CrossRef]
76. Houck, J.M.; Mermier, C.M.; Beltz, N.M.; Johnson, K.E.; VanDusseldorp, T.A.; Escobar, K.A.; Gibson, A.L. Physical Fitness Evaluation of Career Urban and Wildland Firefighters. *J. Occup. Environ. Med.* **2020**, *62*, e302–e307. [CrossRef] [PubMed]
77. Li, K.; Ochoa, E.; Lipsey, T.; Nelson, T. Correlates of Atherosclerotic Cardiovascular Disease Risk in Older Colorado Firefighters. *Occup. Med.* **2018**, *68*, 51–55. [CrossRef]
78. Li, K.; Lipsey, T.; Leach, H.J.; Nelson, T.L. Cardiac Health and Fitness of Colorado Male/Female Firefighters. *Occup. Med.* **2017**, *67*, 268–273. [CrossRef]
79. McAllister, M.J.; Gonzalez, D.E.; Leonard, M.; Martaindale, M.H.; Bloomer, R.J.; Pence, J.; Martin, S.E. Firefighters with Higher Cardiorespiratory Fitness Demonstrate Lower Markers of Cardiovascular Disease Risk. *J. Occup. Environ. Med.* **2022**, *64*, 1036–1040. [CrossRef] [PubMed]
80. Porto, L.G.G.; Schmidt, A.C.B.; de Souza, J.M.; Nogueira, R.M.; Fontana, K.E.; Molina, G.E.; Korre, M.; Smith, D.L.; Junqueira, L.F.; Kales, S.N. Firefighters' Basal Cardiac Autonomic Function and Its Associations with Cardiorespiratory Fitness. *Work* **2019**, *62*, 485–495. [CrossRef] [PubMed]
81. Poston, W.S.C.; Haddock, C.K.; Jahnke, S.A.; Jitnarin, N.; Tuley, B.C.; Kales, S.N. The Prevalence of Overweight, Obesity, and Substandard Fitness in a Population-Based Firefighter Cohort. *J. Occup. Environ. Med.* **2011**, *53*, 266–273. [CrossRef]
82. Punakallio, A.; Lindholm, H.; Luukkonen, R.; Lusa, S. Lifestyle Factors Predicting Changes in Aerobic Capacity of Aging Firefighters at 3-and 13-Year Follow-Ups. *J. Occup. Environ. Med.* **2012**, *54*, 1133–1141. [CrossRef]
83. Vandersmissen, G.J.M.; Verhoogen, R.A.J.R.; van Cauwenbergh, A.F.M.; Godderis, L. Determinants of Maximal Oxygen Uptake (VO_{2max}) in Fire Fighter Testing. *Appl. Ergon.* **2014**, *45*, 1063–1066. [CrossRef]
84. Vicente, M.M.; Herrero, D.C.; Prieto, J.P. Cardiorespiratory Fitness in Spanish Firefighters. *J. Occup. Environ. Med.* **2021**, *63*, e318–e322. [CrossRef] [PubMed]
85. Poston, W.S.C.; Jitnarin, N.; Haddock, C.K.; Jahnke, S.A.; Tuley, B.C. Obesity and Injury-Related Absenteeism in a Population-Based Firefighter Cohort. *Obesity* **2011**, *19*, 2076–2081. [CrossRef] [PubMed]
86. Chizewski, A.; Box, A.; Kesler, R.; Petruzzello, S.J. Fitness Fights Fires: Exploring the Relationship between Physical Fitness and Firefighter Ability. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11733. [CrossRef] [PubMed]
87. Rogers, M.A.; Hagberg, J.M.; Martin, W.H.; Ehsani, A.A.; Holloszy, J.O. Decline in VO_2max with Aging in Master Athletes and Sedentary Men. *J. Appl. Physiol.* **1990**, *68*, 2195–2199. [CrossRef]
88. Harridge, S.D.R.; Lazarus, N.R. Physical Activity, Aging, and Physiological Function. *Physiology* **2017**, *32*, 152–161. [CrossRef]
89. Craighead, D.H.; Freeberg, K.A.; Seals, D.R. The Protective Role of Regular Aerobic Exercise on Vascular Function with Aging. *Curr. Opin. Physiol.* **2019**, *10*, 55–63. [CrossRef]
90. Suarez-Arrones, L.; Lara-Lopez, P.; Maldonado, R.; Torreno, N.; de Hoyo, M.; Nakamura, F.Y.; di Salvo, V.; Mendez-Villanueva, A. The Effects of Detraining and Retraining Periods on Fat-Mass and Fat-Free Mass in Elite Male Soccer Players. *PeerJ* **2019**, *7*, e7466. [CrossRef]

http://etd.uwc.ac.za/

91. Robertson, N.; Vohora, R. Fitness vs. Fatness: Implicit Bias towards Obesity among Fitness Professionals and Regular Exercisers. *Psychol. Sport Exerc.* **2008**, *9*, 547–557. [CrossRef]
92. Myhre, L.G.; Tucker, D.M.; Bauer, D.H.; Fisher, J.R., Jr.; Grimm, W.H. Relationship Between Selected Measures of Physical Fitness and Performance of a Simulated Fire Fighting Emergency Task. *Armstrong Lab Brooks Afb Tx* **1997**.
93. Hauschild, V.D.; de Groot, D.W.; Hall, S.M.; Grier, T.L.; Deaver, K.D.; Hauret, K.G.; Jones, B.H. Fitness Tests and Occupational Tasks of Military Interest: A Systematic Review of Correlations. *Occup. Environ. Med.* **2017**, *74*, 144–153. [CrossRef]
94. Khan, A.; van Iterson, E.H.; Laffin, L.J. The Obesity Paradox in Heart Failure: What Is the Role of Cardiorespiratory Fitness? *Cleve. Clin. J. Med.* **2021**, *88*, 449–458. [CrossRef] [PubMed]
95. Arena, R.; Cahalin, L.P. Evaluation of Cardiorespiratory Fitness and Respiratory Muscle Function in the Obese Population. *Prog. Cardiovasc. Dis.* **2014**, *56*, 457–464. [CrossRef] [PubMed]
96. Fyock-Martin, M.B.; Erickson, E.K.; Hautz, A.H.; Sell, K.M.; Turnbaugh, B.L.; Caswell, S.V.; Martin, J.R. What Do Firefighting Ability Tests Tell Us About Firefighter Physical Fitness? A Systematic Review of the Current Evidence. *J. Strength Cond. Res.* **2020**, *34*, 2093–2103. [CrossRef] [PubMed]
97. Mazic, S.; Suzic Lazic, J.; Dekleva, M.; Antic, M.; Soldatovic, I.; Djelic, M.; Nesic, D.; Acimovic, T.; Lazic, M.; Lazovic, B.; et al. The Impact of Elevated Blood Pressure on Exercise Capacity in Elite Athletes. *Int. J. Cardiol.* **2015**, *180*, 171–177. [CrossRef]
98. Parto, P.; Lavie, C.J.; Swift, D.; Sui, X. The Role of Cardiorespiratory Fitness on Plasma Lipid Levels. *Expert. Rev. Cardiovasc. Ther.* **2015**, *13*, 1177–1183. [CrossRef]
99. Vega, G.L.; Grundy, S.M.; Barlow, C.E.; Leonard, D.; Willis, B.L.; DeFina, L.F.; Farrell, S.W. Association of Triglyceride-to-High Density Lipoprotein Cholesterol Ratio to Cardiorespiratory Fitness in Men. *J. Clin. Lipidol.* **2016**, *10*, 1414–1422.e1. [CrossRef] [PubMed]
100. Rumora, A.E.; Lentz, S.I.; Hinder, L.M.; Jackson, S.W.; Valesano, A.; Levinson, G.E.; Feldman, E.L. Dyslipidemia Impairs Mitochondrial Trafficking and Function in Sensory Neurons. *FASEB J.* **2018**, *32*, 195–207. [CrossRef] [PubMed]
101. Tarp, J.; Støle, A.P.; Blond, K.; Grøntved, A. Cardiorespiratory Fitness, Muscular Strength and Risk of Type 2 Diabetes: A Systematic Review and Meta-Analysis. *Diabetologia* **2019**, *62*, 1129–1142. [CrossRef]
102. Savall, A.; Charles, R.; Bertholon, A.; Gramont, B.; Trombert, B.; Barthélémy, J.C.; Roche, F. Volunteer and Career French Firefighters: Cardiovascular Risk Factors and Cardiovascular Risk Assessment. *Eur. J. Prev. Cardiol.* **2020**, *27*, 107–109. [CrossRef]
103. de Borba, A.T.; Jost, R.T.; Gass, R.; Nedel, F.B.; Cardoso, D.M.; Pohl, H.H.; Reckziegel, M.B.; Corbellini, V.A.; Paiva, D.N. The Influence of Active and Passive Smoking on the Cardiorespiratory Fitness of Adults. *Multidiscip Respir Med.* **2014**, *9*, 34. [CrossRef]
104. Baquet, G.; van Praagh, E.; Berthoin, S. Endurance Training and Aerobic Fitness in Young People. *Sports Med.* **2003**, *33*, 1127–1143. [CrossRef] [PubMed]
105. Gupta, S.; Rohatgi, A.; Ayers, C.R.; Willis, B.L.; Haskell, W.L.; Khera, A.; Drazner, M.H.; de Lemos, J.A.; Berry, J.D. Cardiorespiratory Fitness and Classification of Risk of Cardiovascular Disease Mortality. *Circulation* **2011**, *123*, 1377–1383. [CrossRef] [PubMed]
106. Chu, D.J.; al Rifai, M.; Virani, S.S.; Brawner, C.A.; Nasir, K.; Al-Mallah, M.H. The Relationship between Cardiorespiratory Fitness, Cardiovascular Risk Factors and Atherosclerosis. *Atherosclerosis* **2020**, *304*, 44–52. [CrossRef] [PubMed]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

http://etd.uwc.ac.za/

CHAPTER SIX: PUBLICATON FIVE − ORIGINAL RESEARCH

ARTICLE ONE

Relationship Between Physical Activity, Coronary Artery Disease Risk Factors and Musculoskeletal Injuries in the City of Cape Town Fire and Rescue Service

---

UNIVERSITY of the
WESTERN CAPE

Chapter Six was an original research article published during the PhD candidature from a previous project that provided preliminary data informing the current study.

http://etd.uwc.ac.za/

Check for updates

Original Research Article

INQUIRY: The Journal of Health Care Organization, Provision, and Financing
Volume 59: 1–13
© The Author(s) 2022
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/00469580221084485
journals.sagepub.com/home/inq
SAGE

Relationship Between Physical Activity, Coronary Artery Disease Risk Factors and Musculoskeletal Injuries in the City of Cape Town Fire and Rescue Service

Jaron Ras[1] and Lloyd Leach[1]

Abstract

Musculoskeletal injuries in firefighters are a common occurrence, that increase as firefighters age, and may be related to the firefighters' physical activity habits outside of the job. Certain CAD risk factors, such as obesity, cigarette smoking and ageing may be linked to increased injury risk in firefighters. Although firefighters may meet the recommended minimum physical activity minutes, they may remain at risk for sustaining musculoskeletal injuries. Therefore, this study aims to determine the relationship between physical activity and CAD risk factors, between CAD risk factors and musculoskeletal injuries and between physical activity and musculoskeletal injuries. A total of 124 full-time firefighters, males and females, were conveniently recruited from the City of Cape Town Fire and Rescue Service. A researcher- generated questionnaire was used to collect injury, CAD risk factor and physical activity data. The proportion of firefighters who participated in leisure-time physical activity (LTPA) was 63.7%, and those who were physically inactive was 69.4%. The prevalence musculoskeletal injuries among all firefighters was 27.4%. The most prevalent musculo- skeletal injury was shoulder injuries in 35.3% of firefighters, followed by multiple injuries in 26.5% and back injuries in 14.7%. Age was a significant predictor of physical inactivity in firefighters [P = .002, OR = 1.08], BMI was a significant predictor of physical inactivity [P = .050, OR = 1.08], cigarette smoking was a significant predictor of firefighters not exercising [P = .007, OR = 2.31] and the total amount of vigorous-intensity exercise was a significant predictor of musculoskeletal injuries [P = .050, OR = 1.00]. In conclusion, older firefighters were more physically inactive and had a higher prevalence of musculoskeletal injuries, and the latter decreased significantly after the age of 50 years. Emphasis should be placed on firefighters exercising in their leisure-time, especially as they aged.

UNIVERSITY of the
WESTERN CAPE

Keywords

firefighters, musculoskeletal, injury, CAD, risk factor, physical activity

[1]Department of Sport, Recreation and Exercise Science, University of the Western Cape, Bellville, Western Cape, South Africa

Received 31 October 2021; revised manuscript accepted 14 February 2022

Corresponding Author:
Department of Sport, Recreation and Exercise Science, University of the Western Cape, Robert Sobukwe Rd, Bellville, Western Cape 7535, South Africa.
Email: jaronras@gmail.com

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).

http://etd.uwc.ac.za/

What do we already know about this topic?

Age, obesity and physical activity are significantly related to injuries in firefighters. Physical activity may reduce or increase injuries incidence in firefighters, depending on the overall total workload. In addition, the intensity of physical activity has been shown to be significantly related to CAD risk factors and overall injury incidence. However, these relationships are understudied and more research in the field are needed, especially in the City of Cape Town, where firefighters are understudied.

How does your research contribute to the field?

This paper adds new knowledge on physical activity habits, musculoskeletal injuries and coronary artery disease (CAD) risk factors in firefighters, in the City of Cape Town Fire and Rescue Service (CoCTFRS). In addition, this paper adds valuable knowledge to an understudied population in South Africa. The article highlights the need for behavioural education and rehabilitation in the CoCTFRS and where future research needs to be focused.

What are your research's implications toward theory, practice or policy?

This study highlights the relationship between physical activity and catalysing CAD risk factors and occupational induced workload on firefighters (in a developing country), which is likely linked to the premature morbidity, early retirement and mortality seen in this population, and can inform future policy implementation related to physical fitness and health maintenance programmes in firefighters.

Introduction

Firefighting is a strenuous occupation that places tremendous physical workloads on firefighters.[1-3] Firefighters are routinely exposed to environmental hazards that contribute to the high prevalence of musculoskeletal injury and cardiovascular disease.[1,4,5] Firefighter-specific tasks, such as equipment carries, door breaches and hose-drag cause firefighters to be at high risk of musculoskeletal injuries.[1,4,6] These tasks coupled with the environmental factors, such as severe temperatures, and hazardous terrain, cause significant fatigue, which increases the likelihood of injury.[3,6-8] Consequently, if any underlying cardiovascular or musculoskeletal disorders are present, these can lead to significant morbidity and mortality in firefighters.[1,4,5,9] Therefore, firefighters need to be in peak physical condition and in optimal health in order to prevent the occurrence of injuries and cardiovascular events.[10,11]

Current literature indicates that musculoskeletal injuries in firefighters are a common occurrence, that increase as firefighters age, and may be related to the firefighters' physical activity habits outside of the job.[1,3-5] The increase in musculoskeletal injuries as firefighters age, may be related to the progressive decrease in cardiorespiratory fitness.[1,2,4,8,12,13] Obesity is another key factor that plays a role in on-duty injuries in firefighters.[1,4,5,14] Due to increased body weight, especially fat weight, places more strain on the body's musculoskeletal structures while performing occupational tasks, that predispose firefighters to injury, especially if firefighters are not physically fit.[1,4,10] Obesity has been shown to be a significant predictor of on-duty musculoskeletal injuries and poor cardiorespiratory performance in firefighters.[15-17] Various studies report that the majority of firefighters are physical inactive outside of their occupations, which is alarming given the physically intense nature of their occupation.[18-20] Furthermore, physical inactivity is directly correlated to an increase in coronary artery disease (CAD) risk factors.[19-21] Exercise outside of work has been emphasised in firefighters to maintain their physical fitness and readiness for duty.[6,22] However, many firefighters are not participating in physical activity regularly in their leisure time, which is a cause for concern.[11,23,24]

Currently, in the City of Cape Town Fire and Rescue Service (CoCTFRS), research has indicated that a relatively small percentage of firefighters are physically inactive.[25] However, these statistics include occupational activity minutes, not leisure time activity or recreational activity only. Although firefighters may meet the recommended minimum physical activity minutes, they may remain at risk for sustaining musculoskeletal injuries.[6,8,26] This may be attributes to the strenuous nature of firefighting, the accumulation of overall weekly workload or insufficient muscular strength or endurance to cope with the stressors placed upon them.[1,6,8,14,26] In addition, if firefighters' caloric intake exceeds their physical activity levels, they remain at risk for increased adiposity, which is a risk factor for injuries, especially as firefighters ages.[27-30] It is hypothesised that, firstly, leisure time physical activity (LTPA) and physical inactivity based on recreational exercise will be significantly related to CAD risk factors musculoskeletal health. Secondly, that certain CAD risk factors such as cigarette smoking, physical inactivity and obesity will be related to musculoskeletal injuries. These results will add valuable knowledge on the necessity of firefighters to participate in physical activity recreationally, as a means to reduce CAD risk factor

http://etd.uwc.ac.za/

development and reduce the risk of musculoskeletal injuries. In addition, these results may, potentially, inform policy changes in the CoCTFRS. Therefore, this study aims to determine the relationship between physical activity and CAD risk factors, between physical activity and musculoskeletal injuries and between CAD risk factors and musculoskeletal injuries.

Methods

Study Design and Participants

This study used a quantitative, cross-sectional and correlational design. A total of 124 full-time firefighters, males and females, were conveniently recruited from the City of Cape Town Fire and Rescue Service. The demographic characteristics included were age, gender, family history of CAD, cigarette smoking, and injury type, severity and location, using a researcher-generated questionnaire. Injury type and severity was indicated based on firefighters needing medical treatment/intervention, and excluded injuries that were not medically diagnosed by a physician. The International Physical Activity Questionnaire (IPAQ)[31] was used to gather information about physical activity. The ACSM guidelines were used to categorize physically inactive firefighters, that is, individuals not participating in at least 30 minutes of moderate-intensity physical activity on at least 3 days of the week for at least 3 months, consecutively (American College of Sports Medicine, 2016, p. 27). Firefighters that exercised regularly, but did not meet the minimum recommendations for physical activity and those that did not exercise at all were categories as such.

Research Procedures

The research procedures in the current study have been repeated from a previous published article (Ras and Leach[25]). The principle researcher (Jaron Ras) performed all the physical measures and was responsible for administering the data recording sheet (questionnaire). For further information on the testing procedures followed to determine firefighter stature, body mass, blood pressure, blood glucose and cholesterol, please refer to the article that was previously published (Ras and Leach[25]). Briefly, Stature was measured using a portable stadiometer, standing barefoot and head placed in the Frankfort plane.[32] Body mass was measured with the participant wearing minimal indoor clothing, using a precision electronic scale.[32] Blood pressure was measured using a blood pressure sphygmomanometer and stethoscope, with the appropriate cuff size. The standard auscultatory method of blood pressure measurement was used.[32] Total cholesterol and non-fasting blood glucose were measured using the finger-prick method and a microcapillary blood sample analysed with an AcuTrend® Plus GC meter. Waist circumference was measured at the point of the umbilicus,[32] and hip circumference was taken at the level of the greatest posterior protuberance of the buttocks using a steel tape measure.[33] The research instruments were calibrated, prior to testing, and was assessed for accuracy by comparing the measurements to a calibrated instrument. A minimum test-retest reliability coefficient of .8 was required prior to the commencement of the study and only 1 tester was used in the study.[33]

Obesity was measured as a BMI >30 $kg•m^{-2}$ or a waist circumference for men >102 cm and for woman >88 cm.[32] Hypertension was defined as a resting systolic blood pressure ≥140 mmHg or a resting diastolic blood pressure ≥90 mmHg.[26] Dyslipidemia was defined as total serum cholesterol ≥5.18 $mmol•L^{-1}$.[32] Diabetes is defined as an impaired fasting glucose (IFG) of between 7.77 and 11.04 $mmol•L^{-1}$ or an impaired glucose tolerance (IGT) of 11.1 $mmol•L^{-1}$ or above, confirmed on at least two separate occasions.[32] A family history of heart disease was defined as myocardial infarction, coronary revascularization or sudden cardiac death before the age of 55 years in the father or other male first-degree relative, or before the age of 65 years in the mother or other female first-degree relative.[32] Physical inactivity is defined as individuals not participating in at least 30 minutes of moderate-intensity physical activity on at least 3 days of the week for at least 3 months, consecutively.[32] Age as a risk factor is defined as men ≥45 and woman ≥55, putting them at higher risk for developing CAD.[32] Cigarette smoking as a risk factor is defined as being a current cigarette smoker or those individuals who have quit smoking within the last 6 months or those individuals exposed to second-hand tobacco smoke.[32]

The study took place between September and November 2019. All subjects gave their written informed consent for inclusion before they participated in the study. The study protocol was approved by the Biomedical Research Ethics Committee (BMREC) at the University of the Western Cape (Ethics reference number: BM19/4/3). The study was also approved by the Chief Fire Officer of the City of Cape Town Fire and Rescue Service, as well as the Director of Policy and Strategy of the City of Cape Town.

Analysis

All data was captured by double-entry into a Microsoft Office Excel spreadsheet, and then cleaned of errors, which involved removal of extra spaces, case and spell checking, and error removal. Thereafter, it was exported to the Statistical Package for the Social Sciences (SPSS) version 27 (https://www.ibm.com/za-en/analytics/spss-statistics-software) for descriptive and inferential data analysis. Descriptive statistics (mean, standard deviation and percentages) and inferential statistics (Kruskal Wallis H, Mann-Whitney U, Chi-squared test, and linear and binary regression) and odds ratios were performed. Nagelkerke R square value and odds ratios were used for all predictions. All assumptions required prior to performing a logistic regression analysis were met. The following assumptions were met prior to conducting the regression analysis: (1) the dependent variable was dichotomous, (2) the independent variables were continuous, (3) there were

http://etd.uwc.ac.za/

Table 1. Prevalence of Musculoskeletal Injuries, Leisure-Time Physical Activity and Physical Inactivity in Firefighters According to Gender, Age-Group and CAD Risk Factors.

	Musculoskeletal Injuries	Leisure Time Physical Activity	Minimum PA Requirements Not met[a]	Physically Inactive
	%	%	%	%
Total Firefighters (n = 124)	27.4	63.7	33.1	69.4
Gender				
Male (n = 98)	27.6	63.3	30.6	67.3
Female (n = 26)	26.9	65.4	42.3	76.9
Age Category				
20-29 years (n = 24)	29.2	79.2	20.8	41.7
30-39 years (n = 55)	29.1	60.0	32.7	72.7
40-49 years (n = 30)	30.0	66.7	40.0	73.3
50-65 years (n = 15)	13.3	46.7	40.0	93.3
CAD risk factors				
Age (n = 29)	28.1	53.1	37.5	84.4
Hypertension (n = 41)	18.1	62.2	37.8	75.7
Diabetes (n = 11)	9.1	81.8	63.6	81.8
Dyslipidemia (n = 50)	24.0	66.0	36.0	70.0
Cigarette smoking (n = 49)	28.6	49.0	16.3	67.3
Obesity (n = 45)	23.9	54.3	37.8	82.6
Central obesity (n = 46)	26.1	52.2	36.9	84.8

[a]firefighters who exercised, but do not meet the minimum ACSM requirements for being physically active.

independence of observations and (4) there was a linear relationship between the logit transformation of the dependent variable and the continuous variable. An analysis of residuals was performed and confirmed the assumptions of linearity.

Results

The mean age of all the firefighters was 37.53 ± 9.05 years, and mean body mass and stature were 87.4 ± 17.9 kg and 172.6 ± 7.3 cm, respectively. The majority of firefighters were male (79.1%), with a mean age, body mass and stature of 37.8 ± 9.8 years, 87.8 ± 18.5 kg and 174.7 ± 6.5 cm, respectively, for females, mean age, body mass and stature were 36.4 ± 5.4 years, 85.9 ± 16.2 kg and 164.8 ± 4.5 cm, respectively. When all participants were separated into age-group categories, the age-group 20-29 years represented 19.4% of the participants in the study, the age-group 30-39 years had the highest number of participants with 44.4%, the age-group 40-49 years had 24.2%, and the age-group 50-65 years had the lowest number with 12.1%. For further information on the CAD risk factor prevalence's or mean values for each risk factor, please refer to the previously published article (Ras and Leach[25]).

The proportion of firefighters who participated in leisure-time physical activity (LTPA) was 63.7%, and those who were physically inactive was 69.4% (Table 1). The proportion of male firefighters who participated in LTPA was 63.3%, while those who did not meet the minimum PA requirements was 30.6%, and who were categorized as physically inactive was 67.3%. In female firefighters, 65.4% participated in LTPA, while 42.3% did not meeting the minimum requirements for PA, and 76.9% were physically inactive. The majority (79.2%) of firefighters that participated in LTPA was in the age-group 20-29 years. The age group 30-39 years and 40-49 years had a similar percentage of LTPA and physical inactivity with 60.0% and 66.7%, and 72.7% and 73.3%, respectively. The age group 50-65 years had the lowest (46.7%) percentage of firefighters participating in LTPA and highest prevalence of physical inactivity (93.3%).

The mean occupational minutes per week for low-, moderate- and vigorous-intensity occupational physical activities (OPAs) were 1132.9 ± 641.7 minutes, 900.00 ± 406.2 minutes and 505.7 ± 497.1 minutes, respectively. The mean minutes per week total low-, moderate- and vigorous-intensity physical activity were 916.4 ± 605.1 minutes, 323.1 ± 308.0 minutes and 279.6 ± 415.8 minutes, respectively.

The prevalence musculoskeletal injuries among all firefighters were 27.4% (Table 1). In male firefighters the prevalence of musculoskeletal injuries was 27.3%. In female firefighters, 26.9% had musculoskeletal injuries. The age group 50-65 years had the lowest prevalence of musculoskeletal injury with 13.3%. According to CAD risk factors, Cigarette smokers and firefighters aged 45 years or older reported the highest prevalence of musculoskeletal injuries, with 28.6% and 28.1%, respectively. In addition, aged firefighters and those that had central obesity were the most physically inactive, with 84.4% and 84.8%, respectively. Interestingly, cigarette smokers had the lowest prevalence of

http://etd.uwc.ac.za/

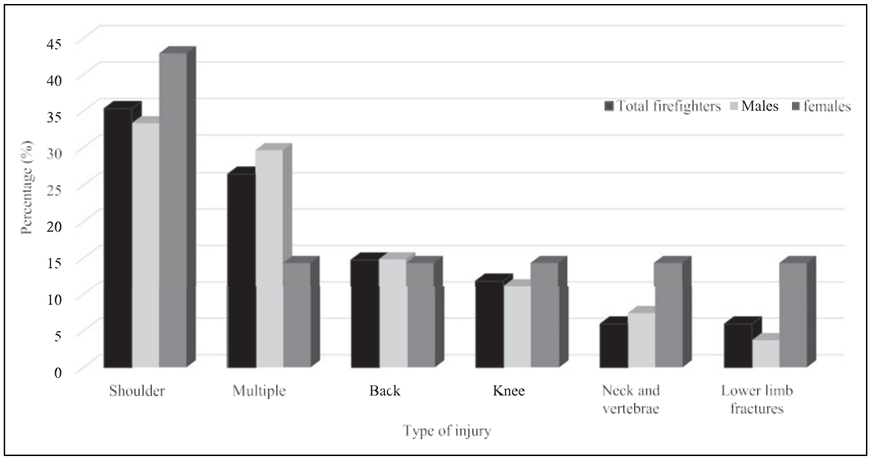


Figure 1. Prevalence of musculoskeletal injuries in firefighters according to gender.

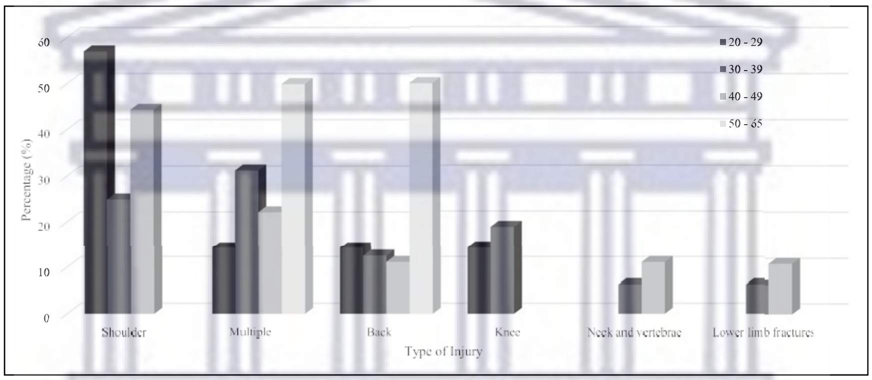


Figure 2. Prevalence of musculoskeletal injuries in firefighters according to age-group.

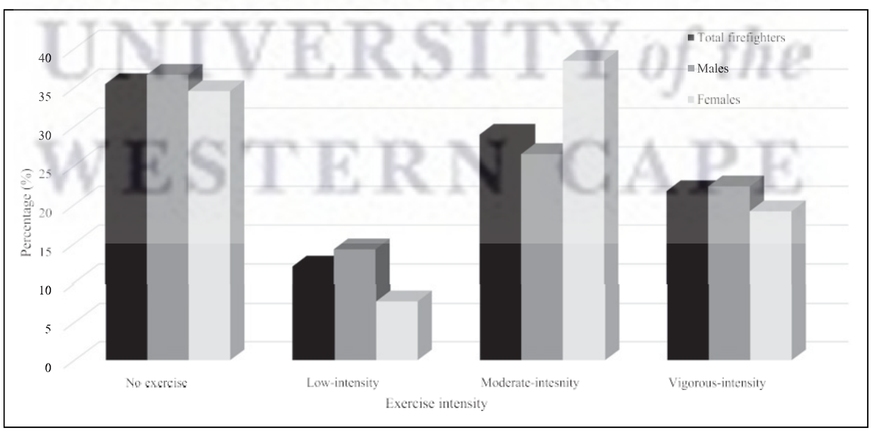


Figure 3. Physical activity intensity during leisure time among firefighters according to gender.

physical inactivity. Most firefighters participated in LTPA (49.0% to 66.0%), but 16.3% to 63.6%, depending on CAD risk factor, did not meet the minimum recommended minutes of physical activity.

In Figure 1, 35.3% of firefighters reported having a shoulder injury that was the most prevalent musculoskeletal injury in firefighters, followed by multiple injuries (defined as 2 or more concurrent injuries sustained) in 26.5%, back injuries in 14.7%, knee injuries in 11.8, neck and vertebra injuries in 5.9% and lower limb fractures in 5.9%. In male firefighters, 33.3% had shoulder injuries, 29.6 had multiple injuries, 14.8% had back injuries, 11.1% had knee injuries,

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

7.4% had neck and vertebra injuries and 3.7% had lower limb fractures. In female firefighters, shoulder injuries were the most common injury in 42.9%, while multiple, back, knee, neck and vertebra injuries, and lower limb fractures all had the same prevalence of 14.3%. Shoulder injuries was most prevalent in the age-group 20-29 years (57.1%) had shoulder injuries (Figure 2), in the age-group 30-39 years most (31.3%) had multiple injuries. In the age-group 40-49 years, 44.4% reported shoulder injuries, and in the age-group 50-65 years, 50% had multiple and back injuries only.

In total, the majority (35.5%) of firefighters reported not exercising at all during the week, 12.1% reported exercising at a low-intensity, 29.0% reported exercising at a moderate-intensity and 21.8% reported exercising at a vigorous-intensity (Figure 3). The mean exercise time per week for low-intensity exercise was 117.2 ± 97.5 minutes, for moderate-intensity exercise it was 175 ± 121.6 minutes and for vigorous-intensity exercise it was 291.2 ± 364.3 minutes. In male firefighters, 36.7% compared to 36.4% in female firefighters reported not exercising. Males preferred exercising at a moderate intensity with 26.5%, whereas 38.5% of females preferred exercising at a moderate intensity. However, more males exercised at vigorous intensity compared to females (22.4% vs 19.2%). In the youngest age-group 20 – 29 years, 45.8% preferred exercising at a vigorous intensity, and had the lowest proportion of firefighters that exercised at a low intensity (4.2%). In the age-group 30 – 39 years, most (40.0%) reported not exercising, and those that did exercise preferred to exercise reported exercising at a moderate-intensity (29.1%), compared to the age-group 40 - 49 years, where 33.3% reported not exercising, and 30% reported exercising at a moderate-intensity. The age-group 50 – 65 years, 53.3% reported not exercising the highest among the age groups, 26.7% reported exercising at a moderate-intensity, but none exercised at a vigorous-intensity (Figure 4).

The mean ages of the firefighters who did not exercise, and who exercised at a low-intensity, moderate-intensity and vigorous-intensity were 39.2 ± 9.6, 41.9 ± 9.5, 37.2 ± 8.2 and 32.9 ± 7.6 years, respectively, that was statistically significant (H = 11.1, P = .011) (Table 2). The mean WCs for firefighters who did not exercise, and who exercised at a low-, moderate- and vigorous-intensity were 99.4 ± 17.6, 102.7 ± 9.8, 93.8 ± 12.1 and 91.5 ± 9.9 cm, that was statistically significant (H = 11.7, P = .008).

After the Bonferroni correction, there was a statistically significant difference in between those that exercised at a vigorous-intensity and those that did not exercise (U = 23.7, P = .036), and between those exercising at a vigorous-intensity and at a low-intensity (U = 33.7, P = .018). There was a significant difference in WC between those that exercised at a vigorous intensity and at a low-intensity (U = 33.9, P = .017). There was a significant difference in WHR between those that exercised at a moderate-intensity and at a low-intensity (U = 38.9, P = .002), and between those that exercised at a vigorous intensity and at a low-intensity (U = 37.1, P = .007).

There were significant negative correlations between age and vigorous-intensity exercise (r = −.520, P = .004), and between BMI and vigorous-intensity exercise (r = −.416, P = .025) (Table 3).

Exercise in leisure-time was significantly associated with cigarette smoking [$\chi^2(1) = 7.6$, P = .006, OR = 2.9 (95% CI: 1.3, 6.1)] and central obesity [$\chi^2(1) = 4.2$, P = .040, OR = 2.2 (95% CI: 1.0, 4.7)] in firefighters (Table 4). Firefighters who exercised in their leisure-time were 2.9 and 2.2 times less likely to be cigarette smokers and have central obesity, respectively. Physical inactivity was significantly associated with age [$\chi^2(1) = 6.0$, P = .032, OR = 3.0 (95% CI: 1.1, 8.6)], obesity [$\chi^2(1) = 2.9$, P = .0014, OR = 2.2 (95% CI: 1.0, 4.7)] and central obesity [$\chi^2(1) = 8.2$, P = .004, OR = 3.7 (95% CI: 1.5, 9.3)] in firefighters. Firefighters who were physically inactive were 6.0, 2.9 and 3.7 times more likely to be aged, obese and to have central obesity, respectively. Firefighters who did not exercise were significantly associated with cigarette smoking [$\chi^2(1) = 4.9$, P = .027, OR = 2.3 (95% CI: 1.1, 4.9)]. Not meeting the minimum PA requirements for healthy adults as recommended by ACSM was significantly associated with cigarette smoking [$\chi^2(1) = 10.4$, P = .001, OR = 3.9 (95% CI: 1.7, 9.1)] and diabetes [$\chi^2(1) = 4.2$, P = .041, OR = 3.6 (95% CI: .9, 13.1)] in firefighters. Firefighters that did not meet the minimum PA requirements were 3.9 and 3.6 times more likely to be cigarette smokers and diabetic, respectively.

Binary logistic regression was performed with physical inactivity, exercise in leisure-time, not exercising and musculoskeletal injuries as the main outcome variables (Table 5). Age was a significant predictor of physical inactivity in firefighters [χ^2 (4) = 10.996, P = .002, OR = 1.08 (95% CI: 1.02, 1.14)]), and predicted 12% of the variation in firefighters who were physically inactive. Aged firefighters were 1.08 times more likely to be physically inactive than younger firefighters. After adjustment for covariates (BMI and WC), age remained a significant predictor of physical inactivity [P = .024, OR = 1.07 (95% CI: 1.01, 1.13)]). BMI was a significant predictor of physical inactivity [χ^2 (4) = 4.021, P = .050, OR = 1.08 (95% CI: 1.00, 1.17)]), and explained 5% of the variation in physical inactivity. Firefighters with increasing BMI were 1.08 times more likely to be physically inactive. After adjustment for covariates (age and WC), BMI was not a significant predictor of physical inactivity. Waist circumference was a significant predictor of physical inactivity [χ^2 (4) = 5.777, P = .019, OR = 1.04 (95% CI: 1.01, 1.07)]), and predicted 7% of the variation in physical inactivity. Firefighters with increased WC were 1.04 times more likely to be physically inactive. After adjustment for covariates, WC was not a significant predictor of physical inactivity.

Cigarette smoking was a significant predictor of firefighters exercising in their leisure-time [χ^2 (1) = 7.6, P = .007, OR = 2.86 (95% CI: 1.34, 6.12)], and predicted 7% of the variation in leisure-time exercise in firefighters. Additionally,

http://etd.uwc.ac.za/

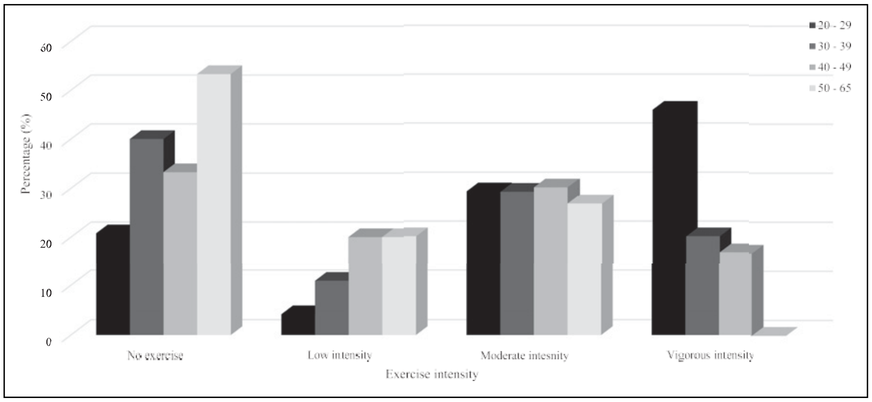


Figure 4. Physical activity intensity during leisure time among firefighters according to age group.

Table 2. CAD Risk Factor Measurements According to Exercise Intensity in Firefighters.

CAD Risk Factors	Exercise Intensity				
	No Exercise	Low	Moderate	Vigorous	
	X̅±	X̅±	X̅±	X̅±	*p*
Age	39.2 ± 9.6	41.9 ± 9.5	37.2 ± 8.2	32.9 ± 7.6	.011*
Body mass index	30.4 ± 7.4	30.4 ± 7.4	28.8 ± 4.7	27.4 ± 3.3	.111
Waist circumference	99.4 ± 17.6	102.7 ± 9.8	93.8 ± 12.1	91.5 ± 9.9	.008**
Waist-to-hip ratio	.91 ± .09	.96 ± .06	.87 ± .07	.88 ± .06	.002**
Systolic blood pressure	123.4 ± 15.5	124.9 ± 14.7	117.9 ± 14.4	121.1 ± 15.7	.246
Diastolic blood pressure	77.9 ± 10.3	80.8 ± 8.5	74.1 ± 10.9	77.2 ± 15.2	.187
Non-fasting blood glucose	5.7 ± 1.3	7.6 ± 5.3	5.5 ± 1.4	5.8 ± 1.1	.428
Total cholesterol	4.9 ± 1.0	4.7 ± 0.7	4.9 ± 0.9	5.1 ± 0.9	.734

*indicates statistically significant differences <.05; **indicates statistically significant differences <.01.

Table 3. Correlation Between Age, BMI and WC and Exercise Intensity in Firefighters.

Variable	Age	Body Mass Index	Waist Circumference
Low-intensity	−.321	.207	.047
Moderate-intensity	−.054	−.060	−.057
Vigorous-intensity	−.520**	−.416*	−.340

Table 4. The Association Between CAD Risk Factors in Firefighters, Firefighters who Exercised in Their Leisure-Time, Firefighters who were Physically Inactive, Firefighters who did not Exercise and Musculoskeletal Injuries.

Variables	Exercised in Leisure-time	Physically Inactive	Did Not Exercise	Minimum PA Requirements Not met	Musculoskeletal Injuries
	OR (95% CI)	OR (95% CI)	OR (95% CI)		OR (95% CI)
Age	1.8 (.8 – 4.1)	3.0* (1.1 – 8.6)	.6 (.3 – 1.3)	1.1 (.5 – 2.6)	.9 (.4 – 2.3)
Obesity	1.9 (.9 – 4.0)	2.9* (1.2 – 7.2)	.6 (.3 – 1.2)	.8 (.4 – 1.7)	1.3 (.6 – 3.1)
Central obesity	2.2* (1.0 – 4.7)	3.7** (1.5 – 9.3)	.5 (.2 – 1.0)	.8 (.4 – 1.7)	1.1 (.5 – 2.5)
Diabetes	.3 (.1 – 1.8)	.5 (.1 – 2.3)	2.9 (.6 – 13.9)	3.6* (.9 – 13.1)	.2 (.0 – 1.9)
Dyslipidemia	.8 (.4 – 1.7)	1.0 (.6 – 2.3)	1.2 (.5 – 2.4)	.9 (.5 – 2.0)	.7 (.3 – 1.7)
Hypertension	1.1 (.5 – 2.4)	.6 (.3 – 1.5)	.9 (.4 – 2.1)	.9 (.4 – 1.9)	.5 (.2 – 1.3)
Cigarette smoking	2.9** (1.3 – 6.1)	1.2 (.5 – 2.5)	2.3* (1.1 – 4.9)	3.9** (1.7 – 9.1)	.9 (.4 – 2.0)

*indicates statistically significant association <.05; **indicates statistically significant association <.01. OR (95% CI) = odds ratio (95% confidence interval.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 5. Binary Logistic Regression to Predict Physical Inactivity, Exercise in Leisure-Time, Firefighters who did not Exercise and Musculoskeletal Injuries in Firefighters.

	Crude					Adjusted				
	B	*df*	R^2	P Value	Or (95% CI)	*B*	*df*	R^2	P Value	Or (95% CI)
Model: Physical inactivity										
Age	.079	1	.12	.002**	1.08 (1.03 – 1.14)	.066	1	.13	.024*	1.07 (1.01 – 1.13)
Body mass index	.800	1	.05	.050*	1.08 (1.00 – 1.17)	.000	1	.13	1.000	1.00 (.84 – 1.19)
Waist circumference	.037	1	.07	.019*	1.04 (1.01 – 1.07)	.017	1	.11	.650	1.02 (.95 – 1.09)
Model: Exercise in leisure-time										
Cigarette smoking	1.052	1	.07	.007**	2.86 (1.34 – 6.12)	1.251	1	.13	.002**	3.49 (1.56 – 7.82)
Model: Did not exercise										
Cigarette smoking	.838	1	.05	.028*	2.31 (1.09 – 4.89)	1.005	1	.10	.012*	2.73 (1.24 – 6.00)
Model: Musculoskeletal injuries										
Total vigorous-intensity exercise	.001	1	.05	.050*	1.00 (1.00 – 1.00)	.001	1	.06	.066	1.00 (1.00 – 1.00)

*indicates statistical significance <.05, **indicates statistical singificance <.01, *B*: Beta coefficient, *df*: degree of freedom, R^2: Nagelkerke R square value, OR (95% CI) = odds ratio (95% confidence interval).

cigarette smokers were 2.86 times more likely not to exercise in their leisure-time compared to non-smokers. After adjustment for covariates (age, BMI and WC), cigarette smoking was a significant predictor of exercise in leisure-time (P = .002; OR = 3.49 (95% CI: 1.56, 7.82).

Cigarette smoking was a significant predictor of firefighters who did not exercise [χ^2 (1) = 8.74, P = .028, OR = 2.31 (95% CI: 1.09, 4.89)], and predicted 5% of the variation in firefighters who did not exercise. Firefighters who, smoked were 2.31 times more likely not to exercise. After adjustment for covariates (age, BMI, WC), cigarette smoking was a significant predictor of firefighters who did not exercise (P = .012; OR = 2.73 (95% CI: 1.24, 6.00).

The total amount of vigorous-intensity exercise (in minutes) was a significant predictor of musculoskeletal injuries [χ^2 (1) = 3.99, P = .050, OR = 1.00 (95% CI: 1.00, 1.00)], and predicted 5% of the variation in musculoskeletal injuries in firefighters. After adjustment for covariates (age, BMI, WC), total vigorous-intensity exercise was not a significant predictor of musculoskeletal injuries. Indicating that aging and body composition influence injury rates in firefighters when they engage in high amounts vigorous-intensity exercise.

Discussion

The present study aimed to determine the relationship between physical activity and CAD risk factors and between physical activity and musculoskeletal injuries in firefighters. The authors hypothesised that LTPA and physical inactivity will be significantly related to CAD risk factors and musculoskeletal health in firefighters. The hypothesis proved to be true in the current study, where a decrease in LTPA and physical inactivity was significantly related to ageing, obesity and cigarette smoking. These results have been consistent with previous research.[11,34-36] In addition, total weekly physical activity minutes was significantly related to musculoskeletal injuries in firefighters which may be attributed to increased overall workload.[1,2,6,14,37] Overall the injury prevalence in the current study is much lower than previous studies.[1,4,6,12,26,37-39] This may be attuited to the current study only considering injuries that were medically diagnosed by a physician, and not subjectively reported, only.

In the present study, the prevalence of musculoskeletal injuries (27.4%) was similar across genders, lowest in the oldest age category (50-65 years) and highest in cigarette smokers. Younger firefighters were generally healthier and were more physically active. However, injury prevalence was similar among the youngest age group (20-29 years) and two middle aged groups (30-39 and 40-49 years). In addition, musculoskeletal injuries were most prevalent in firefighters who were cigarette smokers and were aged. Yoon et al[1] reported a lower prevalence of injuries in 11.66% of firefighters, and that the injuries increased between the ages of 20 and 39 years. In addition, the study reported that former smokers had a significantly higher injury prevalence compared to non-smokers.[1] Cigarette smoking has been linked to reduced tendon health,[40] and with younger firefighters found to have a higher prevalence of cigarette smoking,[25,41-45] can explain why this age range was at most risk. In contrast, Negm et al[3] reported that older firefighters were significantly more likely to have more severe lower-extremity disability and more severe back disability. This may be attributed to the difference in age in the sample between the current study and Negm et al (37.5 vs 42.6 years). There was a trend, in the current results, that as firefighters aged, injuries to the low back became more prevalent, which may be attributed to age related vertebrae and intervertebral disk degeneration.[46,47] Similarly, Nazari et al[5] reported that older firefighters were significantly more likely to have musculoskeletal injuries. The increased musculoskeletal injury prevalence may be accounted for by the age-related decline in soft tissue size and strength, and reduced bone mineral density, which

http://etd.uwc.ac.za/

significantly predisposes individuals to injury, particularly when subjected to repeated high workloads, such as firefighting.[3,5,9,48] An explanation for the similarity of injury prevalence between age-groups in the present study could be due to younger firefighters participating in more vigorous-intensity exercise compared to older firefighters,[4] which have been known to predisposed individuals to injury due to chronic overload.[35,48,49]

In the present study, the most common injury was shoulder injuries (35.3%), which was particularly prevalent in females and the youngest age-group (20-29 years) of firefighters. Neck, vertebra and lower limb fractures were the least prevalent injuries. Vaulerin et al[4] reported that ankle injuries were the most prevalent in 77% of French firefighters. Shoulder injuries was the second most prevalent in 23% of firefighters. The study indicated physical activity was related to increased injuries, which may explain the concentration to the ankle region, due to chronic overuse or fatigue to the surrounding muscularture.[4] In the present study, most ankle injuries were not reported as a single musculoskeletal injury and were often reported together with other musculoskeletal injuries. In contrast, Frost et al[6] reported that the most common location of injury was the back (32%), followed by the knees (17%), ankles (15%) and shoulders (13%). The authors attributed the distribution of injuries to a variation in external factors, such as the distribution of on-duty responsibilities, community demographics and climate. Similarly, Nazari et al[5] reported that back (32%) injuries were the most prevalent injury in Canadian firefighters, followed by shoulder (24%) injuries as the second most common injury location. In the present study, back injuries were the third most prevalent musculoskeletal injury, in 14.7% of firefighters. In addition, Nazari et al[5] reported that the overall incidence of injuries among male and female firefighters were similar, with only neck and knee injuries having a prevalence greater than 5% in males compared to females. Moreover, the study reported that the injury incidence increased as firefighters aged.[5] Soteriades et al[50] reported that the most frequent musculoskeletal injuries by location were back (26%), followed by the shoulder (20.6%), neck (18.5%), upper extremities (10.3%), upper back (9.4%) and ankle (5.5%). These studies indicate that similarities in injury locations exist, where the low back and shoulder regions are the more frequently injured areas. These locations may be due to many firefighting duties being related to repetitive upper body movements requiring high force production, such as hose drags, door breaches, victim drags or carries, especially when firefighters are active outside of working hours.[4,6,14,26,38]

In the present study, the prevalence of physical inactivity was unacceptably high (69.4%), and was similar across both genders, and increased as firefighters aged. As with the present study, Seyedmehdi etal[51]reported that an unacceptably high number (67.4%) of firefighters were not physically active. Similarly, Eastlake et al[52] also reported a high prevalence of physical inactivity in 62% of firefighters. A lower prevalence of physical inactivity were reported by Martin et al[20] and Durand et al[11] where the studies indicated that 45.9% and 49% of firefighters were physical inactive. This is supported by Amodeo and Nickelson[53] who reported that 46.7% of firefighters were physically inactive, and 14% did not participate in any moderate-intensity exercise. As with the present results, firefighters do participate in physical activity, but tended to only exercise at a low-intensity or exercised infrequently. Porto et al[54] reported that 34.2% of firefighters were not physically active while on-duty, and that 15.4% of off-duty firefighters were not physically active. High physical activity levels while on duty have been shown to reduce work performance and increased fatigue, which may explain firefighters' reluctance to be physically active on duty.[55,56] The results of the study indicated male firefighters engaged in more vigorous-intensity exercise than female firefighters, and had a lower prevalence of physical inactivity, particularly in the youngest age-group (20-30 years) of firefighters. Similarly, Gendron et al[57,58] reported that fewer females were physically inactive (62%) compared to 70% of male firefighters. In contrast, another study reported that a higher proportion of female firefighters were physically inactive compared to males.[59] In the present study, the oldest age-group (50-65 years) of firefighters had the highest prevalence of not exercising and not engaging in vigorous-intensity exercise. Punakallio et al[60] reported that in the two firefighter age groups (30 – 34 and 40 – 44 years, respectively), the younger age-group of firefighters had a higher frequency of participating in physical activity (PA), that is, 3 or more times per week (61% vs 55%), and exercised at a higher intensity (27 vs 12%). As firefighters age, their proclivity toward physical activity decreases. Punakallio et al also reported physical inactivity was significantly associated with an increase in musculoskeletal injuries. Potentially, younger firefighters found that the overall workload of exercising off-duty and performing their firefighting tasks when on duty tolerable. This could be explained by younger firefighters having a higher work capacity, better overall recovery, and a lower body mass.[49,61,62] In the present study, 35.5% of firefighters did not exercise, and 33.1% of firefighters who did exercise, did not meet the minimum requirements for physical activity, which was more prevalent in females and as firefighters aged. Similarly, Soteriades et al[50] also reported a high prevalence of physical inactivity among firefighters, where 37.2% reported exercising 1-2 times per week, and 16.7% reported never exercising. The prevalence of inactivity increased as firefighters aged, which was likely as a result of the physical stress of firefighting especially among older firefighters and caused a lack in motivation to exercise.[11,23,59,63]

In the present study, physical inactivity was found to be a significant predictor of ageing, increased BMI and WC in firefighters. Choi et al[18] reported that leisure-time activity was significantly associated with BMI and WC. Similarly, Damacena et al[64] reported that central obesity was more

http://etd.uwc.ac.za/

likely in firefighters who had low PA levels. Gendron et al[65] reported that there was a significant difference in WC and obesity in firefighters who trained while on duty than those who did not. Although firefighters remain active while on duty, because they are not exercising at a moderate-to-high-intensity they do not receive the additional benefits of increased energy expenditure associated with fat loss.[11,35,65] The current results indicated that cigarette smoking was a significant predictor of engaging in leisure-time exercise. This may be due to firefighters acknowledging the harmful effects of cigarette smoking on their overall health and engaging in regular physical activity as a positive lifestyle change.[41,66-68] Overall, the majority of firefighters engaged in PA in their leisure-time. However, this did not relate to a decrease in the prevalence of physical inactivity. As stated by Muegge et al[59] many firefighters reported that they were not educated about physical activity, which may explain why many firefighters were physically active, but this did not translate into lower physical inactivity. The results indicated that younger male firefighters were more likely to engage in PA in their leisure-time, which decreased as they aged. Similarly, Muegge et al[59] reported that more male firefighters met the minimum recommendations for PA in healthy adults compared to female firefighters (72.4% vs 65.3%). Punakallio et al[60] reported that less firefighters exercised regularly in their leisure time in the age-group 40 – 44 years, compared to the age-group 30 – 34 years (82.6% vs 64.3). The prevalence of physical inactivity was unacceptably high in the present study, and poses a significant risk from a personal and public safety point of view. The likely reason for firefighters exercising, but not meeting the minimum PA recommendations, may be due to firefighters not being educated in daily PA recommendations and not having access to exercise opportunities.[59] The promotion of PA in firefighters' leisure-time, as a method to reduce the prevalence of physical inactivity, especially as firefighters aged, should be emphasized.[11,51,52,63] This may be especially important in firefighters in the CoCTFRS, where it has been shown that firefighters tended to adopt a negative attitude toward physical activity as they aged.[30]

The CAD risk factors that clustered around physical inactivity were obesity, age and diabetes. In addition, significant differences were found between the firefighters' exercise habits in their leisure-time and age, WC and WHR, where increased exercise-intensity was negatively correlated with each of these variables. Similar, Barry et al[34] reported that vigorous intensity activity was significantly related to WC in firefighters. Vigorous intensity activity has been related to increased energy expenditure and subsequent fat loss.[11,35] Durand et al[11] reported that blood glucose concentrations were highest in the age-group that exercised the least, supporting the current results. Regular physical activity aids in regulating blood glucose homeostasis and maintains insulin sensitivity.[69,70] In contrast to the results of the present study, Yu et al[35] reported that there was a significant relationship between level of physical activity and bodyfat percentage in firefighters, but no other risk factor. However, this may be related to the cohort of firefighters, where very few firefighters had CAD risk factors present, thus, not providing enough statical power to indicate significance. Seyedmehdi et al[51] reported that aerobic fitness decreased with increased cardiovascular disease risk factors, particularly age, BMI, low-density lipoprotein cholesterol and blood pressure. Exercise has been known to increase high-density lipoprotein cholesterol and decrease triglyceride and blood glucose concentrations.[71-73] This may account for the improvement in blood parameters as firefighters regularly exercised.

The total amount of vigorous-intensity exercise per week in firefighters, both in leisure-time and on-duty, was a significant predictor of musculoskeletal injuries in firefighters. Yoon et al[1] reported that there was no difference in injuries between firefighters who exercised less than 3 days per week compared to those who exercised more than 3 days per week. In contrast, the results of Soteriades et al[50] supported the present study, where it found that exercise in leisure-time had a dose-response relationship that was inversely related to musculoskeletal injuries, where more physically active firefighters were less likely to sustain musculoskeletal injuries. The majority of studies reported that physical activity does reduce injuries in firefighters, however, an excess of physical activity may predispose firefighters to injury.[43,62,74,75] The association between increased injuries and the total amount of weekly vigorous-intensity exercise may be due to the progressive increasing weekly workload, resulting in chronic fatigue and/or overuse and, eventually, acute injuries.[4,6]

Strengths and Limitations

This study provides valuable information on the PA habits in firefighters and injury prevalence in firefighters in the CoCTFRS, and the relationship between CAD risk factors and musculoskeletal injuries. To the best of the authors' knowledge, this was the first study conducted in the CoCTFRS to report on the relationship between musculoskeletal injuries, PA and CAD risk factors according to demographic characteristics. A limitation was that the study used convenient sampling that negatively impacted the external validity. Also, the relatively small sample size negatively impacted the power of the study. The study was also under-represented by female participants. Lastly, all injuries and PA were self-reported and were not objectively measured by the researcher, which could have resulted in under-or-overestimation of PA and injuries, particularly in those firefighters who are unfit, obese and at increased cardiovascular risk.

Conclusion

Older firefighters were more physically inactive and had a higher prevalence of musculoskeletal injuries, and the latter decreased significantly after the age of 50 years. The most prevalent injury was shoulder injuries, especially in female firefighters. Increased age, BMI, WC and cigarette smoking were significant predictors of the PA habits of firefighters.

http://etd.uwc.ac.za/

The total amount of vigorous-intensity exercise per week was a significant predictor of musculoskeletal injuries in firefighters. Emphasis should be placed on firefighters exercising in their leisure-time, especially as they aged. In addition, firefighters who participated in vigorous-intensity physical activity in leisure time, while off-duty, should be monitored for their overall workload and recovery, as this could predispose them to injury while on-duty.

Recommendations

For future studies, it is recommended that researchers use random sampling and that the studies are sufficiently powered in order to ensure external validity. In addition, a more representative sample of female firefighters, and that objective measure of musculoskeletal injuries and PA be conducted.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work is based on the research supported wholly / in part by the National Research Foundation of South Africa (Grant Numbers: 117718) (https://www.nrf.ac.za/).

Data Availability

The captured data contains confidential information on firefighters that cannot be made publicly available as part of the agreement with the City of Cape Town Fire and Rescue Service. Only the researchers directly involved in the study, ie, Jaron Ras and Lloyd Leach, have access to this data. If researchers require the data, requests should be submitted to the corresponding author (Jaron Ras: jaronras@gmail.com), where permission will then be requested from the City of Cape Town Fire and Rescue Service and upon signing a data access agreement in compliance with the City of Cape Town data regulations.

ORCID iD

Jaron Ras https://orcid.org/0000-0002-7915-4883

References

1. Yoon JH, Kim YK, Kim KS, Ahn YS. Characteristics of workplace injuries among nineteen thousand Korean firefighters. *J Kor Med Sci*. 2016;31(10):1546-1552. doi:10.3346/jkms.2016.31.10.1546
2. Nowak A, Molik B, Wójcik A, et al. Physical activity and injuries relating to physical fitness of professional firefighters. *Adv Rehabil*. 2018;32(2):13-22. doi:10.5114/areh.2018.77933
3. Negm A, MacDermid J, Sinden K, D'Amico R, Lomotan M, MacIntyre NJ. Prevalence and distribution of musculoskeletal disorders in firefighters are influenced by age and length of service. *J Military Veteran Family Health*. 2017;3(2):33-41. doi:10.3138/jmvfh.2017-0002
4. Vaulerin J, d'Arripe-Longueville F, Emile M, Colson SS. Physical exercise and burnout facets predict injuries in a population-based sample of French career firefighters. *Appl Ergon*. 2016;54:131-135. doi:10.1016/j.apergo.2015.12.007
5. Nazari G, Macdermid JC, Sinden K, D'Amico R. Prevalence of musculoskeletal symptoms among Canadian firefighters. *Work*. 2020;67(1):185-191. doi:10.3233/WOR-203264
6. Frost DM, Beach TAC, Crosby I, McGill SM. Firefighter injuries are not just a fireground problem. *Work*. 2015;52(4):835-842. doi:10.3233/WOR-152111
7. Negm A, MacDermid J, Sinden K, D'Amico R, Lomotan M, MacIntyre NJ. Prevalence and distribution of musculoskeletal disorders in firefighters are influenced by age and length of service. *J Military Veteran Family Health*. 2017;3(2):33-41. doi:10.3138/jmvfh.2017-0002
8. Hong O, Phelps S, Feld J, Vogel S. Occupational Injuries, Status D, and factors associated with injuries among firefighters. *Workplace Health & Saf*. 2012;60(12):517-523. doi:10.1177/216507991206001203
9. Nazari G, MacDermid J, Cramm H. Prevalence of musculoskeletal disorders among Canadian firefighters: A systematic review and meta-analysis. *J Military Veteran Family Health*. 2020;6(1):83-97. doi:10.3138/jmvfh-2019-0024
10. Nazari G, MacDermid JC, Sinden KE, Overend TJ. The Relationship between Physical Fitness and Simulated Firefighting Task Performance. *Rehab Res Practice*. 2018;2018(2007):1-7. doi:10.1155/2018/3234176
11. Durand G, Tsismenakis AJ, Jahnke SA, Baur DM, Christophi CA, Kales SN. Firefighters' physical activity: Relation to fitness and cardiovascular disease risk. *Med Sci Sports Exerc*. 2011;43(9):1752-1759. doi:10.1249/MSS.0b013e318215cf25
12. Kim YK, Ahn YS, Kim K, Yoon JH, Roh J. Association between job stress and occupational injuries among Korean firefighters: A nationwide cross-sectional study. *BMJ Open*. 2016;6(11):e012002. doi:10.1136/bmjopen-2016-012002
13. Orr R, Simas V, Canetti E, Schram B. A profile of injuries sustained by firefighters: A critical review. *Int J Environ Res Publ Health*. 2019;16(20). doi:10.3390/ijerph16203931
14. Butler RJ, Contreras M, Burton LC, et al. Modifiable risk factors predict injuries in firefighters during training academies. Work 2013;46:11-17. doi:10.3233/WOR-121545
15. Poston WSC, Development N, Haddock CK, et al. The prevalence of overweight, obesity, and substandard fitness in a population-based firefighter cohort. *J Occup Environ Med*. 2018;53(3):266-273. doi:10.1097/JOM.0b013e31820af362.The
16. Soares EMKVK, Smith D, Grossi Porto LG. Worldwide prevalence of obesity among firefighters: A systematic review protocol. *BMJ Open*. 2020;10(1):1-5. doi:10.1136/bmjopen-2019-031282
17. Soteriades ES, Hauser R, Kawachi I, Christiani DC, Kales SN. Obesity and risk of job disability in male firefighters. *Occup Med*. 2008;58(4):245-250. doi:10.1093/occmed/kqm153

http://etd.uwc.ac.za/

18. Choi B, Dobson M, Schnall P, Garcia-Rivas J. 24-Hour work shifts, sedentary work, and obesity in male firefighters. *Am J Ind Med*. 2016;59(6):486-500. doi:10.1002/ajim.22572
19. Nogueira EC, Porto LGG, Nogueira RM, et al. Body composition is strongly associated with cardiorespiratory fitness in a large Brazilian military firefighter cohort: The Brazilian firefighters study. *J Strength Condit Res*. 2016;30(1):33-38. https://journals.lww.com/nsca-jscr/Fulltext/2016/01000/Body_Composition_is_Strongly_Associated_With.5.aspx
20. Martin ZT, Schlaff RA, Hemenway JK, et al. Cardiovascular disease risk factors and physical fitness in volunteer firefighters. *Int J Exercise Sci*. 2019;12(2):764-776. http://www.ncbi.nlm.nih.gov/pubmed/31156744%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC6533096
21. Risavi BL, Staszko J. Prevalence of risk factors for coronary artery disease in Pennsylvania (USA) firefighters. *Prehospital Disaster Med*. 2015;31(1):102-107. doi:10.1017/S1049023X15005415
22. Smith DL. Firefighter fitness: Improving performance and preventing injuries and fatalities. *Curr Sports Med Rep*. 2011;10(3). https://journals.lww.com/acsm-csmr/Fulltext/2011/05000/Firefighter_Fitness__Improving_Performance_and.13.aspx
23. Yu CCW, Au CT, Lee FYF, et al. Association between leisure time physical activity, cardiopulmonary fitness, cardiovascular risk factors, and cardiovascular workload at work in firefighters. *Safe Health Work*. 2015;6(3):192-199. DOI: 10.1016/j.shaw.2015.02.004
24. Cavalcante Neto JL, Calheiros DDS, Calheiros DDS, Neto TDS, Pinto MP, da Rocha DF. Levels of physical activity and associated factors between military policemen and firemen. *Work*. 2019;62:515-521. doi:10.3233/WOR-192886
25. Ras J, Leach L. Prevalence of coronary artery disease risk factors in firefighters in the city of Cape Town fire and rescue service – A descriptive study. *J Publ Health Res*. 2021;10(1):2000. doi:10.4081/jphr.2021.2000
26. Nowak AM, Molik B, Wójcik A, et al. Physical activity and injuries relating to physical fitness of professional firefighters. *Adv Rehabil*. 2018;32(2):13-22. doi:10.5114/AREH.2018.77933
27. Yang J, Farioli A, Korre M, Kales SN. Dietary preferences and nutritional information needs among career firefighters in the United States. *Glob Adv Health Med*. 2015;4(4):16-23. doi:10.7453/gahmj.2015.050
28. Christodoulou A, Sotos-Prieto M, Kales SN, Christophi CA. Dietary patterns and their association with cardio-metabolic outcomes in US firefighters. *Eur J Publ Health*. 2020(supplment_5):30. doi:10.1093/eurpub/ckaa165.717
29. Bonnell E, Huggins C, Huggins C, McCaffrey T, Palermo C, Bonham M. Influences on dietary choices during day versus night shift in shift workers: A mixed methods study. *Nutrients*. 2017;9(3):193. doi:10.3390/nu9030193
30. Ras J, Mosie D, Strauss M, Leach L. Knowledge of and attitudes toward health and cardiovascular disease risk factors among firefighters in Cape Town, South Africa. *J Publ Health Res*. 2021(1):11. doi:10.4081/jphr.2021.2307
31. Bohlmann IM, Mackinnon S, Kruger H, et al. Is the international physical activity questionnaire (IPAQ) valid and reliable in the South African population? *Med Sci Sports Exerc*. 2001;33:S119. doi:10.1097/00005768-200105001-00672
32. American College of Sports Medicine. *ACSM Guidelines for Exercise Testing and PrAmerican College of Sports Medicine. (2018). ACSM Guidelines for Exercise Testing and Preescripción.Eescripción*. Tenth Edition. Wolters Kluwer; 2018.
33. Geeta A, Jamaiyah H, Safiza MN, et al. Reliability, technical error of measurements and validity of instruments for nutritional status assessment of adults in Malaysia. *Singap Med J*. 2009;50(10):1013-1018.
34. Barry AM, Lyman KJ, Dicks ND, et al. Firefighters' physical activity and waist circumference as predictors of of VO2max. *J Occup Environ Med*. 2019;61(10):849-853. doi:10.1097/JOM.0000000000001690
35. Yu CCW, Au CT, Lee FYF, et al. Association between leisure time physical activity, cardiopulmonary fitness, cardiovascular risk factors, and cardiovascular workload at work in firefighters. *Safe Health Work*. 2015;6(3):192-199. doi:10.1016/j.shaw.2015.02.004
36. Donovan R, Nelson T, Peel J, Lipsey T, Voyles W, Israel RG. Cardiorespiratory fitness and the metabolic syndrome in firefighters. *Occup Med*. 2009;59(7):487-492. doi:10.1093/occmed/kqp095
37. Poplin GS, Roe DJ, Peate W, Harris RB, Burgess JL. Original contribution the association of aerobic fitness with injuries in the fire service. *Am J Epidemiol*. 2013;179(2):149-155. doi:10.1093/aje/kwt213
38. Taylor P, Beach TAC, Frost DM, Mcgill SM, Callaghan JP. Physical fitness improvements and occupational low- back loading – an exercise intervention study with firefighters. *Ergonomics*. 2014;57(5):744-763. doi:10.1080/00140139.2014.897374
39. Britton C, Lynch CF, Ramirez M, Torner J, Buresh C, Peek-Asa C. Epidemiology of injuries to wildland firefighters. *Am J Emerg Med*. 2013;31(2):339-345. doi:10.1016/j.ajem.2012.08.032
40. Abate M, Vanni D, Pantalone A, Salini V. Cigarette smoking and musculoskeletal disorders. *Muscle Ligament Tend J*. 2013;3(2):63-69. doi:10.11138/mltj/2013.3.2.063
41. Jitnarin N, Haddock CK, Poston WSC, Jahnke S. Smokeless tobacco and dual use among firefighters in the central united states. *J Environ Publ Health*. 2013:2013. doi:10.1155/2013/675426
42. Jitnarin N, Poston WSC, Haddock CK, Jahnke SA. Tobacco use among women firefighters. *Wom Health Issues*. 2019;29(5):432-439. doi:10.1016/j.whi.2019.05.006
43. Jahnke SA, Poston WSC, Haddock CK, JitnarinObesity N, Obesity and injury incident. Among career firefighters in the central United States. *Obesity*. 2013;21(8):1505-1508. doi:10.1002/oby.20436
44. Haddock CK, Jitnarin N, Poston WSC, Tuley B, Jahnke SA. Tobacco use among firefighters in the central United States. *Am J Ind Med*. 2011;54(9):697-706. doi:10.1002/ajim.20972
45. Jitnarin N, Poston WS, Haddock CK, Jahnke SA, Day RS. Tobacco use pattern among a national firefighter cohort. *Nicotine Tob Res*. 2015;17(1):66-73. doi:10.1093/ntr/ntu131
46. Jang TW, Ahn YS, Byun J, et al. Lumbar intervertebral disc degeneration and related factors in Korean firefighters. *BMJ Open*. 2016;6(6):3-8. doi:10.1136/bmjopen-2016-011587

http://etd.uwc.ac.za/

47. Damrongsak M, Prapanjaroensin A, Brown KC. Predictors of back pain in firefighters. *Workplace Health & Saf*. 2018;66(2): 61-69. doi:10.1177/2165079917709020
48. Drew MK, Cook J, Finch CF. Sports-related workload and injury risk: simply knowing the risks will not prevent injuries: Narrative review. *Br J Sports Med*. 2016;50(21):1306. doi:10.1136/bjsports-2015-095871
49. Mair SD. Seaber Av, Glisson RR, Garrett WEJ. The role of fatigue in susceptibility to acute muscle strain injury. *Am J Sports Med*. 1996;24(2):137-143. doi:10.1177/036354659602400203
50. Soteriades ES, Psalta L, Leka S, Spanoudis G. Occupational stress and musculoskeletal symptoms in firefighters. *Int J Occup Med Environ Health*. 2019;32(3):341-352. doi:10.13075/ijomeh.1896.01268
51. Seyedmehdi SM, Attarchi M, Cherati AS, Hajsadeghi S, Tofighi R, Jamaati H. Relationship of aerobic fitness with cardiovascular risk factors in firefighters. *Work*. 2016;55(1): 155-161. doi:10.3233/WOR-162375
52. Eastlake AC, Knipper BS, He X, Alexander BM, Davis KG. Lifestyle and safety practices of firefighters and their relation to cardiovascular risk factors. *Work*. 2015;50(2):285-294. doi:10.3233/WOR-131796
53. Amodeo KL, Nickelson J. Predicting intention to be physically active among volunteer firefighters. *Am J Health Educ*. 2020; 51(1):1-13. doi:10.1080/19325037.2019.1687368
54. Porto LGG, Schmidt ACB, de Souza JM, et al. Firefighters' basal cardiac autonomic function and its associations with cardiorespiratory fitness. *Work*. 2019;62(3):485-495. doi:10.3233/WOR-192883
55. Dennison KJ, Mullineaux DR, Yates JW, Abel MG. The effect of fatigue and training status on firefighter performance. *J Strength Condit Res*. 2012;26(4). https://journals.lww.com/nsca-jscr/Fulltext/2012/04000/The_Effect_of_Fatigue_and_Training_Status_on.30.aspx
56. Giuliani HK, Gerstner GR, Mota JA, Ryan ED. Influence of demographic characteristics and muscle strength on the occupational fatigue exhaustion recovery scale in career firefighters. *J Occup Environ Med*. 2020;62(3):223-226. doi:10.1097/JOM.0000000000001806
57. Gendron P, Lajoie C, Laurencelle L, Trudeau F. Cardiovascular disease risk factors in que´bec male firefighters. *J Occup Environ Med*. 2018;60(6):e300-e306. doi:10.1097/JOM.0000000000001309
58. Gendron P, Lajoie C, Laurencelle L, Trudeau F. Cardiovascular disease risk in female firefighters. *Occup Med*. 2018;68(6): 412-414. doi:10.1093/OCCMED/KQY074
59. Muegge CM, Zollinger TW, Song Y, Wessel J, Monahan PO, Moffatt SM. Barriers to weight management among overweight and obese firefighters. *J Occup Environ Med*. 2020;62(1): 37-45. doi:10.1097/JOM.0000000000001751
60. Punakallio A, Lindholm H, Luukkonen R, Lusa S. Lifestyle factors predicting changes in aerobic capacity of aging firefighters at 3-and 13-year follow-ups. *J Occup Environ Med*. 2012;54(9):1133-1141. doi:10.1097/JOM.0b013e3182554b11
61. Poston WSC, Jitnarin N, Haddock CK, Jahnke SA, Tuley BC. Obesity and injury-related absenteeism in a population-based firefighter cohort. *Obesity*. 2011;19(10):2076-2081. doi:10.1038/oby.2011.147
62. Phelps SM, Drew-Nord DC, Neitzel RL, Wallhagen MI, Bates MN, Hong OS. Characteristics and Predictors of Occupational Injury Among Career Firefighters. *Workplace Health & Safety*. 2018;66(6):291-301. doi:10.1177/2165079917740595
63. Baur DM, Christophi CA, Cook EF, Kales SN. Age-related decline in cardiorespiratory fitness among career firefighters: Modification by physical activity and adiposity. *J Obesity*. 2012:2012. doi:10.1155/2012/710903
64. Damacena FC, Batista TJ, Ayres LR, Zandonade E, Sampaio KN. Obesity prevalence in Brazilian firefighters and the association of central obesity with personal, occupational and cardiovascular risk factors: A cross-sectional study. *BMJ Open*. 2020;10(3):1-10. doi:10.1136/bmjopen-2019-032933
65. Gendron P, Lajoie C, Laurencelle L, Lemoyne J, Trudeau F. Physical training in the fire station and firefighters' cardiovascular health. *Occup Med*. 2020;70(4):224-230. doi:10.1093/occmed/kqaa060
66. Dobson M, Choi B, Schnall PL, et al. Exploring occupational and health behavioral causes of firefighter obesity: A qualitative study. *Am J Ind Med*. 2013;56(7):776-790. doi:10.1002/ajim.22151
67. Lee CG, Middlestadt SE, Park S, et al. Predicting voluntary exercise training among Korean firefighters: Using elicitation study and the theory of planned behavior. *Int J Environ Res Publ Health*. 2020(2):17. doi:10.3390/ijerph17020467
68. Yu CCW, Au CT, Lee FYF, et al. Association between leisure time physical activity, cardiopulmonary fitness, cardiovascular risk factors, and cardiovascular workload at work in firefighters. *Safe Health Work*. 2015;6(3):192-199. doi:10.1016/j.shaw.2015.02.004
69. Lavie CJ, Arena R, Swift DL, et al. Exercise and the cardiovascular system: Clinical science and cardiovascular outcomes. *Circ Res*. 2015;117(2):207-219. doi:10.1161/CIRCRESAHA.117.305205
70. Fiuza-Luces C, Santos-Lozano A, Joyner M, et al. Exercise benefits in cardiovascular disease: Beyond attenuation of traditional risk factors. *Nat Rev Cardiol*. 2018;15(12):731-743. doi:10.1038/s41569-018-0065-1
71. Alphonse PAS, JonesRevisiting Human Cholesterol Synthesis PJH. Absorption: The reciprocity paradigm and its key regulators. *Lipids*. 2016;51(5):519-536. doi:10.1007/s11745-015-4096-7
72. Soteriades ES, Liarokapis D, Christoudias SG, Tucker SA, Christiani DC. Lipid profile of firefighters over time. *Published online*. 1997:840-846. doi:10.1097/01.jom.0000026643.83602.e7
73. Huang J, Forman M, Dong K, et al. Lipid profile of male firefighters in a Northwest Austin area fire department. *Faseb J*. 2015; 29(1_supplment):LB380. doi:10.1096/fasebj.29.1_supplement.lb380
74. Jahnke SA, Poston WSC, Haddock CK, Jitnarin N. Injury among a population based sample of career firefighters in the central USA. *Inj Prev*. Published online March 1, 2013:injuryprev-2012–040662. doi:10.1136/injuryprev-2012-040662
75. Poplin GS, Roe DJ, Burgess JL, Peate WF, Harris RB. Fire fit: Assessing comprehensive fitness and injury risk in the fire service. *Int Arch Occup Environ Health*. Published online 2015. doi:10.1007/s00420-015-1068-4

http://etd.uwc.ac.za/

CHAPTER SEVEN: PUBLICATION SIX − ORINGIAL RESEARCH ARTICLE TWO

A Pilot Study on the Relationship between Cardiovascular Health, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

European Journal of
Investigation in Health, Psychology and Education

MDPI

Article

A Pilot Study on the Relationship between Cardiovascular Health, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters

Jaron Ras [1,*], Denise L. Smith [2], Elpidoforos S. Soteriades [3,4], Andre P. Kengne [5] and Lloyd Leach [1]

1 Department of Sport, Recreation and Exercise Science, Faculty of Community and Health Sciences, University of the Western Cape, Cape Town 7535, South Africa
2 Health and Human Physiological Sciences, Skidmore College, Saratoga Springs, New York, NY 12866, USA
3 Healthcare Management Program, School of Economics and Management, Open University of Cyprus, 2200 Nicosia, Cyprus
4 Environmental and Occupational Medicine and Epidemiology (EOME), Department of Environmental Health, Harvard T.H. Chan School of Public Health, Harvard University, Boston, MA 02138, USA
5 Non-Communicable Diseases Research Unit, South African Medical Research Council, Cape Town 7500, South Africa
* Correspondence: 3405618@myuwc.ac.za

Abstract: Firefighters' face life threatening situations and are frequently exposed to numerous physical, chemical, biological, ergonomic and psychosocial hazards. The purpose of this pilot study was to investigate the feasibility of conducting a large-scale study on cardiovascular and musculoskeletal health, physical fitness and occupational performance of firefighters. We conducted a cross-sectional pilot study by recruiting 36 firefighters. A researcher-generated questionnaire and physical measures were used to collect data on sociodemographic characteristics, cardiovascular and musculoskele- tal health, physical fitness and occupational performance using a physical ability test (PAT). We documented a high equipment and intra-assessor reliability (r > 0.9). The potential logistic and/or administrative obstacles in the context of a larger study were discerned. Data were successfully retrieved using available equipment and survey instruments. Hypertension (30.6%) dyslipidaemia (33.3%), obesity (36.1%) and physical inactivity (66.7%) were the most prevalent cardiovascular disease risk factors. A significant difference between genders in total PAT completion time was also seen ($p < 0.001$). Cardiorespiratory fitness, lean body mass, grip strength and leg strength were significantly associated with occupational performance ($p < 0.001$). The pilot study supports the larger study feasibility and verified equipment and assessors' reliability for research. Cardiovascular health, musculoskeletal health and physical fitness may be related to PAT performance.

Keywords: firefighters; CVD risk factors; musculoskeletal health; physical fitness; occupational performance

check for updates

Citation: Ras, J.; Smith, D.L.; Soteriades, E.S.; Kengne, A.P.; Leach, L. A Pilot Study on the Relationship between Cardiovascular Health, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters. *Eur. J. Investig. Health Psychol. Educ.* **2022**, *12*, 1703–1718. https://doi.org/10.3390/ejihpe12110120

Academic Editors: María del Mar Molero Jurado and María del Carmen Pérez-Fuentes

Received: 28 October 2022
Accepted: 18 November 2022
Published: 21 November 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Firefighting is a hazardous occupation where firefighters routinely face life threatening situations, and are frequently exposed to high temperatures, toxic chemicals and fumes and many other hazards [1,2]. This necessitates that firefighters wear heavy insulated personal protective equipment (PPE), which places additional physical strain on firefighters [3,4]. In addition, firefighters have been shown to have multiple comorbidities, predisposing them to sudden cardiac events [1,5–7]. Moreover, many firefighters have low musculoskeletal health, and unfavourable physical fitness which restricts their occupational performance while on duty [8,9].

Over 45% of firefighters' on-duty fatalities are related to cardiovascular disease incidents [1]. Moreover, lower extremity, as well as lower back injuries, are highly prevalent in this population, negatively affecting their occupational performance [8,9]. To assist in

http://etd.uwc.ac.za/

maintaining good cardiovascular and musculoskeletal health, firefighters are expected to maintain a satisfactory level of physical fitness [10,11]. However, studies have shown that many firefighters' physical fitness levels do not appear sufficient to cope with the strains of their profession, further predisposing an already at-risk population to early career morbidity, job disability and higher mortality [12–14].

Firefighters have been reported to have a high prevalence of cardiovascular dis- ease (CVD) risk factors, with many firefighters having multiple comorbid CVD risk factors [15–21]. Furthermore, firefighters are reported to have a poor attitude toward health, with many firefighters opting to remain sedentary and engage in unhealthy di- etary habits [22–24]. Several firefighters are physically inactive during their leisure times and frequently suffer from musculoskeletal injuries [25]. Given the reported high levels of physical inactivity and relatively high rates of musculoskeletal injuries, research and associated policies are needed to mitigate the risk of cardiac events and musculoskeletal injuries among firefighters while on duty.

Therefore, the purpose of this pilot study was to investigate the feasibility of conducting a large-scale study on the cardiovascular health, musculoskeletal health, physical fitness and occupational performance among operational active firefighters. Specific aims were to explore possible logistic and/or administrative obstacles of a larger study; determine the intra-tester reliability of selected research equipment and instrument (questionnaire); determine the prevalence of CVD risk factors, musculoskeletal injuries, cardiorespiratory fitness and physical ability test (PAT) failures; and to explore the extent to which CVD risk factors and health metrics, musculoskeletal health and physical fitness are related to occupational performance in firefighters.

2. Materials and Methods

This pilot study used a quantitative, non-experimental, cross-sectional and correlational research design. The pilot study took place between May and June 2022 at one of the largest fire stations in the Cape Town Metropolitan area.

2.1. Participants

The study included all full-time male and female firefighters between the ages of 18 and 65 years. Part-time, volunteer and firefighters on leave were excluded from this study. In addition, administrative staff, or firefighters on administrative duty, due to illness or injury, were excluded from the pilot study. Firefighters were approached at the fire station to participate in the study. Information on the study was provided to each firefighter, before informed consent was signed by each participant.

2.2. Instrument and Tester Reliability and Validity

Prior to commencement of the pilot study, an initial trial was conducted where the assessors measured the reliability of their measurement techniques for all testing procedures used. In order to ensure intra-assessor reliability and validity, a minimum test–retest reliability coefficient of 0.8 was required prior to the commencement of the study to ensure tester reliability and was standardized across all measurements [26–28]. Each tester was tasked to perform one measurement for the duration of data collection to ensure test–retest reliability and data accuracy. Five successive measurements were obtained on all measurable study variables using standard and precision research equipment (CardioChek Plus analyzer, Omron Healthcare, Ltd., Hoofddorp, The Netherlands, blood pressure cuff and the Tanita© BC-1000 Plus BIA scale) and reliability coefficients were calculated. The technical error of measurement (TEM) was within acceptable parameters for the research being conducted [26–28]. The IPAQ was used to measure physical activity, which was shown to be a reliable and valid tool [29,30]. Systematic error of the equipment was tested and an accuracy rating of less than 5% was considered appropriate for research procedures.

http://etd.uwc.ac.za/

2.3. Research Procedures

A researcher-generated questionnaire was used to obtain information on sociodemographic data, cardiovascular health, musculoskeletal health, and lifestyle habits. The musculoskeletal health section of the questionnaire was based on the Cornell Musculoskeletal Discomfort Questionnaire [31]. Questions on physical activity were based on the International Physical Activity Questionnaire (IPAQ) [29].

2.4. Descriptive Measures

Stature was measured using a portable stadiometer (Seca model 700, Gmbh & Co., Hamburg, Germany), standing barefoot on a level floor with the heels together and the heels, buttocks and upper back touching the stadiometer rod. A Tanita© BC-1000 Plus bioelectrical impedance (BIA) analyzer was used to obtain body composition data, which included weight, lean body mass (LBM), fat mass, body fat percentage (BF%) and body mass. For the BIA assessment, firefighters were requested to wear minimal clothing, to stand upright, barefoot, and stationary on the scale. Waist circumference was measured at the point of the belly button [32]. Hip circumference was obtained at the level of the greatest posterior protuberance of the buttocks. Blood pressure was measured using the Omron Healthcare, Inc. M6 comfort intelligence automatic blood pressure monitor. Firefighters were asked to remain in a quiet seated position for 5 min prior to testing, with the left arm elevated onto the testing table. The midline of the bladder of the blood pressure cuff was placed over the brachial artery to ensure accurate and consistent readings. The participants blood pressures were obtained thrice, with at least two-minute intervals between measures. Total cholesterol and non-fasting blood glucose concentration was measured using a CardioChek® Plus analyzer, which has been shown to be accurate and reliable within industry standards [33]. The test entailed a finger prick, wherein the initial blood droplet was wiped off, and a second drop of blood was used for testing purposes.

2.5. Classification of Cardiovascular Disease Risk Factors

Age, as a risk factor, was classified as males over the age of 45 years and females over the age of 55 years [32]. Obesity was classified as a body mass index above 30 $kg \cdot m^{-2}$, central obesity was classified as a waist circumference above 102 cm for men and above 88 cm for woman [32]. Hypertension was classified as either a SBP above 140 mm Hg or a DBP blood pressure above 90 mm Hg or both or confirmed by a physician [32]. Dyslipi- daemia was classified as a total cholesterol concentration above 5.18 mmol·L or previously confirmed by a physician, and diabetes classified as a non-fasting blood glucose concentration above 11.1 mmol·L or previously confirmed by a physician. Cigarette smokers were classified as those that are current smokers or who have quit within the last six months [32]. Physical inactivity was classified as firefighters who exercised less than three days a week for at least 30 min [32]. A family history was classified as those that had a family history of myocardial infarction, coronary revascularization, or sudden cardiac death before 55 years in father or other first degree male relative, or before 65 years in mother or other first degree female relative [32].

2.6. Heart Rate Variability

Heart rate variability was measured at rest using the Polar™ H10 heart rate monitor. The equipment was moistened with room temperature water and fitted to the center of the participant's chest, directly in line with the xiphoid process of the sternum. The participant was asked to maintain a quiet seated position for five minutes before the measurement was taken. The participant's HRV was then recorded over a five-minute period, following the five-minute rest period, giving a total test time of 10 min. The HRV data were analyzed using the Kubio© Software version 3.4.3. The standard deviation of all normal-to-normal (NN) intervals (SDNN), root-mean-square of successive differences (rMSSD), low-frequency, high frequency ranges and also the ratio (LF/HF) are the most widely used HRV indices, and were used as main outcome measures for this pilot study [33–35].

http://etd.uwc.ac.za/

2.7. Physical Fitness

Data components of physical fitness were captured using a researcher-generated data collection sheet and the administration of physical tests and handgrip and back and leg dynamometer.

2.7.1. Cardiorespiratory Fitness

Cardiorespiratory fitness was estimated using the non-exercise method by applying the following formula: VO2max = 3.542+ (−0.014 × Age) + (0.015 × Body Mass [kg]) + (−0.011 × Resting Heart Rate) [36].

2.7.2. Handgrip Strength

Handgrip strength was assessed with a Takei® 5401-C handgrip dynamometer for upper body muscular strength and measured using a following standardized procedures from the American College of Sports Medicine (ACSM) [32]. Manufacturer accuracy for the handgrip ± 2.0-kg force (kgf). The grip bar was adjusted so the second phalangeal joint fit snugly under the handle. The dynamometer was set to zero. The firefighters were asked to hold the handgrip dynamometer in line with the forearm and the level of the thigh, and away from the body. The firefighters were asked to squeeze with as much force as possible, without holding their breath. The procedure was repeated twice and the highest reading of the two measures was recorded.

2.7.3. Leg Strength Dynamometer

Leg strength was measured with a Takei® back and leg strength dynamometer. Manufacturer accuracy for the back and leg strength dynamometer ± 6.0 kgf, respectively. To assess leg strength, the firefighters were asked to remain upright on the base of the dynamometer with their feet shoulder width apart. Firefighters were requested to allow their arms to remain in an extended position with their hands grasping the dynamometer with their palms in prone position holding the bar. The chain was adjusted to ensure that each firefighters' knees was in 110 degrees of flexion, which was approximately the midpoint of the patella tendon. The firefighters were instructed to pull as forcefully as possible on the chain, while attempting to straighten their knees. The procedure was repeated twice and the highest reading of the two was recorded.

2.7.4. Push-Ups

For upper body muscular endurance, the push-ups test was used [32]. The procedures for the push-up test were conducted in accordance with the ACSM guidelines [32]. Males were requested to position themselves in the standard prone position, with their hands positioned forward and under the shoulder, back in a straight position, head level and their toes as the pivotal point. Females were requested to perform the modified push-up position, with their hands shoulder width apart, head up, back straight, with their legs together, lower leg in contact with the mat, ankles in plantar flexion and their knees acting as the pivotal point. Firefighters were required to raise the body off the mat fully extending their elbow joints and returning to the down position. A hedgehog was placed under the chest of firefighters to maintain consistency when counting each repetition. The test was stopped when firefighters could not perform an additional push-up, or when two consecutive push-ups were performed incorrectly.

2.7.5. Sit-Ups

For abdominal muscular endurance, the sit-ups test was used [32]. The firefighters were asked to lay supine on the mat with their knees at 90 degrees flexion, with their hands across the shoulders, elbows pointing forward [37]. The firefighters were required to touch their knees with their elbows and then go back so the shoulders touch the floor. The number of repetitions performed were recorded. The test was ended when the firefighters experienced exhaustion, denoted as the inability to perform another repetition [37].

http://etd.uwc.ac.za/

2.7.6. Flexibility

Lower back and hamstring flexibility was assessed with the sit-and-reach method. The ACSM [32] guidelines for the sit-and-reach were used when conducting this test. The firefighters were asked to position themselves in a seated position, barefoot, where their knees were completely extended and the soles of the feet flat against the sit-and-reach box and the inner edges of the soles roughly 15.2 cm apart. Each firefighter was asked to inhale and, when exhaling, to drop the head between the arms and slowly reach as far forward as possible, holding the stretched position for approximately two seconds. Firefighters were given three attempts, and the most distant point reached with the fingertips was recorded.

2.7.7. Shoulder Reach Flexibility Test

The shoulder reach flexibility test was used to assess shoulder flexibility. The test required firefighters to touch the fingertips of each hand behind the back [38]. The firefighters were asked to flex one shoulder, externally rotate the humerus and flex the elbow while keeping the hand in a prone position against the torso. For the opposite arm, the shoulder joint was extended fully, internally rotated the humerus and flexed the elbow joint with the hand placed in the prone position, facing away from the torso [38]. Flexibility was graded based on whether the fingertips were touching.

2.8. Occupational Performance

The PAT was used to assess operational performance and was conducted according to the testing protocol of the City of Cape Town Fire and Rescue Service (CoCTFRS). The PAT is a test of simulated firefighting tasks and is graded on the time taken for each test (maximum time to complete task), and includes six simulation tasks, namely: (1) step- ups (≤90 s); (2) charged hose drag-and-pull (≤180 s); (3) ladder raise and extension (≤60 s); (4) equipment carry (≤60 s); (5) forcible entry (≤60 s); and (6) rescue drag (≤60 s). Firefighters are required to complete the simulation protocol in under 9 min (540 s) in order to pass, and are required to pass each task in under the recommended time, or the task will be deemed a failure. Firefighters are allowed 20 s recovery between tasks.

2.8.1. Step-Ups

The firefighters were required to place a high-rise pack onto their shoulders, which consisted of two 20 kg weights, made up of in a twin donut method. They were further required to perform 30 step-ups on a 200 mm platform. The step-up required firefighters to place both feet onto a platform for each repetition, and back onto the ground into the starting position.

2.8.2. Charged Hose Drag and Pull

This task required the firefighters to drag a charged 45 mm line 27 m and then pull the remainder of the charged line a further 15 m. To simulate a charged hose, a 45 mm line tied to a tyre was preferred. The event required that firefighters place the hose-line over their shoulder or across the chest and advance the hose to the 27 m mark. Thereafter, the firefighters dropped to at least one knee, or in a seated position and pulled the hose-line to the 15 m mark.

2.8.3. Ladder Raise and Extension

In this task, firefighters were asked to walk a ladder six meters toward the building, raise a 7–8 m aluminum ladder using every rung, in a hand-over-hand fashion, until stationary. Immediately thereafter, the firefighters walked to the second pre-position and, using the hauling line, hoisted a 35 kg drum, pulling down the line hand-over-hand, until the fly section reached the pulley and then lower the ladder once again. The firefighters then walked back the ladder and lowered the ladder using the hand-over-hand technique, returning the ladder to the original position.

http://etd.uwc.ac.za/

2.8.4. Equipment Carry

The equipment carry involved the firefighters carrying two foam drums weighing 25 kg each for a distance of 50 m. Firstly, the firefighter removed two foam drums from a 1.2 m high platform, one at a time, and placed them on the ground. The firefighters then proceeded to carry the drums 25 m around the first marked position, around the cone, and back to the starting point, walking another 25 m. Upon returning, the firefighters placed the foam drums back onto the platform, one at a time.

2.8.5. Forcible Entry

The forcible entry event required firefighters to pick up a 6 kg sledgehammer and strike the tyre to drive the tyre a distance of 600 mm.

2.8.6. Rescue Drag

This event required firefighters to grasp an 80 kg tyre on the shoulders of the harness and drag the tyre 11 m to a prepositioned mark, perform a 180-degree turn, around the mark, and continue an additional 11 m toward the finish line.

2.9. Statistical Analysis

The data were analyzed using SPSS® software, version 28 (Chicago, IL, USA). The data were collected, coded and cleaned for errors using the double entry method on Microsoft Excel. Descriptive statistical analyses, such as the mean, standard deviation, frequencies, and percentages were performed. To assess the test–retest reliability of the equipment and the inter- and intra-assessor reliability, Pearson's correlation was used. A test for normality was performed using the Shapiro–Wilk test, and indicated the data were not normally distributed. Thereafter, inferential statistics, consisting of the Mann–Whitney-U test and Kruskal–Wallis-H for differences and the Spearman's Correlation coefficient for continuous variables were performed. A p-value of <0.05 was used to indicate statistical significance.

3. Results

3.1. Recruitment of Participants

The questionnaire and the static physical measures took approximately 15 to 20 min each to complete, while the physical fitness tests took approximately 10 to 15 min to complete, and the PAT took approximately 5 to 15 min to complete. Overall, the average time for the completion of the testing battery was 40 to 55 min per firefighter. However, three to four firefighters could be tested concurrently and up to four firefighters were allowed to complete a testing battery in an hour, indicating that such data collection is feasible for the larger study. The pilot study provided the researchers with the opportunity to recruit participants to participate in the larger study and allowed researchers to plan and coordinate with staff to test all participants. The response rate was very good, as all the firefighters who were approached agreed to participate in the pilot study.

3.2. Feedback on Questionnaire

The most frequent concerns raised by firefighters were the use of the abbreviation "PPE". Firefighters were not familiar with this word and, often, needed an explanation. The other term was the use of "musculoskeletal", which many were not familiar with either. The firefighters noted that the information required was successfully obtained via the questions, with no confusion or misinterpretation present. The station commanders and platoon commanders confirmed the appropriateness of the questionnaires and provided suggestions for terminology that all firefighters would understand, such as "physical injury", and were able to provide examples of injuries and descriptions for certain questions.

http://etd.uwc.ac.za/

3.3. Assessor and Instrument Reliability

The results from the pilot study indicated that all physical measures were reliably and consistently acquired (r = 0.912–0.998) (Table 1).

Table 1. Assessor and instrument reliability and validity.

Variable	N	r
Body mass (kg)	36	0.988
Height (cm)	36	0.994
Bodyfat (%)	36	0.966
Lean body mass (kg)	36	0.975
Waist circumference (cm)	36	0.953
Hip circumference (cm)	36	0.967
Systolic blood pressure (mm Hg)	34	0.920
Diastolic blood pressure (mm Hg)	34	0.912
Total cholesterol (mmol·L^{-1})	10	0.997
Low-density lipoprotein (mmol·L^{-1})	10	0.999
High-density lipoprotein (mmol·L^{-1})	10	0.999
Triglycerides (mmol·L^{-1})	10	0.995
Non-fasting blood glucose (mmol·L^{-1})	10	0.998

Note: kg—kilogram; cm—centimetre; %—percentage; mm Hg—millimetres mercury; mmol·L^{-1}—millimoles per litre; r—Pearson's correlation coefficient.

Firefighters' demographic characteristics, categorized by gender, are reported in Table 2. The mean age and years of experience of firefighters was 39.1 ± 9.6 years and 14.9 ± 10.5, respectively. The mean cardiorespiratory fitness for firefighters was over the recommended 42 mL·kg·min (12 METs). The overall completion time for the PAT was 418.2 ± 215.9 s. Regarding gender, the mean LBM for males was 61.9 ± 8.1 kg and 44.1 ± 3.5 kg for females (p < 0.001). The mean grip strength for males was 97.0 ± 24.1 kg and 61.4 ± 9.1 kg for females (p < 0.001). The mean leg strength for males was 118.5 ± 30.8 kg and 73.9 ± 11.4 kg for females (p < 0.001. The mean total completion time was 361.9 ± 169.8 s for males and 733.5 ± 178.9 s for females (p = 0.001), with males performing significantly better on all tasks.

Table 2. Demographic characteristics of firefighters according to gender.

Variable	Total Firefighters		Male		Female		*p*-Value
	N	X ± SD	N	X ± SD	N	X ± SD	
Age (years)	36	39.1 ± 9.6	30	38.6 ± 10.0	6	41.2 ± 7.6	0.312
Years of experience (years)	36	14.9 ± 10.5	30	15..3 ± 10.9	6	13.0 ± 8.6	0.717
Body mass (kg)	36	83.4 ± 14.4	30	85.9 ± 14.0	6	70.6 ± 8.3	0.010 *
Stature (cm)	36	173.9 ± 10.3	30	176.9 ± 8.2	6	159.3 ± 7.1	<0.001
BMI (kg·m^{-2})	36	27.6 ± 4.1	30	27.5 ± 4.1	6	27.9 ± 4.4	0.820
Waist circumference (cm)	36	94.0 ± 11.5	30	95.6 ± 11.2	6	86.0 ± 10.8	0.094
Hip circumference (cm)	36	106.4 ± 7.3	30	105.9 ± 7.2	6	109.2 ± 7.8	0.394
Bodyfat percentage (%)	36	24.9 ± 9.0	30	23.1 ± 8.3	6	34.2 ± 7.0	0.005 **
Lean body mass (kg)	36	58.9 ± 10.1	30	61.9 ± 8.1	6	44.1 ± 3.5	<0.001
Systolic blood pressure (mm Hg)	36	130.7 ± 11.9	30	129.7 ± 11.2	6	135.3 ± 15.2	0.418
Diastolic blood pressure (mm Hg)	36	80.1 ± 9.6	30	78.6 ± 8.8	6	87.2 ± 10.9	0.064
Total cholesterol (mmol·L^{-1})	36	4.6 ± 0.9	30	4.6 ± 0.9	6	4.7 ± 0.8	0.725
Low-density lipoprotein (mmol·L^{-1})	36	2.9 ± 0.8	30	2.7 ± 0.8	6	2.7 ± 0.6	0.664
High-density lipoprotein (mmol·L^{-1})	36	1.2 ± 0.3	30	1.2 ± 0.2	6	1.6 ± 0.3	0.741
Triglycerides (mmol·L^{-1})	36	1.6 ± 1.1	30	1.8 ± 1.1	6	1.0 ± 0.3	0.078
Non-fasting blood glucose (mmol·L^{-1})	36	5.2 ± 0.8	30	5.3 ± 0.8	6	4.7 ± 0.6	0.052

http://etd.uwc.ac.za/

Table 2. *Cont.*

Variable	Total Firefighters N	Total Firefighters X ± SD	Male N	Male X ± SD	Female N	Female X ± SD	*p*-Value
Heart rate variability (ms)	34	872.7 ± 165.1	28	877.8 ± 170.4	6	849.0 ± 149.4	0.644
Standard deviation of the N-N intervals (ms)	34	49.5 ± 27.9	28	51.1 ± 29.9	6	42.0 ± 16.7	0.741
Low frequency (Hz)	34	0.08 ± 0.03	28	0.09 ± 0.03	6	0.07 ± 0.02	0.145
High frequency (Hz)	34	0.21 ± 0.06	28	0.20 ± 0.05	6	0.25 ± 0.06	0.074
LF/HF ratio (ms)	34	4.14 ± 6.44	28	4.78 ± 6.95	6	1.2 ± 0.6	0.091
Physical fitness							
VO_{2max} (L·min)	34	3.6 ± 0.2	28	3.6 ± 0.3	6	3.5 ± 0.2	0.838
VO_{2max} (mL·kg·min)	34	44.0 ± 5.9	28	44.3 ± 6.2	6	43.3 ± 5.4	0.768
Grip strength (kg)	35	93.7 ± 21.0	29	97.0 ± 24.1	6	61.4 ± 9.1	<0.001 **
Leg strength (kg)	35	110.9 ± 33.0	29	118.5 ± 30.8	6	73.9 ± 11.4	<0.001 **
Push-up (RPM)	35	32.8 ± 13.9	29	33.2 ± 14.3	6	31.0 ± 12.9	0.815
Sit-up (RPM)	35	27.4 ± 9.8	29	28.6 ± 9.6	6	21.5 ± 9.2	0.093
Sit-and-reach (cm)	35	41.6 ± 8.6	29	41.1 ± 9.2	6	43.8 ± 4.4	0.535
Shoulder flexibility (R)	35	2.3 ± 0.9	29	2.2 ± 1.0	6	2.8 ± 0.4	0.272
Shoulder flexibility (L)	35	2.0 ± 1.0	29	1.9 ± 1.1	6	2.2 ± 0.8	0.815
Physical ability test							
Step-up (s)	33	72.1 ± 26.5	28	65.3 ± 11.3	5	110.0 ± 51.5	0.016 *
Charged hose drag and pull (s)	33	100.3 ± 55.5	28	82.6 ± 32.2	5	199.6 ± 55.9	<0.001 **
Ladder raise and extension (s)	33	78.8 ± 48.5	28	65.0 ± 29.5	5	156.2 ± 64.5	<0.001 **
Equipment carry (s)	33	60.0 ± 41.3	28	54.4 ± 41.1	5	91.8 ± 28.4	0.006 **
Forcible entry (s)	33	42.7 ± 37.2	28	38.2 ± 36.4	5	67.7 ± 34.6	0.039 *
Rescue drag (s)	33	66.3 ± 58.0	28	56.4 ± 52.2	5	135.3 ± 54.9	0.005 **
Total Time (s)	33	418.2 ± 215.9	28	349.4 ± 179.7	5	733.5 ± 178.9	0.001 **

Note: * indicates statistical significance < 0.05; ** indicates statistical significance < 0.01. $\overline{X}$—mean; SD—standard deviation; kg—kilogram; cm—centimetre; %—percentage; mm Hg—millimetres mercury; mmol·L^{-1}—millimoles per litre; ms—milliseconds; Hz—Hertz; L·min—litres per minute; mL·kg·min- millilitres per minute per kilogram; RPM—repetitions per minute; s—seconds.

In Table 3 we report the differences between musculoskeletal injuries and weekly physical activity according to the PAT. The mean completion time for firefighters who had a history of musculoskeletal injures was 79.9 ± 65.3 s and for firefighters without a history of musculoskeletal injury, the completion time was 40.1 ± 27.7 s (p = 0.017) (Table 3).

Table 3. Differences between physical ability test based on gender, injury history and weekly physical activity.

Physical Ability Test	Injuries: Injured X ± SD	Injuries: Never Injured X ± SD	*p*-Value	Weekly Physical Activity: Vigorously Active X ± SD	Weekly Physical Activity: Moderately Active X ± SD	*p*-Value
Step-up (s)	72.7 ± 20.3	71.1 ± 35.9	0.228	64.8 ± 14.7	76.3 ± 30.9	0.069
Charged hose drag and pull (s)	106.1 ± 53.2	90.1 ± 60.4	0.213	86.5 ± 45.6	108.2 ± 60.1	0.075
Ladder raise and extension (s)	82.9 ± 44.6	71.8 ± 56.2	0.131	67.6 ± 37.3	85.2 ± 53.7	0.258
Equipment carry (s)	68.7 ± 48.6	44.8 ± 16.7	0.104	61.3 ± 60.6	59.3 ± 26.6	0.104
Forcible entry (s)	48.1 ± 40.9	33.2 ± 28.5	0.518	40.4 ± 43.6	43.9 ± 34.1	0.326
Rescue drag (s)	79.9 ± 65.3	40.1 ± 27.7	0.017 *	61.9 ± 74.9	68.8 ± 47.2	0.136
Total Time (s)	458.4 ± 227.7	298.2 ± 203.4	0.069	382.6 ± 249.6	438.6 ± 197.8	0.082

Note: * indicates statistical significance < 0.05; $\overline{X}$—mean; SD—standard deviation; s—seconds; ±—standard deviation; p—significance level.

http://etd.uwc.ac.za/

In Table 4, we describe the prevalence of CVD risk factors, musculoskeletal injuries, suboptimal cardiorespiratory fitness and PAT results in our sample. According to the CVD risk factors, 19.4% of firefighters were aged, 26.1% were obese, 30.6% were hypertensive, 5.6% were diabetic, 30.6% were dyslipidaemic, 33.3% were cigarette smokers, 27.8% had a family history of heart disease and 66.7% were physically inactive. All CVD risk factors were categorized according to the ACSM guidelines [32]. A total of 61.1% of firefighters reported experiencing an injury throughout their carriers, with the most prevalent injury being the ankle and foot (21.7%). About half of firefighters (47.2%) did not meet the minimum recommended cardiorespiratory fitness requirement of 42 mL·kg·min for firefighting, while 69.7% of firefighters did not meet the minimum time requirement of 580 s for PAT.

Table 4. Prevalence of CVD risk factors, musculoskeletal injuries, suboptimal physical fitness, and physical ability test failures in firefighters.

Variable	N	%
Aged (years)	7	19.4
Obesity (kg·m^{-2})	13	36.1
Central obesity (cm)	9	25.0
Hypertensive (mm Hg)	11	30.6
Diabetic (mmol·L^{-1})	2	5.6
Dyslipidaemia (mmol·L^{-1})	11	30.6
Cigarette smoking	12	33.3
Physical inactivity (min)	24	66.7
Family history	10	27.8
Musculoskeletal injuries	22	61.1
Neck	1	4.3
Shoulder	3	13.0
Elbow	1	4.3
Wrist and hand	1	4.3
Lower back	4	17.4
Knee	3	13.0
Ankle and foot	5	21.7
Multiple injuries	4	17.4
Suboptimal cardiorespiratory fitness (est. VO_{2max}) #	17	47.2
Physical ability test time (s)	23	69.7

Note: kg—kilogram; cm—centimetre; %—percentage; mm Hg—millimetres mercury; mmol·L^{-1}—millimoles per litre; ms—milliseconds; Hz—Hertz; L·min (estimated)—litres per minute; mL·kg·min (estimated)—millilitres per minute per kilogram (Est.); RPM—repetitions per minute; s—seconds. #—cardiorespiratory fitness defined as an estimated VO_{2max} of 42 mL·kg·min or 12 metabolic equivalents.

As seen in Table 5, there were significant negative correlations between LBM and total completion time (r = −0.725, p < 0.001), between VO_{2max} and total completion time (r = −0.593, p < 0.001), between grip strength and total completion time (r = −0.571, p < 0.001) and between leg strength and total completion time (r = −0.484, p = 0.004). In addition, there were significant positive correlations between BF% and the step-up (r = 0.503, p = 0.003), the charged hose drag and pull (r = 0.368, p = 0.035), and ladder raise and extension (r = 0.363, p = 0.038). Lean body mass, grip strength and leg strength were significantly and negatively correlated to all PAT tasks. In addition, VO_{2max} was significantly and negatively correlated to all occupational tasks, except the stair climb. Finally, there was a significant negative correlation between knee discomfort and the step-up (r = −0.350, p = 0.046), and between foot and ankle discomfort and the step-up (r = −0.364, p = 0.037).

http://etd.uwc.ac.za/

Table 5. Associations between CVD risk factors, heart rate variability, musculoskeletal health, physical fitness, and occupational performance (defined as time to complete each task and overall PAT completion time).

	1	2	3	4	5	6	7
CVD risk factors							
Age	0.302	0.373 *	0.084	0.208	0.145	0.056	0.241
Body mass index	0.391 *	0.067	0.081	−0.026	0.050	−0.166	0.058
Bodyfat percentage	0.503 **	−0.368 *	0.363	0.199	0.296	0.160	0.369 *
Lean body mass	−0.376 *	−0.690 **	−0.693 **	−0.642 **	−0.580 **	−0.697	−0.725 **
Systolic blood pressure	0.187	0.039	0.118	0.116	−0.064	0.021	0.104
Diastolic blood pressure	0.394 *	0.261	0.278	0.225	−0.002	0.174	0.272
Non-fasting blood glucose	−0.207	−0.069	−0.184	−0.008	−0.051	−0.040	−0.092
Total cholesterol	0.359 *	0.304	0.289	0.201	0.016	0.240	0.257
Heart rate variability							
Heart rate variability (N-N interval)	−0.142	−0.168	−0.048	−0.099	0.015	−0.278	−0.133
SDNN	−0.455 *	−0.329	−0.172	−0.166	0.071	−0.146	−0.225
RMSSD	−0.368 *	−0.219	−0.085	−0.109	0.155	−0.111	−0.126
Low frequency range	−0.264	−0.384 *	−0.377 *	−0.322	−0.302	−0.214	−0.365 *
High frequency range	0.243	0.438 *	0.338	0.386 *	0.466 **	0.273	0.398 *
Stress index	0.459 **	0.367 *	0.188	0.218	−0.018	0.165	0.261
Physical fitness							
Estimated VO_{2max} #	−0.258	−0.667 **	−0.459 **	−0.541 **	−0.395 *	−0.626 **	−0.593 **
Grip strength	−0.412 *	−0.589 **	−0.597 **	−0.527 **	−0.384 *	−0.554 **	−0.571 *
Leg strength	−0.301	−0.530 **	−0.466 **	−0.460 **	−0.400 *	−0.457 *	−0.484 **
Push-up	−0.201	−0.288	−0.085	−0.232	−0.215	−0.248	−0.222
Sit-ups	−0.354 *	−0.460 *	−0.189	−0.202	−0.289	−0.154	−0.308
Sit-and-reach	−0.206	−0.006	−0.041	−0.004	−0.105	−0.035	−0.059
Musculoskeletal health							
Neck	0.269	0.083	0.225	−0.115	0.015	−0.090	−0.067
Shoulder	0.107	−0.230	0.007	0.022	−0.306	−0.051	−0.083
Upper back	−0.003	0.082	0.144	0.009	0.149	0.123	0.115
Upper arm	0.230	0.029	0.018	−0.057	−0.024	0.088	0.084
Lower back	0.230	0.029	0.018	−0.057	−0.024	0.088	0.084
Forearm and wrist	−0.222	−0.201	−0.038	−0.127	−0.054	0.032	−0.080
Hip/buttocks	0.172	−0.019	0.002	−0.077	−0.174	−0.027	−0.033
Thigh	0.195	−0.195	0.056	−0.167	−0.139	0.029	−0.037
Knee	0.350 *	−0.097	−0.075	−0.136	0.003	0.195	−0.002
Lower leg	0.195	−0.195	0.056	−0.167	−0.139	0.029	−0.037
Foot and ankle	0.364 *	−0.064	0.101	0.094	0.093	0.140	0.113

Note: * indicates statistical significance < 0.05; ** indicates statistical significance <0.01; #—indicates VO_{2max} estimation from non-exercise equation. SDNN—standard deviation of normal-to-normal intervals; RMSSD—root mean square of successive differences between normal heartbeats; 1—step-up; 2—charged hose and pull; 3—ladder raise and extension; 4—equipment carry; 5—forcible entry; 6—rescue drag; 7—total completion time (overall PAT duration).

4. Discussion

The objectives of the current study were to explore possible logistic or administrative obstacles the researchers would face in a similar larger study; determine the intra-assessor reliability of selected research equipment and survey instrument; determine the prevalence of CVD risk factors, musculoskeletal injuries, poor cardiorespiratory fitness and physical ability test (PAT) failures; and to explore the extent to which CVD risk factors and health metrics, musculoskeletal health and physical fitness are related to occupational performance in firefighters. The pilot study allowed us to determine effective methods of recruiting participants to participate in the larger study and plan and coordinate with fire department staff. The equipment was shown to be reliable and suitable for research purposes (r > 0.9). Face validation and content validation [39,40] of the questionnaire was successful, and accurately retrieved the data that was required from the firefighters. The pilot study indicated that the required information, such as demographics, CVD risk factors and health

http://etd.uwc.ac.za/

metrics, musculoskeletal health, physical fitness and PAT measures could be successfully obtained from the research equipment and instruments used. The pilot study indicated that the battery of tests would take approximately 40 to 55 min per firefighter, with three to four firefighters being tested simultaneously, which is feasible for the large study. Hypertension (30.6%), dyslipidaemia (33.3%), obesity (36.1%) and physical inactivity (66.7%) were the most prevalent CVD risk factors, with the prevalence of hypertension [16,21,41–44], dyslipidaemia [16,20,21,45] and physical inactivity [46–48] being higher than previous studies, and obesity prevalence similar to previous research [15–17,19,21]. The majority of firefighters (61.1%) reported having experienced musculoskeletal injuries, with the ankle and foot being the most frequently injured area (21.7%), which is consistent with previous literature [9]. In addition, 47.2% had not met the minimum recommended cardiorespiratory fitness level of 42 mL·kg·min based on estimated measures. Furthermore, 69.7% of firefighters did not meet the minimum time required to pass the PAT. Further, lean body mass, estimated VO2max, grip strength and leg strength were most related to individual tasks and total completion time for the PAT, which was consistent with previous literature [12,49].

4.1. Challenges Encountered, Feedback from Firefighters and Future Planning

The firefighters indicated that the length of the questionnaire was a concern, with many of the questions being perceived as repetitive. Language used was important in the questionnaire, as several of the terms were confusing to the firefighters, and were changed to simpler terms based on suggestions provided. This feedback provided valuable information for the procedures for the full study, such as a much shorter questionnaire containing simpler terms and phrases. The researchers noted that firefighters required guidance on the self-administered questionnaire, with a designated researcher tasked to ensure that the questionnaire were answered correctly, and that all questions from the firefighters were answered succinctly. Potential obstacles were identified with the PAT, most attributed to researchers needing to ensure that time measuring was initiated at the onset of each activity, and that firefighters follow the correct order for the testing. For the full study, all these obstacles will be addressed to ensure efficiency and standardization of the testing. The validation of the research equipment and instruments was successful, as the data required were successfully obtained from the firefighters.

4.2. Preliminary Results

The non-exercise estimation of VO2max formula that was used in the current study had been validated in a previous study, where it was shown to be reliable when compared to the Astrand submaximal bike test [36]. In addition, the results of that study indicated that the estimated VO2max was a moderately significant predictor of Astrand submaximal VO2max (r = 0.688, $p < 0.001$). Moreover, estimated VO2max has previously been used in studies conducted on firefighters [50,51]. A study investigated the accuracy of the non-exercise estimation of the VO2max method compared to the cooper 12 min test, and reported moderate to high reliability/specificity (71.5%) in firefighters [52]. Another study reported that moderate to moderate correlations existed between non-exercise estimation of VO2max and the Gerkin treadmill test (r = 0.69) and the Queen's College step test (r = 0.51) [53]. The results in the current study indicated that 47.2% of firefighters did not meet the minimum requirement of 42 mL·kg·min for firefighting, as recommended by many researchers. A study by Houck et al. [54] reported that only 27.5% of full-time Urban and Wildland firefighters from New Mexico met the minimum recommended cardiorespiratory fitness level, substantially lower than the current pilot study. Comparably, Baur et al. [55] reported that 56.3% career firefighters in the United States did not meet the minimum recommendation of 42 mL·min·kg. In the current results, 69.7% of firefighters failed to complete the PAT in under 540 s, as stipulated in the firefighters' health and wellness policy document. Stevenson et al. [56] conducted three firefighting tasks, namely, the ladder lift, the ladder lower, and the ladder extension, and found that 61% of firefighters passed the ladder lift, 77% passed the ladder lower and 71% passed the ladder extension. Von

http://etd.uwc.ac.za/

Heimburg et al. [57] found that 7.9% of firefighters failed to meet the requirements to pass the occupational simulation [57], considerably fewer than the present study, and was composed of the puzzle, hose dragging, hose connection and disconnection, heavy can carry, the heat chamber and the "retreat". This may be due to the participants in the study having performed the occupational simulation protocol multiple times [57], as opposed to the current study, where firefighters only performed the simulation once. This is supported in studies by Schonfeld et al. [58] and Stevenson et al. [59] that found that subsequent performances of a simulation protocol resulted in better performances. Furthermore, the current results showed that cardiorespiratory fitness was significantly related to all PAT tasks, except the step-up, and was related to overall completion time. This may, somewhat, explain why numerous firefighters failed to meet the minimum time requirements for the PAT, as many did not meet the minimum fitness requirements. Previous studies supported this finding, as studies have shown that cardiorespiratory fitness may be the most significant factor in occupational performance in firefighters [60–62].

There was a significant difference between all PAT tasks and overall completion time between male and female firefighters. This result is consistent with previous re- search [63–66]. This should be an important consideration when conducting the larger study, as gender differences in performance may be a significant confounder in the comple- tion times. A study by von Heimburg et al. [57] indicated that body mass and height were significantly related to occupational performance in firefighters. Since males are generally heavier and taller than females, this would partly explain the difference in performance. The study noted that shorter males with a lower body mass performed significantly worse on the occupational performance tasks [57]. In addition, many firefighting simulation tests use standardized equipment, requiring all firefighters to perform the same tasks using the same equipment, such as an 80 kg victim drag, and does not account for the relative size or weight of the firefighter performing the duties [60,62,67]. Invariably, lighter and smaller firefighters would exert more effort for the same task compared to their heavier and taller counterparts. On average, males had 36% greater skeletal muscle mass than females, and more specifically, 40% more skeletal muscle mass than females in the upper body and 33% more in the lower body [68]. This may be another important consideration regarding the differences in performance between male and female firefighters.

The results indicated that age, obesity, LBM, cardiorespiratory fitness, grip strength and leg strength were significantly related to occupational performance, which is similar to the results reported in previous studies [12,60–62,67].

4.3. Trends with Correlations

Numerous *p*-values bordered on significance, suggesting they would likely result in significant findings if a larger sample size were studied.

4.4. Strengths and Limitations

A strength of the study was that this pilot would inform the feasibility of a larger study. This study indicated that the equipment used, and intra-assessor reliability was suitable for use in the larger scale study. The preliminary results indicated that significant relationships existed between the variables in this pilot study, suggesting significant results for the larger scale study. A weakness of this study was that only one fire station was used for the pilot. In addition, very few female firefighters partook in this study. The relatively small sample size of the firefighters in this study cannot be generalized to the larger firefighter population, motivating the implementation of the full-scale study. The selection of the participants was recruited via convenient sampling, rather than random sampling.

5. Conclusions

The current pilot study was successful in accomplishing the objectives that were set out, including the face and content validation of the survey questionnaire. The total time for completing the full battery of tests was established and deemed acceptable, especially as up

http://etd.uwc.ac.za/

to four firefighters can progress through the testing battery simultaneously. The assessors involved were given opportunity to familiarize themselves with the tests and the equipment and test–retest reliability showed high validity and reliability for use in the larger study. The preliminary results indicated that hypertension (30.6%) dyslipidaemia (33.3%), obesity (36.1%) and physical inactivity (66.7%) were the most prevalent CVD risk factors, with the majority of firefighters failing to meet the minimum required cardiorespiratory fitness level (47.2%) and required PAT completion time (69.7%). Cardiorespiratory fitness, lean body mass and grip and leg strength were significantly related to PAT tasks, and total completion time. We conclude that the planned larger study is feasible with no significant changes needed regarding the design and methodology.

Recommendations

The questionnaire should be shortened and repetitive questions should be removed. The larger study should attempt to include more female firefighters to strengthen the generalizability of findings to females in the CoCTFRS.

Author Contributions: Conceptualization, J.R.; methodology, J.R., L.L., E.S.S., D.L.S. and A.P.K.; software, J.R.; validation, J.R., L.L., E.S.S., D.L.S. and A.P.K.; formal analysis, J.R.; investigation, J.R. and L.L.; resources, J.R., L.L. and A.P.K.; data curation, J.R.; writing—original draft preparation, J.R.; writing—review and editing, J.R., L.L., E.S.S., D.L.S. and A.P.K.; visualization, J.R.; supervision, J.R., L.L., E.S.S., D.L.S. and A.P.K.; project administration, J.R.; funding acquisition, J.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by The National Research Foundation (NRF), grant number 141282 and The Ryoichi Sasakawa Young Leaders Fellowship Fund (SLYFF), grant number N/A.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the BIOMEDICAL RESEARCH ETHICS COMMITTEE (BMREC) of THE UNIVERSITY OF THE WESTERN CAPE (BM21/10/19) for studies involving humans.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to this being an ongoing study, and the POPIA act, which restricts the access to private information being made publicly available.

Acknowledgments: We would like to thank the station commanders, Smith, Dumsday and Anthony, for allowing the pilot study to be conducted at their station. We would like to thank each firefighter who voluntarily participated in the study.

Conflicts of Interest: The authors declare no conflict of interest.

UNIVERSITY of the
WESTERN CAPE

References

1. Smith, D.L.; Barr, D.A.; Kales, S.N. Extreme Sacrifice: Sudden Cardiac Death in the US Fire Service. *Extrem. Physiol. Med.* **2013**, *2*, 6. [CrossRef] [PubMed]
2. Soteriades, E.S.; Smith, D.L.; Tsismenakis, A.J.; Baur, D.M.; Kales, S.N. Cardiovascular Disease in US Firefighters: A Systematic Review. *Cardiol. Rev.* **2011**, *19*, 202–215. [CrossRef] [PubMed]
3. Smith, D.L.; DeBlois, J.P.; Kales, S.N.; Horn, G.P. Cardiovascular Strain of Firefighting and the Risk of Sudden Cardiac Events. *Exerc. Sport Sci. Rev.* **2016**, *44*, 90–97. [CrossRef] [PubMed]
4. Marcel-Millet, P.; Ravier, G.; Grospretre, S.; Gimenez, P.; Freidig, S.; Groslambert, A. Physiological Responses and Parasympathetic Reactivation in Rescue Interventions: The Effect of the Breathing Apparatus. *Scand. J. Med. Sci. Sport.* **2018**, *28*, 2710–2722. [CrossRef]
5. Smith, D.L.; Haller, J.M.; Korre, M.; Sampani, K.; Porto, L.G.G.; Fehling, P.C.; Christophi, C.A.; Kales, S.N. The Relation of Emergency Duties to Cardiac Death Among US Firefighters. *Am. J. Cardiol.* **2019**, *123*, 736–741. [CrossRef]
6. Farioli, A.; Yang, J.; Teehan, D.; Baur, D.M.; Smith, D.L.; Kales, S.N. Duty-Related Risk of Sudden Cardiac Death among Young US Firefighters. *Occup. Med.* **2014**, *64*, 428–435. [CrossRef]
7. Yang, J.; Teehan, D.; Farioli, A.; Baur, D.M.; Smith, D.; Kales, S.N. Sudden Cardiac Death among Firefighters ≤ 45 Years of Age in the United States. *Am. J. Cardiol.* **2013**, *112*, 1962–1967. [CrossRef]
8. Phelps, S.M.; Drew-Nord, D.C.; Neitzel, R.L.; Wallhagen, M.I.; Bates, M.N.; Hong, O.S. Characteristics and Predictors of Occupational Injury Among Career Firefighters. *Workplace Health Saf.* **2018**, *66*, 291–301. [CrossRef]

http://etd.uwc.ac.za/

9. Frost, D.M.; Beach, T.A.C.; Crosby, I.; McGill, S.M. Firefighter Injuries Are Not Just a Fireground Problem. *Work* **2015**, *52*, 835–842. [CrossRef]
10. Smith, D.L. Firefighter Fitness: Improving Performance and Preventing Injuries and Fatalities. *Curr. Sport. Med. Rep.* **2011**, *10*, 167–172. [CrossRef]
11. Yu, C.C.W.; Au, C.T.; Lee, F.Y.F.; So, R.C.H.; Wong, J.P.S.; Mak, G.Y.K.; Chien, E.P.; McManus, A.M. Association Between Leisure Time Physical Activity, Cardiopulmonary Fitness, Cardiovascular Risk Factors, and Cardiovascular Workload at Work in Firefighters. *Saf. Health Work* **2015**, *6*, 192–199. [CrossRef] [PubMed]
12. Chizewski, A.; Box, A.; Kesler, R.; Petruzzello, S.J. Fitness Fights Fires: Exploring the Relationship between Physical Fitness and Firefighter Ability. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11733. [CrossRef] [PubMed]
13. Mehrdad, R.; Movasatian, F.; Momenzadeh, A.S. Fitness for Work Evaluation of Firefighters in Tehran. *Acta Med. Iran.* **1970**, *51*, 265–269.
14. Donovan, R.; Nelson, T.; Peel, J.; Lipsey, T.; Voyles, W.; Israel, R.G. Cardiorespiratory Fitness and the Metabolic Syndrome in Firefighters. *Occup. Med.* **2009**, *59*, 487–492. [CrossRef]
15. Ras, J.; Leach, L. Prevalence of Coronary Artery Disease Risk Factors in Firefighters in the City of Cape Town Fire and Rescue Service–A Descriptive Study. *J. Public Health Res.* **2021**, *10*, jphr-2021. [CrossRef] [PubMed]
16. Savall, A.; Charles, R.; Bertholon, A.; Gramont, B.; Trombert, B.; Barthélémy, J.C.; Roche, F. Volunteer and Career French Firefighters: Cardiovascular Risk Factors and Cardiovascular Risk Assessment. *Eur. J. Prev. Cardiol.* **2020**, *27*, 107–109. [CrossRef] [PubMed]
17. Martin, Z.T.; Schlaff, R.A.; Hemenway, J.K.; Coulter, J.R.; Knous, J.L.; Lowry, J.E.; Ode, J.J. Cardiovascular Disease Risk Factors and Physical Fitness in Volunteer Firefighters. *Int. J. Exerc. Sci.* **2019**, *12*, 764–776.
18. Mathias, K.C.; Bode, E.D.; Stewart, D.F.; Smith, D.L. Changes in Firefighter Weight and Cardiovascular Disease Risk Factors over Five Years. *Med. Sci. Sport. Exerc.* **2020**, *52*, 2476–2482. [CrossRef]
19. Moffatt, S.M.; Stewart, D.F.; Jack, K.; Dudar, M.D.; Bode, E.D.; Mathias, K.C.; Smith, D.L. Cardiometabolic Health among United States Firefighters by Age. *Prev. Med. Rep.* **2021**, *23*, 101492. [CrossRef]
20. Bode, E.D.; Mathias, K.C.; Stewart, D.F.; Moffatt, S.M.; Jack, K.; Smith, D.L. Cardiovascular Disease Risk Factors by BMI and Age in United States Firefighters. *Obesity* **2021**, *29*, 1186–1194. [CrossRef]
21. Smith, D.L.; Graham, E.; Stewart, D.; Mathias, K.C. Cardiovascular Disease Risk Factor Changes over 5 Years among Male and Female US Firefighters. *J. Occup. Environ. Med.* **2020**, *62*, 398–402. [CrossRef] [PubMed]
22. Ras, J.; Leach, L. Firefighters' Health Knowledge, Cardiovascular Disease Risk Factors and Sociodemographic Characteristics as Predictors of Firefighters Attitudes Toward Health. *J. Occup. Environ. Med.* **2022**, *64*, e705–e713. [CrossRef] [PubMed]
23. Dobson, M.; Choi, B.; Schnall, P.L.; Wigger, E.; Garcia-Rivas, J.; Israel, L.; Baker, D.B. Exploring Occupational and Health Behavioral Causes of Firefighter Obesity: A Qualitative Study. *Am. J. Ind. Med.* **2013**, *56*, 776–790. [CrossRef] [PubMed]
24. Bucala, M.; Sweet, E. Obesity in the Fire Service: An inside Look at the Perceptions of Firefighters towards Obesity and Other Health Issues. *Res. Sq.* **2019**. [CrossRef]
25. Ras, J.; Leach, L. Relationship Between Physical Activity, Coronary Artery Disease Risk Factors and Musculoskeletal Injuries in the City of Cape Town Fire and Rescue Service. *INQUIRY J. Health Care Organ. Provis. Financ.* **2022**, *59*, 00469580221084485. [CrossRef]
26. Geeta, A.; Jamaiyah, H.; Safiza, M.N.; Khor, G.L.; Kee, C.C.; Ahmad, A.Z.; Suzana, S.; Rahmah, R.; Faudzi, A. Reliability, Technical Error of Measurements and Validity of Instruments for Nutritional Status Assessment of Adults in Malaysia. *Singap. Med. J.* **2009**, *50*, 1013–1018.
27. Koo, T.K.; Li, M.Y. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J. Chiropr. Med.* **2016**, *15*, 155–163. [CrossRef]
28. Perini, T.A.; de Oliveira, G.L.; Ornelia, J.S.; de Oliveira, F.P. Technical Error of Measurement in Anthropometry. *Rev. Bras. Med. Esporte* **2005**, *11*, 81–85. [CrossRef]
29. Bohlmann, I.M.; Mackinnon, S.; Kruger, H.; Leach, L.; van Heerden, J.; Cook, I.; Noakes, T.; Lambert, E. Is the International Physical Activity Questionnaire (IPAQ) Valid and Reliable in the South African Population? *Med. Sci. Sport. Exerc.* **2001**, *33*, S119. [CrossRef]
30. Sanda, B.; Vistad, I.; Haakstad, L.A.H.; Berntsen, S.; Sagedal, L.R.; Lohne-Seiler, H.; Torstveit, M.K. Reliability and Concurrent Validity of the International Physical Activity Questionnaire Short Form among Pregnant Women. *BMC Sport. Sci. Med. Rehabil.* **2017**, *9*, 7. [CrossRef]
31. Hedge, A.; Morimoto, S.; McCrobie, D. Effects of keyboard tray geometry on upper body posture and comfort. *Ergonomics* **1999**, *42*, 1333–1349. [CrossRef] [PubMed]
32. Liguori, G.; American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*; American College of Sports Medicine Series; Wolters Kluwer: Alphen aan den Rijn, The Netherlands, 2021; ISBN 9781975150181.
33. Bastianelli, K.; Ledin, S.; Chen, J. Comparing the Accuracy of 2 Point-of-Care Lipid Testing Devices. *J. Pharm. Pract.* **2017**, *30*, 490–497. [CrossRef]
34. Billman, G.E.; Huikuri, H.V.; Sacha, J.; Trimmel, K. An Introduction to Heart Rate Variability: Methodological Considerations and Clinical Applications. *Front. Physiol.* **2015**, *6*, 2013–2015. [CrossRef] [PubMed]

http://etd.uwc.ac.za/

35. Tomes, C.; Schram, B.; Orr, R. Relationships Between Heart Rate Variability, Occupational Performance, and Fitness for Tactical Personnel: A Systematic Review. *Front. Public Health* **2020**, *8*, 729. [CrossRef] [PubMed]
36. Rexhepi, A.M.; Brestovci, B. Prediction of VO2max Based on Age, Body Mass, and Resting Heart Rate. *Hum. Mov.* **2014**, *15*, 56–59. [CrossRef]
37. Bianco, A.; Lupo, C.; Alesi, M.; Spina, S.; Raccuglia, M.; Thomas, E.; Paoli, A.; Palma, A. The Sit up Test to Exhaustion as a Test for Muscular Endurance Evaluation. *Springerplus* **2015**, *4*, 309. [CrossRef]
38. Anderson, M.K.; Hall, S.J.; Martin, M. *Foundations of Athletic Training: Prevention, Assessment, and Management*; Lippincott Williams & Wilkins: Philadelphia, PA, USA, 2004; ISBN 9780781750011.
39. Mosier, C.I. A Critical Examination of the Concepts of Face Validity. *Educ. Psychol. Meas.* **1947**, *7*, 191–205. [CrossRef]
40. Sireci, S.G. The Construct of Content Validity. *Soc. Indic. Res.* **1998**, *45*, 83–117. [CrossRef]
41. Choi, B.K.; Schnall, P.; Dobson, M. Twenty-Four-Hour Work Shifts, Increased Job Demands, and Elevated Blood Pressure in Professional Firefighters. *Int. Arch. Occup. Environ. Health* **2016**, *89*, 1111–1125. [CrossRef]
42. Noh, J.; Lee, C.J.; Hyun, D.S.; Kim, W.; Kim, M.J.; Park, K.S.; Koh, S.; Chang, S.J.; Kim, C.; Park, S. Blood Pressure and the Risk of Major Adverse Cardiovascular Events among Firefighters. *J. Hypertens.* **2020**, *38*, 850–857. [CrossRef]
43. Soteriades, E.S.; Hauser, R.; Kawachi, I.; Christiani, D.C.; Kales, S.N. Obesity and Risk of Job Disability in Male Firefighters. *Occup. Med.* **2008**, *58*, 245–250. [CrossRef] [PubMed]
44. Khaja, S.U.; Mathias, K.C.; Bode, E.D.; Stewart, D.F.; Jack, K.; Moffatt, S.M.; Smith, D.L. Hypertension in the United States Fire Service. *Int. J. Environ. Res. Public Health* **2021**, *18*, 5432. [CrossRef] [PubMed]
45. Smith, D.L.; Fehling, P.C.; Frisch, A.; Haller, J.M.; Winke, M.; Dailey, M.W. The Prevalence of Cardiovascular Disease Risk Factors and Obesity in Firefighters. *J. Obes.* **2012**, *2012*, 908267. [CrossRef] [PubMed]
46. Durand, G.; Tsismenakis, A.J.; Jahnke, S.A.; Baur, D.M.; Christophi, C.A.; Kales, S.N. Firefighters' Physical Activity: Relation to Fitness and Cardiovascular Disease Risk. *Med. Sci. Sport. Exerc.* **2011**, *43*, 1752–1759. [CrossRef] [PubMed]
47. Baur, D.M.; Christophi, C.A.; Cook, E.F.; Kales, S.N. Age-Related Decline in Cardiorespiratory Fitness among Career Firefighters: Modification by Physical Activity and Adiposity. *J. Obes.* **2012**, *2012*, 710903. [CrossRef]
48. Gendron, P.; Lajoie, C.; Laurencelle, L.; Trudeau, F. Cardiovascular Disease Risk Factors in Québec Male Firefighters. *J. Occup. Environ. Med.* **2018**, *60*, e300–e306. [CrossRef]
49. Rhea, M.R.; Alvar, B.A.; Gray, R. Physical Fitness and Job Performance of Firefighters. *J. Strength Cond. Res.* **2004**, *18*, 348–352. [CrossRef]
50. Porto, L.G.G.; Schmidt, A.C.B.; de Souza, J.M.; Nogueira, R.M.; Fontana, K.E.; Molina, G.E.; Korre, M.; Smith, D.L.; Junqueira, L.F.; Kales, S.N. Firefighters' Basal Cardiac Autonomic Function and Its Associations with Cardiorespiratory Fitness. *Work* **2019**, *62*, 485–495. [CrossRef]
51. Poston, W.S.C.; Development, N.; Haddock, C.K.; Development, N.; Jahnke, S.A.; Development, N.; Jitnarin, N.; Development, N.; Development, N.; Tuley, B.C.; et al. The Prevalence of Overweight, Obesity, and Substandard Fitness in a Population-Based Firefighter Cohort. *J. Occup. Environ. Med.* **2018**, *53*, 266–273. [CrossRef]
52. Segedi, L.C.; Saint-Martin, D.R.F.; da Cruz, C.J.G.; von Koenig Soares, E.M.K.; do Nascimento, N.L.; da Silva, L.L.; Nogueira, R.M.; Korre, M.; Smith, D.L.; Kales, S.; et al. Cardiorespiratory Fitness Assessment among Firefighters: Is the Non-Exercise Estimate Accurate? *Work* **2020**, *67*, 173–183. [CrossRef]
53. Heydari, P.; Varmazyar, S.; Safari Variani, A.; Hashemi, F.; Ataei, S.S. Correlation of Gerkin, Queen's College, George, and Jackson Methods in Estimating Maximal Oxygen Consumption. *Electron. Physician* **2017**, *9*, 5525–5530. [CrossRef] [PubMed]
54. Houck, J.M.; Mermier, C.M.; Beltz, N.M.; Johnson, K.E.; VanDusseldorp, T.A.; Escobar, K.A.; Gibson, A.L. Physical Fitness Evaluation of Career Urban and Wildland Firefighters. *J. Occup. Environ. Med.* **2020**, *62*, e302–e307. [CrossRef] [PubMed]
55. Baur, D.M.; Christophi, C.A.; Tsismenakis, A.J.; Cook, E.F.; Kales, S.N. Cardiorespiratory Fitness Predicts Cardiovascular Risk Profiles in Career Firefighters. *J. Occup. Environ. Med.* **2011**, *53*, 1155–1160. [CrossRef] [PubMed]
56. Stevenson, R.D.M.; Siddall, A.G.; Turner, P.F.J.; Bilzon, J.L.J. Physical Employment Standards for UK Firefighters. *J. Occup. Environ. Med.* **2017**, *59*, 74–79. [CrossRef]
57. von Heimburg, E.; Medbø, J.I.; Sandsund, M.; Reinertsen, R.E. Performance on a Work-Simulating Firefighter Test versus Approved Laboratory Tests for Firefighters and Applicants. *Int. J. Occup. Saf. Ergon.* **2013**, *19*, 227–243. [CrossRef] [PubMed]
58. Schonfeld, B.R.; Doerr, D.F.; Convertino, V.A. An Occupational Performance Test Validation Program for Fire Fighters at the Kennedy Space Center. *J. Occup. Environ. Med.* **1990**, *32*, 638–643. [CrossRef]
59. Stevenson, R.D.M.; Siddall, A.G.; Turner, P.J.F.; Bilzon, J.L.J. Validity and Reliability of Firefighting Simulation Test Performance. *J. Occup. Environ. Med.* **2019**, *61*, 479–483. [CrossRef]
60. Skinner, T.L.; Kelly, V.G.; Boytar, A.N.; Peeters, G.; Rynne, S.B. Aviation Rescue Firefighters Physical Fitness and Predictors of Task Performance. *J. Sci. Med. Sport* **2020**, *23*, 1228–1233. [CrossRef]
61. Siddall, A.G.; Stevenson, R.D.M.; Turner, P.J.F.; Bilzon, J.L.J. Physical and Physiological Performance Determinants of a Firefighting Simulation Test. *J. Occup. Environ. Med.* **2018**, *60*, 637–643. [CrossRef]
62. Michaelides, M.A.; Parpa, K.M.; Thompson, J.; Brown, B. Predicting Performance on a Firefighter's Ability Test from Fitness Parameters. *Res. Q. Exerc. Sport* **2008**, *79*, 468–475. [CrossRef]
63. Misner, J.E.; Plowman, S.A.; Boileau, R.A. Performance Differences between Males and Females on Simulated Firefighting Tasks. *J. Occup. Med.* **1987**, *29*, 801–805. [PubMed]

http://etd.uwc.ac.za/

64. Henderson, N.D.; Berry, M.W. Field Measures of Strength and Fitness Predict Firefighter Performance on Physically Demanding Tasks. *Pers. Psychol.* **2007**, *60*, 431–473. [CrossRef]
65. Nazari, G.; MacDermid, J.C.; Sinden, K.E.; Overend, T.J. The Relationship between Physical Fitness and Simulated Firefighting Task Performance. *Rehabil. Res. Pract.* **2018**, *2018*, 3234176. [CrossRef] [PubMed]
66. Myhre, L.G.; Tucker, D.M.; Bauer, D.H.; Fisher Jr, J.R.; Grimm, W.H. *Relationship between Selected Measures of Physical Fitness and Performance of a Simulated Fire Fighting Emergency Task*; Armstrong Lab Brooks: Arlington, TX, USA, 1997.
67. Michaelides, M.A.; Parpa, K.M.; Henry, L.J.; Thompson, G.B.; Brown, B.S. Assessment of Physical Fitness Aspects and Their Relationship to Firefighters' Job Abilities. *J. Strength Cond. Res.* **2011**, *25*, 956–965. [CrossRef] [PubMed]
68. Janssen, I.; Heymsfield, S.B.; Wang, Z.; Ross, R. Skeletal Muscle Mass and Distribution in 468 Men and Women Aged 18–88 Yr. *J. Appl. Physiol.* **2000**, *89*, 81–88. [CrossRef] [PubMed]

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

CHAPTER EIGHT: PUBLICATION SEVEN − ORIGINAL RESEARCH ARTICLE THREE

Association between Cardiovascular and Musculoskeletal Health in Firefighters

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

OPEN

Association between Cardiovascular and Musculoskeletal Health in Firefighters

Jaron Ras, MSc, Elpidoforos S. Soteriades, PhD, Denise L. Smith, PhD, Andre P. Kengne, PhD, and Lloyd Leach, PhD

Downloaded from http://journals.lww.com/joem by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 07/17/2023

Objective: The aim of the study is to determine the association between cardiovascular health (CVH) and musculoskeletal health in firefighters. Methods: This cross-sectional study involved 309 full-time firefighters aged 20 to 65 years. Cardiovascular health encompassed cardiovascular disease risk factors, risk scores, CVH metrics, and heart rate variability. Musculoskeletal health was assessed using two validated questionnaires. Results: Increasing age ($P = 0.004$), body mass index ($P < 0.001$), body fat percentage ($P < 0.001$), diastolic blood pressure ($P = 0.003$), total cholesterol ($P = 0.006$), and Framingham risk score ($P = 0.011$) increased the risk of reporting musculoskeletal injuries (MSIs). Obesity ($P = 0.018$), hypertension ($P = 0.034$), and dyslipidemia ($P = 0.005$) increased the risk of reporting MSIs. Musculoskeletal discomfort was associated with total cholesterol ($P = 0.0.34$) and low-density lipoprotein ($P = 0.014$). Conclusions: Adverse cardiovascular disease risk profile was associated with MSIs and musculoskeletal discomfort in firefighters. Firefighters should maintain an ideal CVH profile, especially as they age.

Keywords: firefighters, cardiovascular disease risk factors, cardiovascular health index, musculoskeletal injuries, musculoskeletal discomfort, risk factor

LEARNING OUTCOMES

After completing this research article, the learner will be better able to:

- Outline and discuss the association between cardiovascular health and musculoskeletal health among firefighters in the City of Cape Town Fire and Rescue Service.
- Outline the cardiovascular health parameters contributing most significantly to musculoskeletal injuries and musculoskeletal discomfort in firefighters.
- Differentiate the impact sociodemographic factors, such as age, sex, and years of experience, have on cardiovascular health in relation to musculoskeletal health in firefighters.
- Suggest ways to improve the cardiovascular and musculoskeletal parameters of firefighters to improve cardiovascular health and prevent work-related musculoskeletal injuries and discomfort.

Firefighting is a physically strenuous and hazardous occupation that involves firefighters placing themselves in life-threatening situations, where they are often exposed to hazardous chemicals and fumes and high temperatures.[1-3] During physically intense duty−related activity, firefighters often reach or even exceed their maximum age-predicted heart rates,[2,4] with many activities requiring forceful repetitive muscular contractions. This necessitates that firefighters maintain good cardiovascular and musculoskeletal health to assist in performing their duties with sufficient speed and efficiency.[5]

From the Department of Sport, Recreation and Exercise Science, Faculty of Community and Health Sciences, University of the Western Cape, Cape Town, South Africa (J.R., L.L.); Healthcare Management Program, School of Economics and Management, Open University of Cyprus, Nicosia, Cyprus (E.S.S.); Environmental and Occupational Medicine and Epidemiology (EOME), Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston, Massachusetts (E.S.S.); Health and Human Physiological Sciences, Skidmore College, Saratoga Springs, New York (D.L.S.); and Non-communicable Diseases Research Unit, South African Medical Research Council, Cape Town, South Africa (A.P.K.).

Ethical Considerations and Disclosures: The study was approved by the Biomedical Research Ethics Committee (BMREC) (BM21/10/9) of the University of the Western Cape (South Africa). All experiments were performed in accordance with the National Health Act and the Declaration of Helsinki. Informed consent was obtained from participants who volunteered to participate in this study.

Conflict of interest: None declared.

Funding sources: This research was funded by the National Research Foundation (NRF) (grant number 141282) and the Ryoichi Sasakawa Young Leaders Fellowship Fund (SLYFF). Neither funding bodies were involved in the study design, data collection, or interpretation of the data.

Address correspondence to: Jaron Ras, MSc, Department of Sport, Recreation and Exericse Science, Faculty of Community and Health Sciences, University of the Western Cape, Robert Sobukwe Road,. Bellville, 7535, CT, South Africa (3405618@myuwc.ac.za).

Copyright © 2023 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American College of Occupational and Environmental Medicine. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.

DOI: 10.1097/JOM.0000000000002872

Studies have indicated that an alarming number of firefighters have several cardiovascular disease (CVD) risk factors and poor cardiovascular health (CVH) metrics, which significantly predisposes them to sustaining a sudden cardiac event while on active duty.[6-9] In addition, firefighters often sustain musculoskeletal injuries (MSIs) while performing fire suppression and other emergency duties.[10-13] Furthermore, many firefighters have mild-to-severe musculoskeletal discomfort (MSD), which limits their ability to perform their duties effectively.[14,15] Previous studies have shown that CVD risk factors and CVH metrics, such as obesity, aging, cigarette smoking, and physical activity, are related to MSIs and MSDs in firefighters.[15-17] In addition, it has been reported that with an increase in body mass index (BMI), firefighters are more susceptible to lower limb injuries, particularly those related to the knees and ankles, due to an increase in nonfunctional weight, commonly associated with high-fat mass.[11-13,18] Aging has been shown to be associated with reduced bone mineral density, connective tissue health, and skeletal muscle size and strength, compounding the negative effect of increased body mass on musculoskeletal health.[10,13] The association between other CVD risk factors, such as diabetes, dyslipidemia and hypertension, and musculoskeletal health (MSH), has been understudied in firefighters. However, studies in the general population have indicated that connective tissues, such as those found in the musculotendinous junctions, may respond similarly to vascular tissue, being susceptible to atherosclerotic lesions and predisposed to injury.[19,20] Moreover, the high blood glucose and cholesterol concentrations contribute to a proinflammatory state that may diminish tissue recovery and prolong the inflammatory responses.[19] These inflammatory responses affect the autonomic nervous system function resulting in depressed heart rate variability (HRV).[21,22] Furthermore, a bidirectional relationship may exist between musculoskeletal health and CVH, as pain, discomfort, or injury may lead to a decrease in physical activity, leading to obesity, elevated blood pressure, and blood lipids.[23-25]

Determining the association between CVH and MSH in firefighters may provide novel findings on the possible associations that

http://etd.uwc.ac.za/

Downloaded from http://journals.lww.com/joem by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 07/17/2023

may exist in this occupational population. Understanding the association may help better understand what is presumed to be a bidirectional relationship between CVH and MSH and lead to new theories about potential mediators of this relationship. Furthermore, because CVD risk factors are more often measured, these parameters may provide insight into the risk of injury. Firefighters are often required to exert maximum effort for extended durations, which may increase the risk of sudden cardiac events[1,2,26] and predisposes them to severe MSIs.[27-29] The establishment of an association between CVH and musculoskeletal health may assist in reducing the likelihood of morbidity and mortality commonly seen in this population. Therefore, the aim of this study was to determine the association between CVH and MSH in firefighters.

METHODS

Study Design and Population

This cross-sectional study used data on MSH (MSIs and MSD) and CVH (CVD risk factors, CVD risk score, HRV, CVH index) from a cohort of firefighters. Full-time male and female firefighters between the ages of 20 to 65 years from the City of Cape Town Fire and Rescue Service, South Africa, were included, after written informed consent. The study was approved by the Biomedical Research Ethics (BM21/10/9) Committee of the University of the Western Cape (South Africa). Approval was granted by the Chief Fire Officer, as well as the research and the Department of Policy and Strategy research branch of the City of Cape Town.

Sampling and Participant Recruitment

The City of Cape Town Fire and Rescue Service employs approximately 1000 full-time firefighters and using the finite population sample size calculation, a minimum sample size of 278 was needed to ensure the precision and the statistical power of the results. Firefighters excluded were those on administrative duty, on sick leave, employed part-time, or on a seasonal basis.

Data collection took place during the City of Cape Town Fire and Rescue Services annual physical fitness assessment, where firefighters from all 96 platoons (32 fire stations) were selected, using random systematic sampling. Using the sampling interval calculation, every third firefighter was recruited. In the instance where the selected participant declined to participate, the next participant was recruited. More specifically, for each day of testing, five to six platoons would be called to participate in the annual physical ability test. Each of the 96 platoons consisted of 8 to 12 firefighters.

Data Collection

A researcher-generated data collection sheet was used to record the sociodemographic, lifestyle, CVH, and musculoskeletal health information, as well as descriptive physical measures. The musculoskeletal health section was based on the Nordic Musculoskeletal Questionnaire[30] and Cornell Musculoskeletal Discomfort Questionnaire,[31] and physical activity habits were gathered using the International Physical Activity Questionnaire,[32] which has been shown to be reliable in a South African population.

Descriptive Measures

Stature, Body Mass, and Circumferences

For stature, firefighters were asked to stand barefoot on the level stadiometer base, with the heels together and the heels, buttocks, and upper back touching the stadiometer rod of a portable stadiometer (Seca model 700; Gmbh & Co, Germany). A Tanita© (Tanita©, Tokyo, Japan) BC-1000 Plus bioelectrical impedance analyzer was used to obtain body composition data, which included body mass (weight), fat mass, and body fat percentage (BF%). When taking body mass and BF%, firefighters were requested to wear minimal clothing, stand upright, barefoot, and stationary on the scale. Waist circumference was measured at the point of the belly button.[33] Hip circumference was taken at the level of the greatest posterior protuberance of the buttocks.

Blood Pressure

Blood pressure was measured using the Omron Healthcare, Inc, M6 comfort intelligence (Omron Healthcare Co, Ltd, Hoofddorp, the Netherlands) automatic blood pressure monitor. Firefighters were asked to remain in a quiet seated position for 5 minutes before testing, with the left arm elevated onto the testing table. The midline of the bladder of the blood pressure cuff was placed over the brachial artery to ensure accurate and consistent readings. The participants' blood pressures were taken thrice, with at least 2-minute intervals between measures. The average of the three measurements was used as the final measurement.

Blood Tests

Total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), triglycerides, and nonfasting blood glucose (NFBG) concentrations were measured using a CardioChek® Plus analyzer (PTS Diagnostics, IN), which has been shown to be accurate and reliable within industry standards.[34] The test entailed a finger-prick, wherein the initial blood droplet was wiped off, and a second drop of blood was used for testing purposes.

Classification of CVH Parameters

In the current study, CVH was used as an umbrella term and investigated using several approaches. These approaches included three main subcomponents, those being CVD risk factors, CVH metrics and HRV. The subcomponents of CVD risk factors and CVH metrics have variables that overlap. The CVD risk factors include age, obesity, hypertension, dyslipidemia, diabetes, cigarette smoking, physical inactivity and family history. For CVH, the metrics included BMI, blood pressure, cholesterol, blood glucose, physical inactivity, cigarette smoking, and diet.

Cardiovascular Disease Risk Factors

Age, as a risk factor, was classified as males older than 45 years and females older than 55 years.[33] Obesity was classified as a BMI at or greater than 30 $kg \cdot m^{-2}$, and central obesity was classified as a waist circumference more than 94 cm for men and more than 80 cm for women.[33] Hypertension was classified as systolic blood pressure (SBP) ≥140 mm Hg and/or diastolic blood pressure (DBP) ≥90 mm Hg or history of physician diagnosis.[33] Dyslipidemia was defined as a TC ≥5.18 mmol·L or previously confirmed by a physician, and diabetes was defined as random blood glucose ≥11.1 mmol·L or previously confirmed by a physician. Hypertriglyceridemia was classified as a triglyceride ≥1.70 mmol·L. Cigarette smoking was based on cigarette use in the last 6 months.[33] Physical inactivity was based on exercising less than 3 days a week for at least 30 minutes at a moderate intensity.[33] Physical activity was classified into three categories, namely, total low, moderate, and vigorous intensity weekly minutes. Weekly metabolic equivalents were calculated using the method described by the International Physical Activity Questionnaire, using the total minutes of low-, moderate-, vigorous-intensity activity. A positive family history was based on a history of myocardial infarction, coronary revascularization, or sudden cardiac death before 55 years in the father or other first-degree male relative, or before 65 years in the mother or first-degree female relative.[33]

Cardiovascular Disease Risk Score

Framingham risk, lifetime, and 10-year atherosclerotic cardiovascular disease (ASCVD) were calculated to assess the cardiovascular risk of firefighters.[35] The Framingham risk score was used to assess the risk of coronary artery disease over a 10-year period in firefighters and included six risk factors, namely, age, gender, TC, HDL-C, cigarette smoking and SBP.[35] The 10-year ASCVD risk score was used

© 2023 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American College of Occupational and Environmental Medicine.

http://etd.uwc.ac.za/

Downloaded from http://journals.lww.com/joem by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 07/17/2023

to assess the CVD risk of firefighters older than 40 years, only, and estimated using SBP, DBP, TC, HDL-C, LDL-C, diabetes history, and smoking status.[36] For lifetime risk, all previous risk factors were included; however, only firefighters between the ages of 20 to 59 years were included.[37]

Cardiovascular Health Metrics

The American Heart Association used these seven CVH metrics to classify individuals as having a good index for CVH or a poor index. The CVH index (CVHI) was inversely associated with all-cause mortality and cardiovascular events.[38,39] For this study, CVHI was classified as "poor" if two or fewer CVH metrics were classified as good, classified as "intermediate" if firefighters had three to four metrics classified as good, and classified as "good" if firefighters had five to seven metrics rated as good or ideal. The metrics used for the CVHI included BMI, blood pressure, TC, NFBG, physical activity, cigarette smoking, and diet. These factors had the same cutoff values as the CVD risk factors previously described in the section "cardiovascular disease risk factors."[38,39] Diet was scored as good if four or five components were good, intermediate 2 to 3 components were good and poor if 0 to 1 components were good. The diet questions were based on the recommendations by the American Heart Association for a healthy diet and included questions on fruit and vegetable intake, a weekly serving of fish, fiber-rich whole grains, salt intake, and sugar intake.[38,39] There were five questions with each question with three questions having a total point score of three points and two questions with a total point score of four points accumulating to a total of 17 points.

Heart Rate Variability

Heart rate variability was measured at rest using the Polar™ (Polar Electro Oy, Kempele, Finland) H10 heart rate monitor. The equipment was moistened with room temperature water and fitted to the center of the participant's chest, directly in line with the xiphoid process of the sternum. The participant was asked to maintain a quiet seated position for 5 minutes before the measurement was taken. The participant's HRV was then recorded over a 5-minute period, following the 5-minute rest period, giving a total test time of 10 minutes. The HRV data were analyzed using the Kubio© Software version 3.4.3. The standard deviation of all normal-to-normal (NN) intervals (SDNN), root-mean-square of successive differences (RMSSD), low-frequency (LF), high-frequency (HF) ranges, and the ratio (LF/HF) was used as main outcome measures for HRV for this study.[40,41] The frequency band for LF ranged between 0.04 and 0.15 Hz and ranged between 0.15 and 0.40 for HF.

Classification of Musculoskeletal Health

Musculoskeletal health was subcategorized as MSI and MSD status. For MSI status, firefighters were categorized as those who sustained an injury while on duty during their time in the fire services based on their responses to the Nordic Musculoskeletal Questionnaire. Musculoskeletal discomfort status was classified as those firefighters that reported experiencing MSD in the past week, using the Cornell Musculoskeletal Discomfort Questionnaire.

Statistical Analysis

The data were analyzed using SPSS® software, version 28 (Chicago, IL). The Shapiro-Wilks test was used to test the distribution of the data, which were shown to be not normally distributed. Then, group comparisons were based on the Kruskal-Wallis test, because of the departure from a normal distribution of many variables. Continuous variables are summarized as the medians and 25th to 75th percentile. Univariable and multivariable logistic regressions were performed to determine the association between CVH parameters, which were treated as the independent variables, and MSH which designated the outcome variable. Cardiovascular health was analyzed using several approaches in logistic regressions, specifically as continuous cardiovascular measures (age, BMI, blood pressure, lipids, glucose, physical activity, HRV, and risk scores), traditional cardiovascular disease risk factors (age, obesity, dyslipidemia, diabetes, hypertension, cigarette smoking, physical inactivity, family history), CVD risk scores (Framingham risk score, lifetime, and 10-year ASCVD risk), CVH metrics (American Heart Association). The selection of exploratory variables was evidence based and selected based on previous research that consistently reported an association between MSIs and MSD in firefighters. Two models were selected to adjust for age and years of experience separately, to reduce collinearity. In model 2, covariates adjusted for included age, sex, and BMI (only nonadiposity-related measure) and in model 3 covariates adjusted for included years of experience, sex, and BMI (only nonadiposity-related measure). Moreover, to ensure collinearity was not present, all covariates had a correlation less than 0.5 and a VIF of less than 5. Variables not following a normal distribution were fractionally ranked and then normalized using the inverse DF, IDF.NORMAL transformation.[42] A P value less than 0.05 was used to indicate statistical significance.

RESULTS

Table 1 shows the descriptive characteristics of firefighters overall and by sex. The median (IQR) age, height, and weight were 38.0 (18.0) years, 173.1 (9.9) cm, and 81.5 (18.0) kg, respectively. The males were taller ($P < 0.001$), heavier ($P < 0.001$), and had a higher BF% ($P < 0.001$), DBP ($P = 0.003$), triglyceride concentration ($P < 0.001$), and CVD risk scores ($P < 0.001$) when compared with females.

Table 2 describes the CVH values for firefighters with and without MSI or MSD. Never-injured firefighters were younger ($P = 0.002$), had fewer years of experience ($P < 0.001$), and weighed less ($P = 0.008$). In addition, BMI ($P = 0.002$), waist circumference ($P = 0.008$), BF% ($P < 0.001$), SBP ($P = 0.035$), DBP ($P = 0.001$), TC ($P = 0.004$), LDL-C ($P = 0.009$), triglycerides ($P = 0.042$), Framingham risk score ($P = 0.002$), and LF range (p 0.042) was different between injured and noninjured firefighters. Total cholesterol ($P = 0.034$), LDL-C ($P = 0.009$), SDNN ($P = 0.006$), and RMSSD ($P = 0.004$) were significantly different between firefighters experiencing musculoskeletal discomfort and those without.

Table 3 describes the association between CVH (CVD risk factors, risk score, CVH metrics, and HRV) and MSI status in firefighters. For every 1-year increase in age and years of experience and firefighters that were of female sex, increased the risk of MSI by a factor of 1.03 ($P = 0.004$), 1.04 ($P < 0.001$), and 2.19 ($P = 0.033$), respectively. A 1-unit increase in BMI and BF% and TC was associated with an increase in the risk of MSI by a factor of 1.09 ($P < 0.001$), 1.05 ($P < 0.001$), and 1.27 ($P = 0.011$), respectively. In the multivariate analysis, after adjustment for years of experience and BMI, the female sex was associated with a risk of MSI that was 2.30 greater compared with males ($P = 0.031$). In addition, as BMI and BF% increased by 1 $kg \cdot m^{-2}$ and 1%, the risk of MSI increased by a factor of 1.07 ($P = 0.023$) and 1.03 ($P = 0.044$), respectively. Obesity and a high BF% increased the risk of MSI by a factor of 1.84 ($P = 0.018$) and 1.95 ($P = 0.034$), respectively. Hypertension, dyslipidemia and hypertriglyceridemia increased the risk of MSI by a factor of 1.64 ($P = 0.034$), 1.98 ($P = 0.005$), and 1.81 ($P = 0.013$), respectively. In addition, poor CVHI increased the risk of MSI by a factor of 1.62 ($P = 0.049$) and a good CVHI decreased the risk of MSI by a factor of 0.41 ($P = 0.037$).

Table 4 presents the association between CVH (CVD risk factors, risk score, CVH metrics, and HRV) and MSD in firefighters. Univariable analysis indicated that every 1-unit increase in TC and LDL-C increased the odds of MSD by a factor of 1.22 ($P = 0.034$) and 1.32 ($P = 0.014$), respectively. Every 1-unit increase in SDNN

© 2023 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American College of Occupational and Environmental Medicine.
http://etd.uwc.ac.za/

Downloaded from http://journals.lww.com/joem by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 07/17/2023

TABLE 1. Descriptive Characteristics of Firefighters Overall and by Sex

	Total Firefighters		Males		Females		
	n	$\tilde{X}(p_{25th}–p_{75th})$	*n*	$\tilde{X}(p_{25th}–p_{75th})$	n	$\tilde{X}(p_{25th}–p_{75th})$	*P*
Age, y	309	38.0 (30–48.0)	275	38.0 (30.0–48.0)	34	39.0 (30.0–45.0)	0.786
Years of experience, y	309	14.0 (5.0–22.0)	275	14.0.0 (5.0–23.0)	34	14.0 (5.0–17.3)	0.252
Height, cm	309	173.1 (168.1–177.9)	275	174 (170.5–178.3)	34	162.9 (158.1–167.0)	<0.001**
Weight, kg	309	81.5 (72.5–90.5)	275	82.4 (73.9–91.0)	34	73.2 (63.1–81.0)	<0.001**
BMI, $kg·m^{-2}$	309	27.1 (24.1–30.4)	275	27.0 (24.2–30.1)	34	28.4 (23.4–31.9)	0.264
Waist circumference, cm	309	93.0 (84.3–101.0)	275	93.5 (85.0–103.0)	34	86.8 (77.8–98.2)	0.002**
BF%, %	309	20.2 (14.9–27.2)	275	19.0 (14.2–24.0)	34	34.3 (27.6–40.8)	<0.001**
SBP, mm Hg	309	137.3 (125.0–145.5)	275	137.5 (126.7–146.7)	34	127.5 (115.7–141.0)	0.003**
DBP, mm Hg	309	81.7 (74.2–90.8)	275	81.7 (74.0–90.5)	34	82.3 (74.2–92.6)	0.710
NFBG, $mmol·L^{-1}$	309	5.4 (4.9–6.2)	275	5.4 (4.9–6.2)	34	5.4 (4.8–6.1)	0.970
TC, $mmol·L^{-1}$	309	4.6 (3.9–5.4)	275	4.6 (3.9–5.4)	34	4.8 (3.9–5.4)	0.835
LDL-C, $mmol·L^{-1}$	309	2.6 (2.1–3.4)	275	2.6 (2.1–3.4)	34	2.8 (2.0–3.3)	0.705
HDL, $mmol·L^{-1}$	309	1.2 (1.0–1.4)	275	1.2 (1.0–1.4)	34	1.5 (1.3–1.7)	<0.001**
Triglycerides, $mmol·L^{-1}$	309	1.4 (0.9–2.2)	275	1.5 (0.9–2.2)	34	0.9 (0.7–1.7)	<0.001**
Diet score	309	10.0 (8.0–11.0)	275	9.0 (8.0–11.0)	34	10.0 (9.0–12.0)	0.186
Physical activity level							
TLIPAM, min	309	123.0 (60.0–360.0)	275	120 (60.0–300.0)	34	120.0 (75.0–540.0)	0.473
TMIPAM, min	309	420.0 (240.0–660.0)	275	420 (240.0–660.0)	34	360.0 (90.0–540.0)	0.170
TVIPAM, min	309	340.0 (180.0–720.0)	275	310.0 (180.0–720.0)	34	405.0 (150.0–885.0)	0.915
TWMETM	309	2397.0 (1320.0–4416.0)	275	2400.0 (1320.0–4464.0)	34	2080.0 (1320.0–3879.0)	0.663
Cardiovascular disease risk score							
Lifetime ASCVD risk score	303	5.5 (2.4–9.9)	275	5.1 (3.2–10.6)	33	0.8 (0.5–1.1)	<0.001**
Framingham risk	309	1.1 (0.2–5.9)	275	0.6 (0.3–6.3)	34	0.2 (0.0–0.5)	<0.001**
ASCVD risk score[a]	138	50.0 (39.0–50.0)	123	50.0 (46.0–50.0)	15	39.0 (27.0–39.0)	<0.001**
Heart rate variability							
HRV, ms	304	713.5 (628.3–821.5)	270	716.0 (632.0–826.3)	34	690.0 (619.5–817.0)	0.326
SDNN, ms	304	32.5 (21.5–46.5)	270	32.6 (21.7–46.7)	34	28.2 (19.2–44.1)	0.514
RMSSD, ms	304	22.6 (13.8–37.6)	270	22.65 (13.9–37.6)	34	21.9 (12.4–39.0)	0.802
LF, Hz	304	0.09 (0.07–0.11)	270	0.09 (0.07–0.11)	34	0.08 (0.06–0.09)	0.034*
HF, Hz	304	0.18 (0.16–0.22)	270	0.17 (0.16–0.21)	34	0.19 (0.16–0.29)	0.075
LF/HF ratio, Hz	304	2.90 (1.6–5.1)	270	2.9 (1.7–5.5)	34	2.6 (1.4–3.9)	0.089
Musculoskeletal discomfort[bc]	130	4.8 (3.0–20.0)	112	4.5 (1.5–20.0)	18	9.5 (3.0–20.0)	0.467
Neck	34	3.0 (1.5–6.0)	31	3.0 (1.5–6.0)	3	1.5 (1.5)	0.645
Shoulder	43	4.5 (2.0–10.0)	42	4.5 (2.0–10.0)	1	1.5 (1.5–1.5)	0.186
Upper back	25	5.0 (2.0–6.0)	22	4.3 (1.9–6.0)	3	6.0 (3.0)	0.353
Upper arm	21	3.5 (2.0–6.0)	21	3.5 (1.9–6.0)	0	—	—
Forearm and elbow	24	4.5 (2.0–6.0)	23	3.0 (2.0–6.0)	1	60.0 (60.0–60.0)	0.083
Wrist and hand	32	6.0 (1.5–6.0)	30	6.0 (1.5–6.0)	2	5.8 (1.5)	0.901
Low back	72	3.0 (1.6–6.0)	64	3.0 (1.5–6.0)	8	5.5 (3.0–9.8)	0.353
Hip and buttocks	20	6.0 (2.0–6.0)	18	6.0 (2.0–6.0)	2	20.8 (1.5)	0.947
Thigh	19	3.5 (2.0–6.0)	19	3.5 (2.0–6.0)	0	—	—
Knee	48	3.0 (1.5–6.0)	43	3.0 (1.5–6.0)	5	3.5 (2.3–30.5)	0.246
Lower leg	19	3.5 (2.0–6.0)	18	2.8 (1.9–6.0)	1	10.0 (10.0–10.0)	0.211
Foot and ankle	29	2.0 (1.5–6.0)	25	3.0 (1.5–6.0)	4	1.5 (1.5–2.6)	0.124
Musculoskeletal injuries, n (%)[d]	130 (42.1)		110 (40.0)		20 (58.8)		
Neck, n (%)	10 (3.2)		8 (2.9)		2 (5.9)		
Shoulder, n (%)	17 (5.5)		14 (5.1)		3 (8.8)		
Upper back, n (%)	7 (2.3)		7 (2.5)		0 (0)		
Forearm and elbow, n (%)	3 (0.9)		3 (1.1)		0 (0)		
Wrist and hand, n (%)	12 (3.9)		10 (3.6)		2 (5.9)		
Lower back, n (%)	24 (7.8)		22 (8.0)		2 (5.9)		
Hip and buttocks, n (%)	4 (1.3)		4 (1.5)		0 (0)		
Thigh, n (%)	3 (1)		3 (1.1)		0 (0)		
Knee,n (%)	31 (10.0)		24 (8.7)		0 (0)		
Lower leg, n (%)	1 (0.3)		1 (0.4)		2 (5.9)		
Ankle and foot, n (%)	39 (12.6)		31 (11.3)		8 (23.5)		

*Indicates statistical significance <0.05.

**Indicates statistical significance <0.01.

[a]The ASCVD risk score calculated for firefighters older than 40 years, only.

[b]Musculoskeletal discomfort did not include injury data.

[c]Indicates that only firefighters reported experiencing musculoskeletal discomfort.

[d]Indicates only firefighters who reported a musculoskeletal injury.

$\tilde{X}$,median; BF%, body fat percentage; BMI, body mass index; DBP, diastolic blood pressure; HDL, high-density lipoprotein; HF, high frequency; HRV, heart rate variability; LDL-C, low-density lipoprotein; LF, low frequency; LF/HF, low- and high-frequency ratio; NFBG, nonfasting blood glucose; $p_{25th}–p_{75th}$, 25th percentile to 75th percentile; RMSSD, root-mean- square of successive differences; SBP, systolic blood pressure; SDNN, standard deviation of all normal-to-normal; TC, total cholesterol; TLIPAM, total low-intensity physical activity mi- nutes; TMIPAM, total moderate-intensity physical activity minutes; TVIPAM, total vigorous-intensity physical activity minutes; TWMETM, total weekly metabolic equivalent minute.

© 2023 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American College of Occupational and Environmental Medicine.

http://etd.uwc.ac.za/

Downloaded from http://journals.lww.com/joem by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 07/17/2023

TABLE 2. Differences between CVH and Musculoskeletal Health in Firefighters

	Injured		Never Injured			Musculoskeletal Discomfort		Without Discomfort		
	n	$\tilde{X}$(p_{25th}–p_{75th})	*n*	$\tilde{X}$(p_{25th}–p_{75th})	*P*	*n*	$\tilde{X}$(p_{25th}–p_{75th})	*n*	$\tilde{X}$(p_{25th}–p_{75th})	*P*
Age, y	130	42.0 (32.0–49.0)	178	36.0 (29.0–46.0)	0.002**	130	39.0 (32.0–46.5)	179	37.0 (29.0–48.0)	0.478
Years of experience, y	130	17.0 (7.0–25.0)	178	11.0 (4.0–19.0)	<0.001**	130	15.0 (6.8–22.3)	179	13.0 (5.0–22.0)	0.219
Height, cm	130	172.9 (167.5–178.0)	178	173.5 (169.0–177.9)	0.765	130	173.0 (168.4–178.0)	179	173.3 (168.0–177.9)	0.707
Weight, kg	130	82.4 (74.0–95.9)	178	80.8 (72.1–87.5)	0.008**	130	80.7 (71.9–91.6)	179	82.0 (73.0–90.1)	0.942
BMI, kg·m^{-2}	130	27.6 (25.1–31.7)	178	26.8 (23.9–29.6)	0.002**	130	27.0 (24.5–31.1)	179	27.2 (23.9–30.2)	0.469
WC, cm	130	95.0 (86.9–104.3)	178	90.8 (83.0–100.0)	0.008**	130	93.5 (84.0–101.0)	179	91.5 (84.5–101.5)	0.770
BF%, %	130	22.1 (16.7–28.3)	178	18.3 (13.7–24.7)	<0.001**	130	21.3 (14.9–28.5)	179	19.5 (14.6–25.9)	0.118
SBP, mm Hg	130	140.0 (128.3–146.0)	178	134.5 (123.2–145.1)	0.035*	130	139.0 (128.4–145.4)	179	136.3 (124.3–146.0)	0.200
DBP, mm Hg	130	85.0 (77.5–92.4)	178	79.7 (72.5–88.5)	0.001**	130	81.8 (73.7–91.1)	179	81.7 (74.7–90.0)	0.853
NFBG, mmol·L^{-1}	130	5.4 (4.9–6.1)	178	5.4 (4.9–6.2)	0.999	130	5.4 (4.8–6.1)	179	5.4 (5.0–6.3)	0.183
TC, mmol·L^{-1}	130	4.9 (4.1–5.6)	178	4.4 (3.8–5.2)	0.004**	130	4.8 (4.1–5.6)	179	4.5 (3.9–5.2)	0.034*
LDL-C, mmol·L^{-1}	130	2.8 (2.2–3.5)	178	2.5 (2.0–3.2)	0.030*	130	2.8 (2.3–3.5)	179	2.5 (1.9–3.3)	0.009**
HDL-C, mmol·L^{-1}	130	1.2 (1.0–1.4)	178	1.2 (1.0–1.4)	0.690	130	1.2 (1.0–1.4)	179	1.2 (1.1–1.4)	0.939
Triglycerides, mmol·L^{-1}	130	1.6 (0.9–2.2)	178	1.3 (0.9–1.4)	0.042*	130	1.4 (0.8–2.2)	179	1.4 (0.9–2.2)	0.482
Diet score	130	10.0 (8.0–11.0)	178	10.0 (8.8–11.0)	0.961	130	10.0 (9.0–11.0)	179	10.0 (8.0–11.0)	0.358
TLIPAM, min	130	120.0 (60.0–345.0)	178	145.0 (62.5–360.0)	0.372	130	130.0 (60.0–360.0)	179	120.0 (60.0–360.0)	0.512
TMIPAM, min	130	360.0 (240.0–660.0)	178	480.0 (215.0–660.0)	0.281	130	380.0 (210.0–630.0)	179	480.0 (240.0–700.0)	0.463
TVIPAM, min	130	240.0 (180.0–720.0)	178	360.0 (180.0–720.0)	0.004**	130	360 (180.0–720.0)	179	320.0 (180.0–720.0)	0.060
TWMETM, MET·Min	130	2080.0 (1202.5–3699.0)	178	2580.0 (1578.0–5310.0)	0.589	130	2080.0 (2607)	179	2655.0 (1440.0–4986)	0.474
Cardiovascular disease risk score										
Lifetime ASCVD risk score	129	50.0 (46–50.0)	175	50.0 (36.0–50.0)	0.365	129	50.0 (42.5–50.0)	175	46.0 (36.0–50.0)	0.284
Framingham risk score	129	2.6 (0.5–6.8)	180	0.8 (0.1–5.2)	0.002**	130	2.0 (0.5–5.9)	179	0.7 (0.1–5.9)	0.203
ASCVD risk score[a]	70	5.3 (2.5–9.9)	67	5.5 (2.3–9.8)	0.973	63	4.9 (2.3–8.0)	75	6.2 (2.6–10.6)	0.058
Heart rate variability										
Heart rate variability, ms	128	723.0 (637.0–825.0)	176	708.5 (612.0–820.5)	0.293	128	722.5 (647.0–829.0)	175	701.0 (610.5–817.8)	0.054
SDNN, ms	128	29.8 (21.5–44.9)	176	33.2 (20.4–48.1)	0.450	128	35.0 (23.9–49.6)	175	29.4 (19.0–43.5)	0.006**
RMSSD, ms	128	22.0 (13.9–35.6)	176	22.9 (13.8–40.2)	0.897	128	27.2 (16.2–41.8)	175	21.2 (12.3–35.0)	0.004**
LF, Hz	128	0.09 (0.06–0.10)	176	0.09 (0.07–0.11)	0.041*	128	0.09 (0.07–0.10)	175	0.09 (0.07–0.11)	0.489
HF, Hz	128	0.17 (0.16–0.22)	176	0.18 (0.16–0.22)	0.664	128	0.18 (0.16–0.21)	175	0.18 (0.16–0.22)	0.336
LF/HF ratio, Hz	128	2.9 (1.6–5.1)	176	2.8 (1.7–5.4)	0.688	128	2.6 (1.5–4.5)	175	2.9 (1.8–5.4)	0.075

*Indicates statistical significance <0.05.

**Indicates statistical significance <0.01.

[a]The ASCVD risk score calculated for firefighters older than 40 years, only.

$\tilde{X}$, median; ASCVD, atherosclerotic cardiovascular disease; BMI, body mass index; DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; HF, high frequency; LDL-C, low-density lipoprotein; LF, low frequency; LF/HF, low- and high-frequency ratio; NFBG, nonfasting blood glucose; p_{25th}–p_{75th}, 25th percentile to 75th percentile; RMSSD, root-mean-square of successive differences; SBP, systolic blood pressure; SDNN, standard deviation of all normal-to-normal; TC, total cholesterol; TLIPAM, total low-intensity physical activity minutes; TMIPAM, total moderate-intensity physical activity minutes; TVIPAM, total vigorous-intensity physical activity minutes; TWMETM, total weekly metabolic equivalent minute; WC, waist circumference.

WESTERN CAPE

and RMSSD increased the odds of MSD by a factor of 1.02 (*P* = 0.010) and 1.01 (*P* = 0.008), respectively. In the multivariable analyses, after adjustment for age, sex and BMI, for every 1-unit increase in TC and LDL-C, the odds of MSD increased by a factor of 1.22 (*P* = 0.044) and 1.32 (*P* = 0.018), respectively, and after adjustment for years of experience, sex and BMI, every 1-unit increase in LDL-C, the odds of MSD increased by a factor of 1.03 (*P* = 0.028). Similarly, after adjustment for age, sex, and BMI, the odds of MSD increased by a factor of 1.02 (*P* = 0.002) and 1.02 (*P* = 0.002), for every 1-unit increase in SDNN and RMSSD, respectively, and after adjustment for years of experience, sex, and BMI, every 1 unit increase in SDNN and RMSSD increased the odds of MSD by a factor of 1.02 (*P* = 0.001) and 1.02 (*P* = 0.001), respectively.

DISCUSSION

The aim of this study was to determine the association between CVH and MSH in firefighters. The results indicated an increase in the odds of firefighters reporting MSIs among those with prevalent CVD risk factors and poor health metrics, particularly related to aging, obesity, hypertension, and dyslipidemia. Previous studies indicated that aging and obesity were significantly related to an increase in injuries in firefighters.[10,11,13,15] This may be due to the progressive deterioration in connective tissue health, which may also be related to a reduction in physical activity levels commonly seen in older firefighters.[10,13,43] In addition, it is likely that older firefighters are more physically inactive[24] and thus have a lower cardiorespiratory fitness level,[23,24] predisposing them to injury.[18] This may, somewhat, explain why more physically active firefighters were associated with lower of MSIs in firefighters in previous studies.[10,12,44]

The results indicated that both TC and LDL-C were associated with an increase in reporting of MSIs and MSD and that hypertriglyceridemia was associated with reporting of MSIs, only. This positive association between lipid profiles and MSIs is supported by a systematic review conducted by Tilley et al.[20] who reported that an increase in TC and LDL-C was related to an increase in the likelihood of reported tendon pathologies.[20] The study suggested that tendons respond similarly to arteries regarding their metabolic environments and, as such, are prone to atherosclerotic lesion development due to shear and compression forces, precipitating cholesterol and fatty acid deposition and plaque build-up.[20] This, in turn, predisposes the area to injuries, such as sudden tendon rupture.[19,20] In addition, Tilley et al.[20] noted that

 © 2023 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American College of Occupational and Environmental Medicine.

http://etd.uwc.ac.za/

Downloaded from http://journals.lww.com/joem by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 07/17/2023

TABLE 3. Association between CVH and Musculoskeletal Injuries in Firefighters

	Univariable Models[a]		Multivariable Models[b]			
	Model 1		Model 2[c]		Model 3[d]	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Intercept (null model)	−0.341					
General characteristics[e]						
Age, y	1.03 (1.01−1.06)	0.004**	—	—	0.99 (0.94−1.04)	0.538
Sex (females)	2.19 (1.06−4.53)	0.033*	2.11 (0.99−4.47)	0.051	2.30 (1.08−4.90)	0.031*
Years of experience, y	1.04 (1.02−1.06)	<0.001**	1.04 (0.99−1.09)	0.100	—	—
CVH parameters[e]						
BMI, kg·m^{-2}[f]	1.09 (1.04−1.15)	<0.001**	1.07 (1.02−1.13)	0.012*	1.07 (1.01−1.13)	0.023*
Waist circumference, cm[f]	1.03 (1.01−1.04)	0.006**	1.02 (0.99−1.04)	0.090	0.99 (0.95−1.03)	0.532
BF%, %[f]	1.05 (1.02−1.07)	<0.001**	1.03 (1.00−1.06)	0.046*	1.03 (1.00−1.06)	0.030
SBP, mm Hg	1.01 (0.99−1.03)	0.067	—	—	—	—
DBP, mm Hg	1.03 (1.01−1.05)	0.003**	1.02 (0.99−1.04)	0.125	1.02 (0.99−1.04)	0.135
NFBG, mmol·L^{-1}	1.01 (0.86−1.18)	0.941	—	—	—	—
TC, mmol·L^{-1}	1.28 (1.07−1.54)	0.009**	1.18 (0.97−1.44)	0.094	1.17 (0.96−1.42)	0.119
LDL-C, mmol·L^{-1}	1.23 (0.99−1.53)	0.056	—	—	—	—
HDL, mmol·L^{-1}	1.14 (0.63−2.05)	0.676	—	—	—	—
Triglycerides, mmol·L^{-1}	1.21 (0.98−1.49)	0.077	—	—	—	—
Diet score	1.01 (0.91−1.13)	0.841	—	—	—	—
Framingham risk score	1.27 (1.06−1.53)	0.011*	1.05 (0.97−1.13)	0.238	1.03 (0.96−1.10)	0.446
Weekly MET minutes	0.69 (0.39−1.21)	0.197	—	—	—	—
Heart rate variability[e]						
Heart rate variability, ms	1.00 (0.99−1.00)	0.421	—	—	—	—
SDNN, ms	0.99 (0.99−1.01)	0.512	—	—	—	—
RMSSD, ms	1.00 (0.99−1.01)	1.000	—	—	—	—
LF, Hz	0.00 (0.00−1.47)	0.061	—	—	—	—
HF, Hz	0.50 (0.01−19.49)	0.714	—	—	—	—
LF/HF ratio, Hz	0.99 (0.94−1.04)	0.694	—	—	—	—
CVD risk factors and CV health metrics[g]						
Age	0.71 (0.44−1.17)	0.179	—	—	—	—
Obesity[f]	1.84 (1.11−3.04)	0.018*	0.67 (0.29−1.54)	0.343	0.67 (0.29−1.56)	0.358
Central obesity[f]	1.45 (0.92−2.28)	0.112	—	—	—	—
High BF%[f]	1.95 (1.17−3.23)	0.010*	1.02 (0.52−1.00)	0.953	1.02 (0.52−1.99)	0.964
Hypertension	1.64 (1.04−2.59)	0.034*	1.01 (0.99−1.03)	0.320	1.01 (0.99−1.03)	0.340
Diabetes	1.09 (0.39−3.03)	0.855	—	—	—	—
Dyslipidemia	1.98 (1.23−3.18)	0.005**	1.56 (0.93−2.59)	0.091	1.49 (0.89−2.49)	0.126
High LDL-C	1.56 (0.94−2.57)	0.085	—	—	—	—
High HDL-C	0.85 (0.49−1.49)	0.569	—	—	—	—
Hypertriglyceridemia	1.81 (1.14−2.88)	0.013*	1.62 (0.97−2.69)	0.063	1.61 (0.97−2.68)	0.067
Physical inactivity	1.29 (0.79−2.08)	0.299	—	—	—	—
Cigarette smoking	1.13 (0.71−1.82)	0.608	—	—	—	—
Diet	1.14 (0.68−1.89)	0.615	—	—	—	—
Family history	1.68 (0.96−2.95)	0.068	—	—	—	—
Poor CVH index	1.62 (1.00−2.62)	0.049*	1.26 (0.75−2.14)	0.383	1.25 (0.74−2.13)	0.403
Good CVH index	0.41 (0.18−0.95)	0.037*	0.45 (0.17−1.19)	0.108	0.44 (0.16−1.15)	0.093

*Indicates statistical significance <0.05.
**Indicates statistical significance <0.01.
[a]Univariable models using binary logistic regression.
[b]Evidence-based explanatory variables reported to be significantly related to musculoskeletal injuries were entered into the same multivariable model.
[c]Covariates: age, sex, BMI.
[d]Covariates: years of experience, sex, BMI.
[e]Continuous variables.
[f]Body mass index removed from model.
[g]Dichotomous categorical variables indicating positive CVD risk factors and poor CVH metrics.
BF%, body fat percentage; BMI, body mass index; CI, confidence interval; CVH, cardiovascular health; DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; HF, high frequency; LDL-C, low-density lipoprotein cholesterol; LF, low frequency; LF/HF, low- and high-frequency ratio; MET, metabolic equivalents; NFBG, nonfasting blood glucose; OR, odds ratio; RMSSD, root mean square of successive differences; SBP, systolic blood pressure; SDNN, standard deviation of all normal-to-normal; TC, total cholesterol.

participants with an altered lipid profile reported more MSD than those with normal lipid profiles. In the present study, firefighters used statins as a treatment for their dyslipidemia, which has been associated with increased symptoms of MSD and pain,[17] providing an additional explanation for the association between dyslipidemia and MSD seen in the present study. A study by Squier et al.[19] noted that hypercholesteremia altered Achilles tendon biomechanics and increased the risk for injuries, due to abnormal loading. Altered force distribution, particularly in firefighters who are often required to move in awkward positions,[45,46] may predispose them to injury. Moreover, altered force distribution in tendons may also predispose firefighters to pain and discomfort due to the uneven loading.

Arteries and tendons have a similar collagen makeup,[19,20] and because of this, it is likely that other major CVD risk factors may have

© 2023 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American College of Occupational and Environmental Medicine.

http://etd.uwc.ac.za/

Downloaded from http://journals.lww.com/joem by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 07/17/2023

TABLE 4. Association between CVH and Musculoskeletal Discomfort in Firefighters

	Univariable Models[a]		Multivariable Models[b]			
	Model 1		Model 2[c]		Model 3[d]	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Intercept (null model)	−0.326					
General characteristics[e]						
Age, y	1.01 (0.98–1.03)	0.666	—	—	—	—
Sex (females)	1.64 (0.80–3.35)	0.177	—	—	—	—
Years of experience	1.01 (0.99–1.03)	0.290	—	—	—	—
CVH parameters[e]						
BMI, kg·m^{-2}	1.03 (0.98–1.08)	0.280	—	—	—	—
Waist circumference, cm	1.00 (0.99–1.02)	0.657	—	—	—	—
Body fat percentage (%)	1.02 (0.99–1.05)	0.084	—	—	—	—
SBP, mm Hg	1.01 (0.99–1.03)	0.184	—	—	—	—
DBP, mm Hg	1.01 (0.99–1.03)	0.603	—	—	—	—
NFBG, mmol·L^{-1}	0.89 (0.76–1.06)	0.193	—	—	—	—
TC, mmol·L^{-1} [c]	1.22 (1.02–1.46)	0.034*	1.22 (1.01–1.48)	0.044*	1.19 (0.99–1.44)	0.070
LDL-C, mmol·L^{-1} [c]	1.32 (1.06–1.64)	0.014*	1.32 (1.05–1.66)	0.018*	1.03 (1.03–1.62)	0.028*
HDL-C, mmol·L^{-1}	1.08 (0.59–1.94)	0.810	—	—	—	—
Triglycerides, mmol·L^{-1}	0.90 (0.74–1.11)	0.339	—	—	—	—
Diet score	1.05 (0.94–1.17)	0.382	—	—	—	—
Framingham risk score	1.03 (0.99–1.08)	0.141	—	—	—	—
Weekly MET minutes	0.64 (0.36–1.12)	0.121	—	—	—	—
Heart rate variability[e]						
Heart rate variability	1.00 (1.00–1.00)	0.071	—	—	—	—
SDNN [c]	1.02 (1.00–1.03)	0.010*	1.02 (1.01–1.03)	0.002**	1.02 (1.01–1.03)	0.001**
RMSSD [c]	1.01 (1.00–1.02)	0.008**	1.02 (1.01–1.03)	0.002**	1.02 (1.01–1.03)	0.001**
LF	0.06 (0.00–437.13)	0.534	—	—	—	—
HF	0.08 (0.00–3.24)	0.182	—	—	—	—
LF/HF ratio	0.95 (0.90–1.01)	0.077	—	—	—	—
CVD risk factors and CV health metrics[f]						
Age	0.87 (0.53–1.43)	0.593	—	—	—	—
Obesity	1.13 (0.68–1.86)	0.640	—	—	—	—
Central obesity	1.12 (0.71–1.76)	0.627	—	—	—	—
High BF%	1.47 (0.89–2.44)	0.132	—	—	—	—
Hypertension	1.14 (0.72–1.79)	0.577	—	—	—	—
Diabetes	0.44 (0.14–1.40)	0.166	—	—	—	—
Dyslipidemia	1.35 (0.84–2.16)	0.215	—	—	—	—
High LDL-C	1.32 (0.80–2.19)	0.275	—	—	—	—
Low HDL-C	1.45 (0.83–2.50)	0.189	—	—	—	—
Hypertriglyceridemia	1.39 (0.88–2.21)	0.160	—	—	—	—
Physical inactivity	1.14 (0.71–1.83)	0.584	—	—	—	—
Cigarette smoking	1.30 (0.81–2.09)	0.271	—	—	—	—
Diet	0.73 (0.44–1.23)	0.241	—	—	—	—
Family history	1.02 (0.59–1.75)	0.957	—	—	—	—
Poor CVH index	1.39 (0.86–2.25)	0.177	—	—	—	—
Good CVH index	0.73 (0.35–1.53)	0.398	—	—	—	—

*Indicates statistical significance <0.05.

**Indicates statistical significance <0.01.

[a]Univariable models using binary logistic regression.

[b]Evidence-based explanatory variables reported to be significantly related to musculoskeletal discomfort were entered into the same multivariable model.

[c]Covariates: age, sex, BMI.

[d]Covariates: years of experience, sex, BMI.

[e]Continuous variables.

[f]Dichotomous categorical variables indicating positive CVD risk factors and poor cardiovascular health metrics.

BF%, body fat percentage; BMI, body mass index; CI, confidence interval; CVD, cardiovascular disease; CVH, cardiovascular health; DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; HF, high frequency; LDL-C, low-density lipoprotein cholesterol; LF, low frequency; LF/HF, low- and high-frequency ratio; MET, metabolic equivalents; NFBG, nonfasting blood glucose; OR, odds ratio; RMSSD, root-mean-square of successive differences; SBP, systolic blood pressure; SDNN, standard deviation of all normal-to-normal; TC, total cholesterol.

a similar effect on the progressive development of atherosclerotic plaque within tendons.[47] This may provide a hypothetical explanation for DBP increasing the likelihood of MSIs in firefighters, as blood pressure is a significant factor in the development of atherosclerotic plaque in arteries.[48,49] The results of the present study indicated that the Framingham risk score and poor CVHI increased the odds of MSIs by 27% and 62%, respectively. As these risk scores are predictive of risk for atherosclerotic diseases, this relationship may help explain the association between these measures and MSIs.[17,19,20,50] Moreover, several factors included in the Framingham risk score and CVHI were independently associated with an increased likelihood of injury in the current results, making the cumulative CVD risk scores association with MSIs unsurprising. In addition, a good CVHI reduced the odds of MSIs by 41% in firefighters. Healthier and younger firefighters

 © 2023 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American College of Occupational and Environmental Medicine.

http://etd.uwc.ac.za/

Downloaded from http://journals.lww.com/joem by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 07/17/2023

may, overall, have better cardiovascular and musculoskeletal health, likely reducing the likelihood of injury, which has been noted in previous studies.[11-13]

An augmenting factor to the reporting of MSIs and MSDs may be BMI and BF%, as previous studies have shown that heavier firefighters are particularly susceptible to lower limb injuries,[11,12] and may be a result of the combination of the factors (age, TC, LDL-C, triglycerides) noted in the present study. The increase in nonfunctional mass, commonly seen in obese firefighters, may add additional strain to already susceptible tendons, exacerbating the risk for sudden tendon ruptures considerably.[11-13] In addition, firefighters who are physically inactive, and are required to perform physically strenuous duties, particularly those that are obese with underlying cholesterol issues, may be especially susceptible to sudden tendon sprain.[11-13]

We found that increased SDNN and RMSSD were associated with an increased likelihood of MSD in firefighters. Chuang et al.[22] noted that a direct relationship between musculoskeletal pain and SDNN and RMSSD existed, where a decreased in MSD caused a subsequent increase in SDNN and RMSSD. However, the current results are in contrast to Chuang et al.,[22] where it was found as MSD decreased, SDNN and RMSSD decreased and, in particular, those participants that reported high levels of MSD. Measures of HRV have been reported to be closely linked to various physiological processes, such as stress and discomfort, in firefighters.[41,51-53] Most importantly, HRV, particularly SDNN and RMSSD, have been related to autonomic disturbance and inflammatory responses, similar to those related to musculoskeletal pain and discomfort.[21,22] The conflicting results in the current study compared with the findings of Chuang et al.[22] may be related to firefighters that experienced MSD being more vigorously physically active than firefighters without discomfort (360 vs 320 minutes) and the additional physical activity causing chronic inflammation due to the higher workloads; however, this is only speculation. The current results indicated that TC, LDL-C, SDNN, and RMSSD remained significantly associated with MSD after adjustment for covariates. Another possible explanation would be that high LDL-C is a source of oxidative stress within the tendons.[20,22] The oxidative stress, accompanied by inflammation, may present as a reduction in HRV, which is supported by studies that showed reduced symptoms of musculoskeletal pain and discomfort were associated with increased HRV measures, such as N-N intervals, RMSSD, and SDNN.[21,22] The results of the present study showed that firefighters that were never injured were the most vigorously active (360 vs 240 minutes), but also reported the highest musculoskeletal discomfort. Perhaps, firefighters experienced more discomfort due to their higher levels of vigorous activity, which may have been fitter, but also had higher levels of TC and LDL-C concentrations, which has been shown to increase inflammation and pain.[17,22] Moreover, studies have shown that HRV was linked to overtraining and overuse, providing a potential link between HRV and MSH,[54,55] particularly in the firefighter population, which is known to be a physically demanding profession. In this current study, higher levels of vigorous weekly physical activity had a protective effect on the prevalence of MSIs of firefighters, which is not unexpected, given the protective effect of physical activity on musculoskeletal health, which is well documented in firefighters.[5,29] This is in contrast to a previous study in this population, which noted higher weekly physical activity was related to an increase in MSIs.[56] Nevertheless, physical activity has been reported to be a central factor in reducing the incidence of MSIs and MSDs alike in firefighters.[18,44,57]

In the current study, sex was significantly associated with firefighters reporting MSIs, where female firefighters were 2.1 times as likely to report an MSI compared with male firefighters. Nazari et al.[43] reported that females were 1.6 times more likely to sustain two or more injuries, compared with male firefighters. Similarly, a study by O'Leary et al.[58] noted that in military, personal females were at higher risk for musculoskeletal injury compared with males, particularly related to the lower limbs. A recent study noted that reduced lean body mass predisposed males to injury, whereas a higher fat mass predisposed females to injury.[50] The current results indicated that a significant difference existed between male and female BF%, which could, possibly, explain the association between sex and injuries seen in the current study. In addition, generally, males having more muscle mass, a higher bone mineral density, and relatively stronger connective tissues[59,60] which could further explain why females were more likely to report an MSI. Studies have shown that firefighting PPE has been designed to fit male firefighters more comfortably than female firefighters, likely contributing to the higher injury incidence in female firefighters.[61,62] Moreover, because of discrimination in the fire services, female firefighters may be less likely to ask male firefighters for assistance on physically strenuous tasks increasing the probability of injury in females.[61]

Age and years of experience were significantly associated with injuries in firefighters, where every 1-year increase in experience increased the likelihood of injury by 3% and 4%, and approached statistical significance in the adjusted models. However, after adjustment, significance was removed. This was consistent with previous literature, where both aging and years of experience were significantly associated with firefighters sustaining MSIs.[10,13,43] Firefighting is a strenuous occupation that places significant strain on the musculoskeletal system.[10,63] Compounded with age increasing along with experience, firefighters become significantly predisposed to MSIs. Moreover, aging, independently, causes physiological changes that reduce MSH[12,13] and as a result of the attrition in MSH associated with increasing years as a firefighter,[12,13,27] predisposes this population to injury. Previous studies have noted that with the normal wear and tear of firefighting, older firefighters, generally, would have a higher risk of injury, likely as a result of the increase in years of service.[10,13,43]

Strengths and Limitations

Strengths of the present study include the application of multilevel modeling to account for the hierarchical nature of the data and the use of objective measures for the CVH components and all tools used were reliable and valid. In addition, this article adds novel information into an area, which has been understudied in firefighters. There are, however, several limitations to the present study. First, this study used a cross-sectional design, which precludes the inference of causal relationships. Second, MSIs and MSD were self-reported. Thirdly, female firefighters were underrepresented, limiting the generalizability to the female firefighter population. Finally, although the study met the minimum required sample size, the number of comparisons made may introduce chance findings.

CONCLUSIONS

Multiple CVD risk factors and CVH metrics were associated with MSIs and MSD in firefighters. Musculoskeletal injuries were significantly higher in aged, obese, hypertensive, and dyslipidemic firefighters. In addition, MSD was significantly higher in firefighters with high TC, LDL-C, SDNN, and RMSSD. Thus, older female firefighters with a higher BF% are most likely to have ever sustained a musculoskeletal line-of-duty injury. In addition, those with elevated blood lipid levels are most likely to have musculoskeletal discomfort. Our results add to the limited research in this topic area, particularly on the potential relationships that exist between CVH, and musculoskeletal health in firefighters. The results of this study add novel information on the associations between CVH and MSH in firefighters, specifically the association between MSIs and MSD and blood lipid and HRV irregularities, providing new insights into risk factors for MSIs in this population. Maintaining one's CVH may have an added benefit of maintaining MSH in firefighters and that commonly obtained health metrics may provide valuable insight into who is most at risk for MSI and MSD. Therefore, maintenance of an ideal body composition and blood lipid profile is recommended, particularly as firefighters age, as it

© 2023 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American College of Occupational and Environmental Medicine.

Downloaded from http://journals.lww.com/joem by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 07/17/2023

may have a positive and long-term benefit in maintaining the well-being and ensuring career longevity in firefighters.

Recommendations

Future studies should use a longitudinal study design to establish the causal factors related to MSIs and MSD in firefighters. A more representative sample of female firefighters should be included to increase the generalizability to the female firefighter population.

ACKNOWLEDGMENTS

The authors thank all firefighters who consented to voluntarily participate in the study.

REFERENCES

1. Smith DL, Haller JM, Korre M, et al. The relation of emergency duties to cardiac death among US firefighters. *Am J Cardiol*. 2019;123:736–741.
2. Smith DL, Barr DA, Kales SN. Extreme sacrifice: sudden cardiac death in the US fire service. *Extrem Physiol Med*. 2013;2:1–9.
3. Soteriades ES, Smith DL, Tsismenakis AJ, Baur DM, Kales SN. Cardiovascular disease in US firefighters: a systematic review. *Cardiol Rev*. 2011;19:202–215.
4. Smith DL, DeBlois JP, Kales SN, Horn GP. Cardiovascular strain of firefighting and the risk of sudden cardiac events. *Exerc Sport Sci Rev*. 2016;44:90–97.
5. Ras J, Smith DL, Kengne AP, Soteriades EE, Leach L. Cardiovascular disease risk factors, musculoskeletal health, physical fitness, and occupational performance in firefighters: a narrative review. *J Environ Public Health*. 2022; 2022:7346408–7346420.
6. Smith DL, Graham E, Stewart D, Mathias KC. Cardiovascular disease risk factor changes over 5 years among male and female US firefighters. *J Occup Environ Med*. 2020;62:398–402.
7. McAllister MJ, Gonzalez DE, Leonard M, et al. Firefighters With higher cardiorespiratory fitness demonstrate lower markers of cardiovascular disease risk. *J Occup Environ Med*. 2022;64:1036–1040 Available at: https://journals.lww.com/joem/Fulltext/9900/Firefighters_with_higher_cardiorespiratory_fitness.102.aspx.
8. Risavi BL, Staszko J. Prevalence of risk factors for coronary artery disease in Pennsylvania (USA) firefighters. *Prehosp Disaster Med*. 2015;31:102–107.
9. Ras J, Leach L. Prevalence of coronary artery disease risk factors in firefighters in the city of Cape Town fire and rescue service—a descriptive study. *J Public Health Res*. 2021;10:2000.
10. Negm A, MacDermid J, Sinden K, D'Amico R, Lomotan M, MacIntyre NJ. Prevalence and distribution of musculoskeletal disorders in firefighters are influenced by age and length of service. *J Mil Veteran Fam Health*. 2017;3:33–41.
11. Frost DM, Beach TAC, Crosby I, McGill SM. Firefighter injuries are not just a fireground problem. *Work*. 2015;52:835–842.
12. Hong O, Phelps S, Feld J, Vogel S. Occupational injuries, duty status, and factors associated with injuries Among firefighters. *Workplace Health Saf*. 2012;60: 517–523.
13. Yoon JH, Kim YK, Kim KS, Ahn YS. Characteristics of workplace injuries among nineteen thousand Korean firefighters. *J Korean Med Sci*. 2016;31:1546–1552.
14. Damrongsak M, Prapanjaroensin A, Brown KC. Predictors of back pain in firefighters. *Workplace Health Saf*. 2018;66:61–69.
15. Nazari G, Osifeso TA, MacDermid JC. Distribution of number, location of pain and comorbidities, and determinants of work limitations among firefighters. *Rehabil Res Pract*. 2020;2020:1942513–1942519.
16. Punakallio A, Lusa S, Luukkonen R, Airila A, Leino-Arjas P. Musculoskeletal pain and depressive symptoms as predictors of trajectories in work ability among Finnish firefighters at 13-year follow-up. *J Occup Environ Med*. 2014; 56:367–375.
17. Buettner C, Davis RB, Leveille SG, Mittleman MA, Mukamal KJ. Prevalence of musculoskeletal pain and statin use. *J Gen Intern Med*. 2008;23:1182–1186.
18. Nowak AM, Molik B, Wójcik A, et al. Physical activity and injuries relating to physical fitness of professional firefighters. *Adv Rehabil*. 2018;32:13–22.
19. Squier K, Scott A, Hunt MA, et al. The effects of cholesterol accumulation on Achilles tendon biomechanics: a cross-sectional study. *PLoS One*. 2021;16: e0257269.
20. Tilley BJ, Cook JL, Docking SI, Gaida JE. Is higher serum cholesterol associated with altered tendon structure or tendon pain? A systematic review. *Br J Sports Med*. 2015;49:1504–1509.
21. Hallman DM, Olsson EMG, von Schéele B, Melin L, Lyskov E. Effects of heart rate variability biofeedback in subjects with stress-related chronic neck pain: a pilot study. *Appl Psychophysiol Biofeedback*. 2011;36:71–80.
22. Chuang C-C, Chung W-Y, Shu C, Chen M-W. Pain assessment in musculoskeletal pain patients by heart rate variability. *J Musculoskelet Pain*. 2007;15:67–74.
23. Durand G, Tsismenakis AJ, Jahnke SA, Baur DM, Christophi CA, Kales SN. Firefighters' physical activity: relation to fitness and cardiovascular disease risk. *Med Sci Sports Exerc*. 2011;43:1752–1759.
24. Yu CC, Au CT, Lee FY, et al. Association between leisure time physical activity, cardiopulmonary fitness, cardiovascular risk factors, and cardiovascular workload at work in firefighters. *Saf Health Work*. 2015;6:192–199.
25. Barry AM, Lyman KJ, Dicks ND, et al. Firefighters' physical activity and waist circumference as predictors of VO2max. *J Occup Environ Med*. 2019;61:849–853.
26. Kales SN, Soteriades ES, Christophi CA, Christiani DC. Emergency duties and deaths from heart disease among firefighters in the United States. *N Engl J Med*. 2007;356:1207–1215.
27. Phelps SM, Drew-Nord DC, Neitzel RL, Wallhagen MI, Bates MN, Hong OS. Characteristics and predictors of occupational injury among career firefighters. *Workplace Health Saf*. 2018;66:291–301.
28. Jahnke SA, Poston WS, Haddock CK, Jitnarin N. Injury among a population based sample of career firefighters in the Central USA. *Inj Prev*. 2013;19:393–398.
29. Bpe LL, Randall JR, Gross DP, Senthilselvan A, Voaklander D. The relationship between physical fitness and occupational injury in emergency responders: a systematic review. *Am J Ind Med*. 2019;62:3–13.
30. Chairani A. Validity and reliability test of the Nordic Musculoskeletal Questionnaire with formal and informal sector workers. *Childhood Stunting, Wasting, and Obesity, as the Critical Global Health Issues: Forging Cross-Sectoral Solutions*. Masters Program in Public Health, Universitas Sebelas Maret:100–106.
31. Hedge A, Morimoto S, Mccrobie D. Effects of keyboard tray geometry on upper body posture and comfort. *Ergonomics*. 1999;42:1333–1349.
32. Bohlmann IM, Mackinnon S, Kruger H, et al. Is the International Physical Activity Questionnaire (IPAQ) valid and reliable in the South African population? *Med Sci Sports Exerc*. 2001;33:S119.
33. Liguori G, American College of Sports Medicine, Fountaine CJ. ACSM's Guidelines for Exercise Testing and Prescription. Alphen aan den Rijn, Netherlands: Wolters Kluwer. Available at: https://books.google.co.za/books?id=6P-azQEACAAJ. 2021. Accessed February 1, 2023.
34. Bastianelli K, Ledin S, Chen J. Comparing the accuracy of 2 point-of-care lipid testing devices. *J Pharm Pract*. 2017;30:490–497.
35. D'Agostino RB, Vasan RS, Pencina MJ, et al. General cardiovascular risk profile for use in primary care. *Circulation*. 2008;117:743–753.
36. Lloyd-Jones DM, Braun LT, Ndumele CE, et al. Use of risk assessment tools to guide decision-making in the primary prevention of atherosclerotic cardiovascular disease: a special report from the American Heart Association and American College of Cardiology. *Circulation*. 2019;139:e1162–e1177.
37. Lloyd-Jones DM, Leip EP, Larson MG, et al. Prediction of lifetime risk for cardiovascular disease by risk factor burden at 50 years of age. *Circulation*. 2006;113:791–798.
38. Ketelaar EJ, Vos AG, Godijk NG, et al. Ideal cardiovascular health index and its determinants in a rural South African population. *Glob Heart*. 2020;15:1–11.
39. Kim S, Chang Y, Cho J, et al. Life's simple 7 cardiovascular health metrics and progression of coronary artery calcium in a low-risk population. *Arterioscler Thromb Vasc Biol*. 2019;39:826–833.
40. Billman GE, Huikuri HV, Sacha J, et al An introduction to heart rate variability: methodological considerations and clinical applications. *Front Physiol*. 2015;6: 2013–2015.
41. Tomes C, Schram B, Orr R. Relationships between heart rate variability, occupational performance, and fitness for tactical personnel: a systematic review. *Front Public Health*. 2020;8:583336.
42. Templeton GF. A two-step approach for transforming continuous variables to normal: implications and recommendations for IS research. *Commun Assoc Inform Syst*. 2011;28:41–58.
43. Nazari G, Macdermid JC, Sinden K, D'Amico R. Prevalence of musculoskeletal symptoms among Canadian firefighters. *Work*. 2020;67:185–191.
44. Poplin GS, Roe DJ, Burgess JL, Peate WF, Harris RB. Fire fit: assessing comprehensive fitness and injury risk in the fire service. *Int Arch Occup Environ Health*. 2016;89:251–259.
45. Park K, Sy JF, Horn GP, et al. Assessing gait changes in firefighters after firefighting activities and while carrying asymmetric loads. *Appl Ergon*. 2018;70:44–50.
46. von Heimburg E, Medbø JI, Sandsund M, Reinertsen RE. Performance on a work-simulating firefighter test versus approved laboratory tests for firefighters and applicants. *Int J Occup Saf Ergon*. 2013;19:227–243.
47. Hashimoto T, Minami Y, Kakizaki R, et al. Achilles tendon thickening is associated with disease severity and plaque vulnerability in patients with coronary artery disease. *J Clin Lipidol*. 2019;13:194–200.
48. Fahs CA, Smith DL, Horn GP, et al. Impact of excess body weight on arterial structure, function, and blood pressure in firefighters. *Am J Cardiol*. 2009;104:1441–1445.
49. Noh J, Lee CJ, Hyun DS, et al. Blood pressure and the risk of major adverse cardiovascular events among firefighters. *J Hypertens*. 2020;38:850–857.
50. Domaradzki J, Koźlenia D. The performance of body mass component indices in detecting risk of musculoskeletal injuries in physically active young men and women. *PeerJ*. 2022;10:e12745.

 © 2023 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American College of Occupational and Environmental Medicine.

http://etd.uwc.ac.za/

Downloaded from http://journals.lww.com/joem by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC1y0abggQZXdtwnfKZBYtws= on 07/17/2023

51. Ras J, Leach L. Use of mobile technology in assessing occupational performance and stress in firefighters. In: Mentor D, ed. *Handbook of Research on New Media, Training, and Skill Development for the Modern Workforce*. Hershey, PA: IGI Global; 2022:150–186.
52. Marcel-Millet P, Ravier G, Esco MR, Groslambert A. Does firefighters' physical fitness influence their cardiac parasympathetic reactivation? Analysis with post-exercise heart rate variability and ultra-short-term measures. *Int J Occup Saf Ergon*. 2022;28:153–161.
53. Marcel-Millet P, Groslambert A, Gimenez P, Grosprêtre S, Ravier G. Psychophysiological responses of firefighters to day and night rescue interventions. *Appl Ergon*. 2021;95:103457.
54. Mourot L, Bouhaddi M, Perrey S, et al. Decrease in heart rate variability with overtraining: assessment by the Poincaré plot analysis. *Clin Physiol Funct Imaging*. 2004;24:10–18.
55. Gisselman AS, Baxter GD, Wright A, Hegedus E, Tumilty S. Musculoskeletal overuse injuries and heart rate variability: is there a link? *Med Hypotheses*. 2016;87:1–7.
56. Ras J, Leach L. Relationship between physical activity, coronary artery disease risk factors and musculoskeletal injuries in the City of Cape Town Fire and Rescue Service. *Inquiry*. 2022;59:469580221084485.
57. Vaulerin J, d'Arripe-Longueville F, Emile M, Colson SS. Physical exercise and burnout facets predict injuries in a population-based sample of French career firefighters. *Appl Ergon*. 2016;54:131–135.
58. O'Leary TJ, Wardle SL, Rawcliffe AJ, Chapman S, Mole J, Greeves JP. Understanding the musculoskeletal injury risk of women in combat: the effect of infantry training and sex on musculoskeletal injury incidence during British Army basic training. *BMJ Mil Health*. 2023;169:57–61.
59. Janssen I, Heymsfield SB, Wang Z, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. *J Appl Physiol*. 2000;89:81–88.
60. Kelly PJ, Twomey L, Sambrook PN, Eisman JA. Sex differences in peak adult bone mineral density. *J Bone Miner Res*. 1990;5:1169–1175.
61. Sinden K, MacDermid J, Buckman S, Davis B, Matthews T, Viola C. A qualitative study on the experiences of female firefighters. *Work*. 2013;45:97–105.
62. McQuerry M, Kwon C, Johnson H. A critical review of female firefighter protective clothing and equipment workplace challenges. *Res J Textile Apparel*. 2019;23:94–110.
63. Nazari G, MacDermid JC, Sinden KE, Overend TJ. The relationship between physical fitness and simulated firefighting task performance. *Rehabil Res Pract*. 2018;2018:3234176–3234177.

UNIVERSITY of the WESTERN CAPE

© 2023 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American College of Occupational and Environmental Medicine.

http://etd.uwc.ac.za/

CHAPTER NINE: PUBLICATION EIGHT − ORIGINAL RESEARCH ARTICLE FOUR

Association between Physical Fitness and Cardiovascular Health in Firefighters

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

International Journal of
Environmental Research and Public Health

MDPI

Article

Association between Physical Fitness and Cardiovascular Health in Firefighters

Jaron Ras [1,*], Denise L. Smith [2], Elpidoforos S. Soteriades [3,4], Andre P. Kengne [5] and Lloyd Leach [1]

[1] Department of Sport, Recreation and Exercise Science, Faculty of Community and Health Sciences, University of the Western Cape, Cape Town 7535, South Africa; lleach@uwc.ac.za
[2] Health and Human Physiological Sciences, Skidmore College, Saratoga Springs, NY 12866, USA; dsmith@skidmore.edu
[3] Healthcare Management Program, School of Economics and Management, Open University of Cyprus, Nicosia 2220, Cyprus; elpidoforos.soteriades@ouc.ac.cy
[4] Harvard T.H. Chan School of Public Health, Department of Environmental Health, Environmental and Occupational Medicine and Epidemiology (EOME), Boston, MA 02115, USA
[5] Non-Communicable Diseases Research Unit, South African Medical Research Council, Cape Town 7505, South Africa; andre.kengne@mrc.ac.za
* Correspondence: 3405618@myuwc.ac.za

Abstract: Firefighters perform strenuous work in dangerous and unpredictable environments requiring optimal physical conditioning. The aim of this study was to investigate the association between physical fitness and cardiovascular health (CVH) in firefighters. This cross-sectional study systematically recruited 309 full-time male and female firefighters between the ages of 20 to 65 years in Cape Town, South Africa. Physical fitness was assessed using absolute (ab$\dot{V}O_{2max}$) and relative oxygen consumption (relVO_{2max}), grip and leg strength, push-ups and sit-ups, sit-and-reach for flexibility and lean body mass (LBM). CVH encompassed age, smoking, blood pressure (BP), blood glucose, lipid profile, body mass index, body fat percentage (BF%), and waist circumference. Linear regressions and logistic regressions were applied. Multivariable analysis indicated that relVO_{2max} was associated with systolic BP ($p < 0.001$), diastolic BP ($p < 0.001$), non-fasting blood glucose ($p < 0.001$), and total cholesterol ($p = 0.037$). Poor CVH index was negatively associated with rel$\dot{V}O_{2max}$ ($p < 0.001$), leg strength ($p = 0.019$), and push-ups ($p = 0.012$). Furthermore, age was inversely associated with $\dot{V}O_{2max}$ ($p < 0.001$), push-up and sit-up capacity ($p < 0.001$), and sit-and-reach ($p < 0.001$). BF% was negatively associated with ab$\dot{V}O_{2max}$ ($p < 0.001$), grip and leg strength ($p < 0.001$), push-ups ($p = 0.008$), sit-ups ($p < 0.001$), and LBM ($p < 0.001$). Cardiorespiratory fitness, muscular strength, and muscular endurance were significantly associated with a better overall CVH profile.

Keywords: firefighters; physical fitness; risk factor; cardiorespiratory; strength; endurance; cardiovascular health

check for updates

Citation: Ras, J.; Smith, D.L.; Soteriades, E.S.; Kengne, A.P.; Leach, L. Association between Physical Fitness and Cardiovascular Health in Firefighters. *Int. J. Environ. Res. Public Health* **2023**, *20*, 5930. https://doi.org/10.3390/ijerph20115930

Academic Editor: Isidora Vujcic

Received: 21 March 2023
Revised: 9 May 2023
Accepted: 15 May 2023
Published: 23 May 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Firefighters routinely perform strenuous work in dangerous and unpredictable environments [1,2]. This requires firefighters to wear heavy, insulated personal protective equipment (PPE) that places additional strain on their bodies [2–4]. This necessitates that firefighters maintain all aspects of their physical fitness to cope with such stressors. Research has shown that in the first three minutes before the arrival to an alarm response, energy output increases by 400 to 600% [5]. While performing their duties, firefighters rapidly reach near-maximum heart rates and are, often, required to sustain these levels for prolonged periods of time [6,7].

It is well documented that close to 50% of all firefighting-related deaths are attributed to underlying CVD risk factors, with the majority of these deaths occurring during or shortly after fire suppression [8]. It has also been shown that there is an increase of up to

http://etd.uwc.ac.za/

20.9% in metabolic rate while firefighters wear PPE [9]. Several firefighting tasks average an oxygen consumption ($\dot{V}O_2$) of 26.1 to 30.4 mL·kg·min, with the most strenuous tasks requiring an average of 44.0 mL·kg·min [10]. Firefighters were reported to spend the least time on fire suppression and fireground activities [11], but these duties resulted in the highest energy requirement and highest incidence of cardiovascular incidents [1]. Research suggests that firefighters should maintain a cardiorespiratory fitness level of 42 mL·kg·min to manage these job stressors adequately [12]. The metabolic demands of firefighting highlight the need for firefighters to maintain an adequate level of physical fitness in order to perform their duties aptly [9,10]. Many firefighting tasks require firefighters to perform multiple forceful repetitions and/or maintain strong isometric contractions, such as during forcible entry, equipment carries, equipment hoist and hose drag [13–15]. Moreover, the higher the force produced by firefighters, the more efficiently firefighters can perform their duties [13–15]. Generally, more fit and stronger firefighters would participate in regular physical activity, which is crucial in maintaining adequate levels of physical fitness, which is particularly important as firefighters age [2,16,17]. It has been documented that firefighters are aware of the necessity of maintaining adequate levels of physical fitness and the benefit of remaining physically active [18,19]. However, many firefighters reported developing poor attitudes toward their health, particularly as they age and remained longer in the profession [20,21]. Ageing has also been related to a progressive decrease in cardiorespiratory fitness, muscular strength and endurance in firefighters [22–25]. In addition, ageing has been related to the gradual decrease in CVH [26–28], making this population particularly vulnerable when performing fire and rescue operations.

The association between physical fitness and CVH is bidirectional, where physical fitness influences CVH and vice versa [7,29–33]. Firefighters that are fitter and stronger with higher muscular strength were found to have a more favourable body composition, and better overall CVH profile [30–32,34]. Most studies on firefighters have been conducted in the United States, Canada, Europe and Australia [35]. However, this association has not been studied among firefighters on the African continent. Previous studies have shown that firefighters, in South Africa, have a high prevalence of CVD risk factors, particularly those related to obesity, hypertension and physical inactivity [18,26,36], with this population having a poor attitude toward physical activity and physical fitness [18,20]. This suggests that this population likely have a poor level of physical fitness and CVH compared to other firefighting populations previously mentioned, which, generally, had a, comparatively, healthier firefighting population [28,31,37]. However, more research is needed assessing the CVH of firefighters in South Africa, where very little research exists. In addition, because the population of firefighters where the association between physical fitness and CVH had been assessed were, generally, healthier, it is expected that the current study may provide unique outcomes in comparison. The absence of research on the African firefighter population likely contributes toward the paucity of policy regulations compared to the aforementioned nations, particularly on firefighters maintaining minimum physical fitness and cardiovascular health standards aimed at ensuring the physical well-being of firefighters. There have not been any previous studies investigating the association between measures of physical fitness and CVH, and the literature contains little information about CVH index (CVHI) in firefighters. In addition, the findings of this study will highlight the importance of physical fitness in maintaining CVH and vice versa in firefighters. Therefore, the aim of this study was to investigate the association between physical fitness and CVH in firefighters in South Africa.

2. Materials and Methods

2.1. Study Design and Population

In this study, we used a quantitative, non-experimental, cross-sectional research design by collecting data on physical fitness (cardiorespiratory fitness, muscular strength and endurance, flexibility, and body composition), CVH [cardiovascular disease (CVD) risk factors, CVD risk score, heart rate variability (HRV), and CVH index (CVHI)] in firefighters.

http://etd.uwc.ac.za/

This study was implemented between June and August 2022. Each volunteer participant provided written informed consent. In total, 309 full-time male and female firefighters between the ages of 20 to 65 years from the CoCTFRS participated in this study. Ethical approval was granted by the Biomedical Research Ethics Committee (ethical clearance number: BM21/10/9) of the University of the Western Cape. Approval was also granted by the Chief Fire Officer as well as the Department of Policy and Strategy research branch of the City of Cape Town.

2.2. Sampling and Participant Recruitment

Data collection took place during the annual physical fitness assessment conducted by the CoCTFRS at a standardised fire station located in the City of Cape Town metropolitan area. Systematic random sampling was used to select firefighters to participate in this study, where every third firefighter was selected to participate from 96 platoons (32 fire stations). Each of the 96 platoons consisted of 8 to 12 firefighters. All full-time firefighters between the age range of 20–65 years were recruited to participate. Firefighters were excluded from participation if they were on administration duty, on sick leave, employed on a part-time or seasonal basis, and did not participate in the physical ability test (PAT) on the day of testing.

2.3. Descriptive Measures

Data were collected using a researcher-generated questionnaire retrieving information on firefighters' sociodemographic and lifestyle information. Descriptive measures were objectively measured by trained researchers [38] and included height, weight, body fat percentage (BF%), lean body mass (LBM), blood pressure, non-fasting blood glucose (NFBG) concentration, blood cholesterol concentrations, and heart rate variability (HRV).

Briefly, for stature, firefighters were asked to stand barefoot on the level stadiometer base, with the heels together and the heels, buttocks, and upper back touching the stadiometer rod of a portable stadiometer (Seca model 700, Gmbh & Co., Hamburg, Germany). Body mass, body fat percentage and lean body mass were obtained using a Tanita© (Tanita©, Tokyo, Japan) BC-1000 Plus bioelectrical impedance (BIA) analyser. When taking body mass and BF%, firefighters were requested to wear minimal clothing and to stand barefoot, upright, with feet apart. Waist circumference was measured at the point of the belly button [39]. Hip circumference was taken at the level of the greatest posterior protuberance of the buttocks [39]. Blood pressure was taken thrice using an Omron Healthcare, Inc. M6 comfort intelligence (Omron Healthcare Co., Ltd., Hoofddorp, The Netherlands) automatic blood pressure monitor, with at least two-minute intervals between measures. Blood measures were measured using a CardioChek® Plus analyser (PTS Diagnostics, Indiana, IN, USA), using the finger prick method and a standard pipet. A detailed explanation of the methods used to conduct each test and the cut-offs for each CVD risk factor can be found at Ras et al. [38] (https://doi.org/10.3390/ejihpe12110120, accessed on 10 February 2023).

2.4. Physical Fitness Measures

2.4.1. Cardiorespiratory Fitness

Due to concerns about the possibility that a maximum exercise stress test would cause undue fatigue in firefighters, who were also required to return to shift after testing and perform firefighting duties, cardiorespiratory fitness was estimated using the non-exercise method via the following formula: $\dot{V}O_{2max}$ = 3.542 + (−0.014 × Age) + (0.015 × Body Mass [kg]) + (−0.011 × Resting Heart Rate) [40]. Two measures were used for cardiorespiratory fitness, namely absolute $\dot{V}O_{2max}$ (ab$\dot{V}O_{2max}$) and relative $\dot{V}O_{2max}$ (rel$\dot{V}O_{2max}$).

2.4.2. Handgrip Strength

Using a Takei®5401-C handgrip dynamometer, handgrip strength was used to assess upper body muscular strength using the standardized procedures recommended by the American College of Sports Medicine (ACSM) [39]. To ensure that the second phalangeal joint fits comfortably under the handle. To ensure consistency, firefighters were requested

http://etd.uwc.ac.za/

to hold the handgrip dynamometer in line with the forearm and the level of the thigh and away from the body. If firefighters flexed their elbow joint or moved the dynamometer significantly from the starting position, the firefighter was asked to repeat the measure. The dynamometer was set to zero, and, thereafter, firefighters were asked to squeeze with as much force as possible without holding their breath. The procedure was repeated twice, and the highest reading of the two measures was recorded. Manufacturer accuracy for the handgrip is ±2.0 kg force (kgf).

2.4.3. Leg Strength Dynamometer

Leg strength was measured with a Takei® back and leg strength dynamometer. Firefighters were requested to remain upright, with their feet placed shoulder width apart, on the base of the dynamometers. With their palms in the prone position, firefighters were requested to maintain an extended position in their elbow joints while their hands grasped the dynamometer hand bar. The chain was adjusted to the midpoint of the patella tendon to ensure that each firefighter's knees were in approximately 110 degrees of flexion. The firefighters were instructed to pull as forcefully as possible on the chain while attempting to straighten their knees. The procedure was repeated twice, and the highest reading of the two was recorded. Manufacturer accuracy for the back and leg strength dynamometer were ±6.0 kgf, respectively.

2.4.4. Push-Ups

Upper body muscular endurance was assessed using the push-ups test [39] and conducted in accordance with the ACSM guidelines [39]. Males were requested to position themselves in the standard prone position, with their hands positioned under the shoulder joint, back in a straight position and level position, in line with the head and their toes serving as the pivotal point. Females were requested to perform the modified push-up position, with their hands positioned under the shoulder joint, back straight and in line with the head, legs together, with their lower leg in contact with the mat, ankles placed in a planter-flexed position, and their knees acting as the pivotal point. For each repetition, firefighters were required to fully raise their body off the mat extending their elbow joints and returning to the down position. A hedgehog was placed under the chest of firefighters to maintain consistency when counting each repetition. The test was stopped when firefighters could not perform an additional push-up or two consecutive push-ups were performed incorrectly.

2.4.5. Sit-Ups

The sit-ups test was used to assess abdominal muscular endurance [39]. The firefighters were requested to lie down in a supine position on the mat with their knees at 90 degrees flexion, with their hands across the shoulders and elbows pointing forward [41]. For each repetition, firefighters were required to touch their knees with their elbows and then go back to the starting position, ensuring their shoulders touch the floor. The number of repetitions performed in 60 s was recorded. The test ended when one minute had passed or the firefighters' experienced exhaustion, which presented as the inability to perform another repetition [40].

2.4.6. Flexibility

To assess lower back and hamstring flexibility, the sit-and-reach method was used and conducted in accordance with the guidelines recommended by the ACSM [39]. The firefighters were asked to position themselves in a seated position, barefoot, with their knees completely extended and the soles of their feet in contact with the sit-and-reach box roughly 15.2 cm apart. Each firefighter was asked to inhale and, when exhaling, to drop the head between the arms and slowly reach as far forward as possible, holding the stretched position for approximately two seconds. Firefighters were given three attempts; the most distant point reached with the fingertips was recorded.

http://etd.uwc.ac.za/

2.5. Cardiovascular Health Parameters

In this current study, CVH was used as an umbrella term and was investigated using several approaches. These approaches included three main subcomponents, namely, CVD risk factors, CVH metrics, and HRV. The subcomponents of CVD risk factors and CVH metrics included some overlapping variables. The CVD risk factors and CVH metrics included age, body mass index (BMI), waist circumference (WC), body fat percentage (BF%), systolic blood pressure (SBP), diastolic blood pressure (DBP), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), triglycerides, non-fasting blood glucose (NFBG), physical activity, and diet.

2.5.1. Cardiovascular Health Metrics

The American Heart Association (AHA) used these seven CVH metrics to classify individuals as having a good index for cardiovascular health or a poor index. The CVHI was inversely related to all-cause mortality and cardiovascular events [41]. For this study, CVHI was classified as "poor" if two or fewer CVH metrics were classified as ideal and classified as "good" if firefighters had five to seven metrics rated ideal [41]. Firefighters with 3 to 4 metrics that were classified as ideal were categorized as having an intermediate CVHI. The metrics used for the CVHI included BMI, blood pressure, TC, NFBG, physical activity, cigarette smoking and diet. These factors had the same cut-off values as the CVD risk factors previously described [42,43].

Good BMI was classified as a BMI ≤ 24.9 $kg \cdot m^{-2}$, intermediate if BMI was between 25.0 and 29.9 $kg \cdot m^{-2}$ (overweight) and poor if ≥30 $kg \cdot m^{-2}$ (obese) [39,43,44]. Obesity was further classified as class I if BMI was between 30 $kg \cdot m^{-2}$ and 34.9 $kg \cdot m^{-2}$, class II if between 35 $kg \cdot m^{-2}$ and 39.9 $kg \cdot m^{-2}$ and class III if above 40 $kg \cdot m^{-2}$. Ideal blood pressure was classified as SBP ≤ 120 mmHg and DBP ≤ 90 mmHg, intermediate health (prehypertension) as an SBP between 121 and 139 mmHg and/or DBP between 81 and 89 mmHg, or controlled through hypertensive medication, and hypertensive as an SBP ≥ 140 mmHg and/or a DBP ≥ 90 mmHg, respectively [39,41–43]. Hypertension was further classified as stage 1 if SBP was between 140 mmHg and 159 mmHg and DBP between 90 and 99 mmHg, stage 2 if SBP ranged between 160 and 179 mmHg and DBP ranged between 100 mmHg and 109 mmHg and stage 3 if SBP was above 180 mmHg and DBP was above 110 mmHg [45]. Good TC was classified as a total cholesterol concentration <5.18 mmol·L, intermediate as a total cholesterol between ≥5.18 mmol·L and 6.19 mmol·L (borderline high) or controlled through medication, and poor (high) if cholesterol is above 6.2 mmol·L [39,41]. As a risk factor dyslipidaemia was considered if TC was ≥5.18 mmol·L or if on lipid-lowering medication [39]. Good NFBG concentration of <7.77 mmol·L, intermediate (prediabetic) if blood glucose concentration falls between 7.78 and 11.09 mmol·L, and poor (diabetic) if blood glucose is above 11.1 mmol·L [39,41]. Good status for cigarette smoking was classified as those that were never smokers or those who have quit for more than six months, intermediate as those who quit within six months and poor as those who are current smokers [39,41,42]. Cigarette smoking was further classified as light smokers if firefighters smoked ≤5 cigarettes a day, moderate smokers if 6 to 19 cigarettes a day and heavy smokers if ≥20 cigarettes a day [46]. Good physical activity was classified as firefighters who exercised for at least three days a week at a moderate intensity accumulating up to 150 minutes or 75 minutes of vigorous-intensity physical activity, intermediately active if they exercised for 1–149 minutes a week and physically inactive for those who do not exercise at all during a week [41–43]. Diet encompassed five components, namely, fruit and vegetable intake, fish intake, fibre-rich whole grains, sodium intake and sugar-sweetened-beverage intake. Diet was scored as good if four or five components were good, intermediate 2–3 components were good and poor if 0–1 components were good [41,43].

2.5.2. Cardiovascular Disease Risk Score

Framingham risk [47] and lifetime and 10-year atherosclerotic cardiovascular disease (ASCVD) were calculated to assess the cardiovascular risk of firefighters [44,48].

http://etd.uwc.ac.za/

2.5.3. Heart Rate Variability

Heart rate variability (HRV) was measured at rest using the Polar™ (Polar Electro Oy, Kempele, Finland) H10 heart rate monitor. The HRV data were analyzed using the Kubio© Software version 3.4.3, where the results were then exported and captured onto the data collection sheet. The measures used were the variability of N-N intervals (HRV), the standard deviation of all normal-to-normal (NN) intervals (SDNN), root-mean-square of successive differences (RMSSD), low-frequency (LF), high frequency (HF) ranges and the ratio (LF/HF) [49,50].

2.6. Statistical Analysis

The data were analysed using SPSS® software, version 28 (Chicago, IL, USA). The data were collected, coded, and cleaned for errors using the double-entry method on Microsoft Excel (version 16, 2019). Shapiro–Wilks test indicated that the physical fitness variables were normally distributed and that the majority of CVH metrics and CVD risk factors were not normally distributed. Descriptive statistical analyses, such as the means and standard deviations, were performed for the measures of physical fitness and medial, and 25th and 75th percentiles were used for CVH parameters. Independent samples T-tests and analysis of variance (ANOVA) were conducted to determine differences between physical fitness parameters based on sex and CVHIs. Univariable and multivariable linear regressions were conducted on the continuous data measures of physical fitness and CVH, and multinomial regression was conducted on CVHI and physical fitness. The linear regression models were cross-validated using the holdout method, randomly dividing the data into an 80% training and 20% test split. Model prediction quality was presented as R^2 difference between the split. For the multivariable models, the hierarchical methods were preferred; covariates adjusted for in model 2 were age and sex, and in model 3, weekly physical activity and height were added to the model. Root-mean-square error (RMSE) was used to assess the model quality of each analysis conducted. The following equation was used to calculate RMSE:

$$\text{RMSE} = \frac{\sqrt{\sum(\text{P} - \text{O})^2}}{\text{n} - 2}$$

For the regression analysis, steps were taken to ensure that there was no multicollinearity present in the results. Firstly, collinearity was assessed using correlations to ensure autocorrelation was not present and deemed acceptable if all values had correlation coefficients less than 0.8. Lastly, the variance inflation factor (VIF) was calculated for each variable to ensure multicollinearity was not present with the subsequent entry of variables in each model. A VIF of less than 5 was considered acceptable. Linear least absolute shrinkage and selection operator (LASSO) regression was also used to build a prediction model for each CVH parameter to reduce the number of predictors. To ensure cross-validation of the model and evaluate the predictive ability of the model a five-fold cross-validation method was used. For reporting, the more parsimonious model within 1 standard error of the optimal model was preferred. Indicators (physical fitness) with non-zero coefficients were reported only. A p-value of <0.05 was used to indicate statistical significance.

3. Results

Table 1 presents the descriptive statistics and prevalence of CVD factors and CVHI in firefighters according to sex and age group. In total, 11.4% of firefighters reported having a good CVHI, 55.0% had an intermediate CVHI, and 34.0% had a poor CVHI. More males had a poor CVHI than females, especially those in the oldest age groups. The median age of the firefighters was 38.0 (38.0 and 48.0) years. Female firefighters had a higher BMI and BF%, which was seen in the older groups of firefighters as well. Firefighters' cardiovascular health decreased as they aged, especially male firefighters.

http://etd.uwc.ac.za/

Table 1. Descriptive characteristics, prevalence of cardiovascular disease risk factors, and cardiovascular health metrics in firefighters according to sex and age group.

	Good CVHI		Intermediate Health		Poor CVHI	
	N	%	N	%	N	%
Total Firefighters (n = 309)	34	11.0	170	55.0	105	34.0
Male (n = 275)	24	56.0	154	56.0	97	35.3
Female (n = 34) 20–	10	29.4	16	47.1	8	23.5
29 years (n = 72)	16	22.2	41	56.9	15	20.8
30–39 years (n = 95)	11	11.6	56	58.9	28	29.5
40–49 years (n = 83)	6	7.2	45	54.2	32	38.6
50–65 years (n = 58)	1	1.7	27	46.6	30	51.7
Cardiovascular health metric/cardiovascular disease risk factor	N		$\tilde{X}$ (p25th–p75th)		N	%
Age ¶ §	309		38.0 (38.0, 48.0)		93	30.1
Body mass index	309		27.1 (24.1, 30.4)			
Obese ¶ ***	-		-		86	27.8
Ideal *	-		-		94	30.4
Overweight **	-		-		129	41.8
Obese class I	-		-		67	21.7
Obese class II	-		-		14	4.5
Obese class III	-		-		4	1.3
High body fat percentage ¶	309		20.2 (14.9, 27.2)		84	27.2
Central obesity ¶	309		93.0 (84.3, 101.0)		159	51.5
Hypertension ¶ ***	-		-		144	46.6
Ideal *	-		-		35	11.3
Pre-hypertensive **	-		-		130	42.1
Hypertension stage 1	-		-		114	36.9
Hypertension stage 2	-		-		13	4.2
Hypertension stage 3	-		-		4	1.3
Systolic hypertension	309		137.3 (125.0, 145.5)		133	43.0
Diastolic hypertension	309		81.7 (74.2, 90.8)		86	27.8
Dyslipidaemia ¶					109	35.3
Total cholesterol	309		4.6 (3.9, 3.4)			
Ideal (<5.18 mmol·L) *	-		-		211	68.3
Borderline high (5.18–6.19 mmol·L) **	-		-		69	22.3
High (>6.2 mmol·L) ***	-		-		29	9.4
Low-density lipoprotein cholesterol ¶	309		2.6 (2.1, 3.4)			
Ideal (<3.35 mmol·L)	-		2.3 (1.9, 2.8)		228	73.8
Borderline high (3.35–4.12 mmol·L)	-		2.4 (2.4, 3.3)		52	16.8
High (4.13–4.9 mmol·L)	-		1.2 (1.1, 1.5)		16	5.2
Very high (>4.9 mmol·L)	-		3.2 (2.3, 3.7)		12	3.9
High-density lipoprotein cholesterol	309		1.2 (1.0, 1.4)		65	21.0
Low (<1.03 mmol·L)	-		1.2 (1.1, 1.4)		70	22.7
Desirable (1.3–1.55 mmol·L)	-		1.2 (0.8, 1.9)		184	59.5
High (>1.55 mmol·L)	-		1.2 (1.1, 1.5)		55	17.8
Hypertriglyceridemia ¶	309		1.4 (0.9, 2.2)		119	38.5
Normal (<1.7 mmol·L)	-		1.1 (0.8, 1.7)		191	61.8
Borderline high (1.7–2.25 mmol·L)	-		1.2 (0.8, 1,9)		52	16.8
High (2.26–5.64 mmol·L)	-		1.6 (1.1, 2.3)		60	19.4
Very high (>5.65 mmol·L)	-		2.0 (1.3, 2.8)		6	1.9
Non-fasting blood glucose	309		5.4 (4.9, 6.2)			
Normal (<7.77 mmol·L) *	-		5.2 (4.6, 5.9)		289	93.5
Prediabetes (7.8–11.1 mmol·L) **	-		5.4 (4.8, 6.0)		15	4.9
Diabetic (>11.1 mmol·L) ***	-		5.4 (4.9, 6.3)		5	1.6
Diet	309		10.0 (8.0, 11.0)		-	-
Ideal diet *	-		-		2	0.6
Intermediate diet **	-		-		55	17.6
Poor diet ***	-		-		252	78.3

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 1. *Cont.*

	Good CVHI		Intermediate Health		Poor CVHI	
	N	%	N	%	N	%
Weekly physical activity (METs) ¶	309		2240.0 (1165.0, 3986.5)		179	57.9
*Physically active **	-		-		96	42.1
*Insufficiently active ***	-		-		83	26.9
*Completely inactive ****	-		-		96	31.1
Cigarette smoking ¶ ***	22		10.0 (5.0, 20.0)		108	35.0
*Never **	-		-		201	65.0
*Quit within 6 months ***	-		-		1	0.9
Light smoker (<5)	-		-		27	25.0
Moderate smoker (≥6–19)	-		-		46	42.6
Heavy smoker (>20)	-		-		30	27.8
Framingham risk score	309		1.1 (0.2, 5.9)		-	-
Low (<10%)	-		-		278	86.3
Moderate (10–19%)	-		-		23	7.1
High (≥20)	-		-		8	2.5
Lifetime ASCVD risk score •	304		50.0 (39.0, 50.0)		-	-
10-year ASCVD risk score ꞁ'	138		5.5 (2.4, 9.9)		-	-
Low risk (<5%)	-		-		62	19.3
Borderline risk (5–7.5%)	-		-		26	8.1
Intermediate risk (7.5–20%)	-		-		45	14.0
High risk (≥20%)	-		-		3	0.9

Note: $\tilde{X}$—median; p25th–p75th–25th percentile to 75th percentile; CVHI—cardiovascular health index; ¶—indicates positive cardiovascular disease risk factor; *—indicates good cardiovascular health metric; **—indicates intermediate health metric; ***—indicates poor cardiovascular health metric; §—indicates males ≥ 45 years and females ≥ 55 years; •—indicates 5 firefighters were not included in lifetime ASCVD risk score due to being over 60 years old. ꞁ'—indicates that 171 firefighters were removed due to being under the age of 40 years.

Table 2 indicates the mean physical fitness levels and differences between sex in firefighters. Male firefighters were stronger, leaner, and had more muscular stamina compared to female firefighters. Female firefighters had higher cardiorespiratory fitness than male firefighters.

Table 2. Descriptive characteristics of firefighters' physical fitness according to sex.

	Total Firefighters		Sex				
			Males		Females		
Physical fitness	N	$\bar{x}$ ± SD	N	$\bar{x}$ ± SD	N	$\bar{x}$ ± SD	$p^{§}$
ab$\dot{V}O_{2max}$ (L·min)	309	3.4 ± 0.3	275	3.4 ± 0.3	34	3.3 ± 0.3	**0.014**
rel$\dot{V}O_{2max}$ (mL·kg·min)	309	42.3 ± 6.1	275	41.9 ± 5.9	34	45.1 ± 7.4	**0.005**
Grip strength (kg)	304	89.7 ± 17.5	270	92.9 ± 15.4	34	64.6 ± 12.0	**<0.001**
Right grip strength (kg)	304	45.2 ± 9.2	270	46.7 ± 8.2	34	32.7 ± 6.3	**<0.001**
Left grip strength (kg)	304	44.5 ± 8.9	270	46.1 ± 7.9	34	31.9 ± 6.1	**<0.001**
Leg strength (kg)	304	116.3 ± 29.3	270	120.6 ± 26.9	34	82.0 ± 23.9	**<0.001**
Push-ups (rpm)	304	30.9 ± 13.9	270	31.4 ± 14.3	34	26.7 ± 10.1	0.105
Sit-ups (rpm)	304	28.4 ± 10.4	270	28.7 ± 10.4	34	25.9 ± 9.9	0.140
Sit-and-reach (cm)	304	42.8 ± 9.1	270	42.3 ± 9.1	34	46.9 ± 8.7	**0.006**
Lean body Mass (kg)	309	60.4 ± 9.8	275	62.4 ± 8.1	34	43.8 ± 5.7	**<0.001**

Note: Bold indicates statistical significance. $\dot{V}O_{2max}$–oxygen consumption; L·min—litres per min; mL·kg·min—millilitres per kilogram per minute; kg—kilogram; cm—centimetres; rpm—repetitions per minute. §—indicates independent samples *t*-test that was conducted.

Table 3 indicates the mean physical fitness levels and differences between CVHI in firefighters. Firefighters with a good CVHI had a higher cardiorespiratory fitness level, push-up and sit-up capacity, and sit-and-reach score but had the lowest grip and leg strength. Surprisingly, firefighters with poor CVHI had the highest LBM.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 3. Descriptive characteristics of firefighters' physical fitness according to cardiovascular health index.

	Cardiovascular Health Index						
	Poor CVHI		Intermediate CVHI		Good CVHI		
Physical fitness	N	$\bar{x} \pm$ SD	N	$\bar{x} \pm$ SD	N	$\bar{x} \pm$ SD	p [#]
abV̇ O_{2max} (L·min)	101	3.4 ± 0.3	174	3.4 ± 0.3	34	3.3 ± 0.2	0.253
relV̇ O_{2max} (mL·kg·min)	101	39.0 ± 4.7	174	42.9 ± 5.8	34	49.3 ± 4.9	**<0.001**
Grip strength (kg)	99	89.7 ± 15.9	174	91.4 ± 17.6	34	80.9 ± 19.2	**0.006**
Right grip strength (kg)	99	45.2 ± 8.6	171	45.9 ± 9.1	34	41.3 ± 10.2	**0.026**
Left grip strength (kg)	99	44.6 ± 8.1	171	45.5 ± 9.0	34	39.7 ± 9.5	**0.002**
Leg strength (kg)	99	118.1 ± 26.5	171	116.2 ± 29.6	34	111.7 ± 31.4	0.538
Push-ups (rpm)	99	26.4 ± 13.2	171	32.7 ± 13.8	34	34.6 ± 12.1	**<0.001**
Sit-ups (rpm)	99	24.5 ± 11.0	171	29.9 ± 9.9	34	32.1 ± 5.8	**<0.001**
Sit-and-reach (cm)	99	40.3 ± 9.3	171	43.9 ± 8.9	34	45.0 ± 8.9	**0.003**
Lean body Mass (kg)	100	62.5 ± 9.1	174	60.5 ± 9.8	34	53.3 ± 7.5	**<0.001**

Note: Bold indicates statistical significance. V̇ O_{2max}—oxygen consumption; L·min—litres per min; mL·kg·min—millilitres per kilogram per minute; kg—kilogram; cm—centimetres; rpm—repetitions per minute; [#]—indicates the analysis of variance conducted.

Table 4 describes the association between physical fitness and CVH in firefighters. AbV̇ O_{2max} was significantly associated with systolic blood pressure (R^2 = 2.5%), NFBG (R^2 = 2.7%), HDL-C (R^2 = 4.0%), Framingham risk score (R^2 = 4.1%), and weekly MET minutes (R^2 = 2.9%). After adjustment for age, sex, weekly METs, and height, every one standard deviation increase in abV̇ O_{2max} was associated with a decrease of 0.249 and 0.268 standard deviations for SBP and HDL-C. RelV̇ O_{2max} was significantly associated with SBP (R^2 = 12.5%), DBP (R^2 = 15.0%), NFBG (R^2 = 8.9%), TC (R^2 = 6.9%), LDL-C (R^2 = 4.2%), HDL-C (R^2 = 5.4%), triglycerides (R^2 = 17.5%), and Framingham risk score (R^2 = 29.7%). In model 3, every one standard deviation increase in relV̇ O_{2max} was associated with a decrease of 0.256, 0.391, 0.290, 0.290, 0.427 and 0.117 standard deviations in SBP, DBP, NFBG, HDL-C, triglycerides and Framingham risk score, respectively. Based on muscular strength and endurance, after adjustment for age, sex, weekly METs, and height, an increase of one standard deviation in leg strength was associated with an increase in SBP, triglycerides, and weekly METs by 0.186, 0.192, and 0.226 standard deviations, respectively, and a decrease of 0.188 standard deviation in HDL-C concentration. One standard deviation increase in push-ups and sit-up capacity was associated with a decrease of 0.138 and 0.176 standard deviations for DBP and a decrease of 0.179 and 0.241 standard deviations in triglyceride concentration, respectively.

Based on CVH, age was significantly associated with abV̇ O_{2max} (R^2 = 11.4%), relV̇ O_{2max} (R^2 = 30.5%), leg strength (R^2 = 4.9%), sit-ups (R^2 = 23.2%), push-ups (R^2 = 20.2%), sit-and-reach (R^2 = 4.0%), and LBM (R^2 = 2.4%). After adjustment for sex, weekly METs and height, every one standard deviation in age decreased abV̇ O_{2max}, relV̇ O_{2max}, leg strength, push-ups, sit-ups, sit-and-reach, and LBM by 0.316, 0.552, 0.196, 0.451, 0.451, 0.199, and 0.178 standard deviations, respectively. Body mass index was significantly associated with abV̇ O_{2max} (R^2 = 19.1%), relV̇ O_{2max} (R^2 = 61.2%), leg strength (R^2 = 1.7%), push-ups (R^2 = 8.6%), sit-ups (R^2 = 14.0%), sit-and-reach (R^2 = 6.2%), and LBM (R^2 = 10.6%). After adjustment for covariates, for every one standard deviation increases in BMI, abV̇ O_{2max}, relV̇ O_{2max}, push-ups, sit-ups, and sit-and-reach decreased by 0.730, 0.153, 0.252, and 0.233 standard deviations, respectively. Bodyfat percentage was significantly associated with abV̇ O_{2max} (R^2 = 4.4%), relV̇ O_{2max} (R^2 = 24.7%), grip strength (R^2 = 2.9%), leg strength (R^2 = 2.7%), sit-ups (R^2 = 10.5%), push-ups (R^2 = 16.1%), sit-and-reach (R^2 = 2.1%), and LBM (R^2 = 2.8%). After adjustment for age, sex, weekly METs, and height, every one standard deviation increases in BF% decreased relV̇ O_{2max}, push-ups, sit-ups, and sit-and-reach by 0.631, 0.228, 0.341, and 0.240 standard deviations, respectively.

http://etd.uwc.ac.za/

Table 4. Linear regression indicating the association between physical fitness and cardiovascular health in firefighters.

	Univariate Linear Models [a]							Multivariate Linear Models [b]											
	Model 1							Model 2 [c]						Model 3 [d]					
Variables	B	SE	β	R^2	RMSE	CV [•]	*p*	B	SE	β	R^2	RMSE	*p*	B	SE	β	R^2	RMSE	*p*-Value
Exploratory variable: ab$\dot{V}O_{2max}$																			
Systolic blood pressure (mmHg)	8.738	3.106	0.159	0.025	15.254	1.3	**0.005**	14.101	3.111	0.247	0.162	14.189	**<0.001**	13.684	3.355	0.249	0.164	14.210	**<0.001**
Diastolic blood pressure (mmHg)	−0.754	2.373	0.096	0.000	11.656	0.0	0.751	-	-	-	-	-	-	-	-	-	-	-	-
Non-fasting blood glucose (mmol·L)	−0.808	0.277	−0.164	0.027	1.360	10.9	**0.004**	−0.511	0.293	−0.095	0.064	1.338	0.082	-	-	-	-	-	-
Total cholesterol (mmol·L)	−0.320	0.259	−0.070	0.005	1.274	0.8	0.218	-	-	-	-	-	-	-	-	-	-	-	-
Low-density lipoprotein cholesterol (mmol·L)	−0.322	0.217	−0.081	0.007	1.066	0.09	0.139	-	-	-	-	-	-	-	-	-	-	-	-
High-density lipoprotein (mmol·L)	−0.276	0.077	−0.201	0.040	0.377	11.0	**<0.001**	−0.283	0.080	−0.193	0.115	0.363	**<0.001**	−0.365	0.085	−0.268	0.137	0.359	**<0.001**
Triglycerides (mmol·L)	0.056	0.225	0.014	0.000	1.104	1.2	0.802	-	-	-	-	-	-	-	-	-	-	-	-
Framingham risk score	−0.011	0.003	−0.203	0.041	5.163	3.2	**<0.001**	0.005	0.005	0.091	0.663	3.064	0.322	-	-	-	-	-	-
Weekly MET minutes	1746.3	573.22	0.172	0.029	2811.269	4.6	**0.003**	1306.261	614.100	0.114	0.044	2799.691	**0.034**	1193.3	658.262	0.117	0.044	2803.237	0.071
Exploratory variable: rel$\dot{V}O_{2max}$																			
Systolic blood pressure (mmHg)	−0.888	0.170	−0.353	0.125	14.511	3.7	**<0.001**	−0.671	0.161	−0.267	0.153	14.262	**<0.001**	−0.642	0.170	−0.256	0.158	14.278	**<0.001**
Diastolic blood pressure (mmHg)	−0.735	0.100	−0.388	0.150	10.754	19.6	**<0.001**	−0.637	0.121	−0.336	0.166	10.681	**<0.001**	−0.742	0.126	−0.391	0.186	10.569	**<0.001**
Non-fasting blood glucose (mmol·L)	−0.067	0.012	−0.299	0.089	1.314	6.5	**<0.001**	−0.055	0.015	−0.246	0.090	1.316	**<0.001**	−0.065	0.016	−0.290	0.108	1.309	**<0.001**
Total cholesterol (mmol·L)	−0.054	0.011	−0.262	0.069	1.237	−11.8	**<0.001**	−0.027	0.014	−0.130	0.116	1.205	**0.048**	−0.026	0.014	−0.126	0.116	1.207	0.068
Low-density lipoprotein cholesterol (mmol·L)	−0.036	0.010	−0.206	0.042	1.049	−15.5	**<0.001**	−0.017	0.012	−0.095	0.078	1.031	0.157	-	-	-	-	-	-
High-density lipoprotein (mmol·L)	0.015	0.003	0.232	0.054	0.371	6.2	**<0.001**	0.015	0.067	0.242	0.118	0.363	**<0.001**	0.018	0.004	0.290	0.134	0.359	**<0.001**
Triglycerides (mmol·L)	−0.077	0.012	−0.422	0.175	0.999	3.8	**<0.001**	−0.064	0.011	−0.355	0.194	0.995	**<0.001**	−0.077	0.012	−0.427	0.231	0.976	**<0.001**
Framingham risk score	−0.637	0.056	−0.545	0.297	4.429	6.2	**<0.001**	−0.100	0.034	−0.117	0.671	3.027	**0.004**	−0.100	0.036	−0.117	0.674	3.018	**0.006**
Weekly MET minutes	0.000	0.000	0.172	0.010	2811.269	1.2	0.073	-	-	-	-	-	-	-	-	-	-	-	-
Exploratory variable: Grip strength																			
Systolic blood pressure (mmHg)	0.079	0.050	0.090	0.008	15.385	1	0.119	-	-	-	-	-	-	-	-	-	-	-	-
Diastolic blood pressure (mmHg)	−0.038	0.038	−0.057	0.003	11.499	8.1	0.322	-	-	-	-	-	-	-	-	-	-	-	-
Non-fasting blood glucose (mmol·L)	0.002	0.005	0.021	0.000	1.376	1.8	0.363	-	-	-	-	-	-	-	-	-	-	-	-
Total cholesterol (mmol·L)	−0.001	0.004	−0.015	0.000	1.282	0.0	0.798	-	-	-	-	-	-	-	-	-	-	-	-
Low-density lipoprotein cholesterol (mmol·L)	0.001	0.004	0.009	0.000	1.0469	0.1	0.881	-	-	-	-	-	-	-	-	-	-	-	-
High-density lipoprotein (mmol·L)	−0.004	0.001	−0.163	0.027	0.376	−9.6	**0.004**	−0.001	0.001	−0.034	0.081	-	0.604	-	-	-	-	-	-
Triglycerides (mmol·L)	0.002	0.004	0.028	0.001	1.107	0.1	0.633	-	-	-	-	-	-	-	-	-	-	-	-
Framingham risk score	0.012	0.017	0.039	0.002	5.279	0.0	0.501	-	-	-	-	-	-	-	-	-	-	-	-
Weekly MET minutes	6.358	9.378	0.039	0.002	2854.287	5.6	0.678	-	-	-	-	-	-	-	-	-	-	-	-
Exploratory variable: Leg strength																			
Systolic blood pressure (mmHg)	0.092	0.030	0.173	0.030	15.224	1.1	**0.003**	0.101	0.033	0.189	0.127	14.448	**0.002**	0.099	0.034	0.186	0.137	14.404	**0.004**
Diastolic blood pressure (mmHg)	0.018	0.023	0.045	0.004	11.497	0.1	0.303	-	-	-	-	-	-	-	-	-	-	-	-
Non-fasting blood glucose (mmol·L)	0.001	0.003	0.028	0.001	1.375	−0.1	0.687	-	-	-	-	-	-	-	-	-	-	-	-
Total cholesterol (mmol·L)	0.000	0.003	0.005	0.000	1.282	−4.5	0.981	-	-	-	-	-	-	-	-	-	-	-	-
Low-density lipoprotein cholesterol (mmol·L)	0.000	0.002	−0.010	0.000	1.074	4.1	0.810	-	-	-	-	-	-	-	-	-	-	-	-
High-density lipoprotein (mmol·L)	−0.002	0.001	−0.219	0.048	0.373	−11.9	**<0.001**	−0.002	0.001	−0.146	0.097	0.368	**0.020**	−0.002	0.001	−0.188	0.110	0.365	**0.004**
Triglycerides (mmol·L)	0.005	0.002	0.119	0.016	1.098	−6.5	**0.038**	0.006	0.002	0.147	0.124	1.041	**0.017**	0.007	0.002	0.192	0.146	1.033	**0.003**
Framingham risk score	−0.011	0.011	−0.061	0.004	5.293	−5.2	0.291	-	-	-	-	-	-	-	-	-	-	-	-
Weekly MET minutes	22.2	5.556	0.225	0.055	2728.984	−3.6	**<0.001**	23.062	6.268	0.234	0.069	2761.658	**<0.001**	22.334	6.365	0.226	0.070	2764.178	**<0.001**
Exploratory variable: Push-ups																			
Systolic blood pressure (mmHg)	−0.133	0.064	−0.119	0.014	15.368	13.7	**0.038**	−0.026	0.070	−0.024	0.100	14.677	0.708	-	-	-	-	-	-

http://etd.uwc.ac.za/

Table 4. *Cont.*

	Univariate Linear Models [a]							Multivariate Linear Models [b]											
	Model 1							Model 2 [c]						Model 3 [d]					
Variables	**B**	**SE**	**β**	**R^2**	**RMSE**	**CV •**	***p***	**B**	**SE**	**β**	**R^2**	**RMSE**	***p***	**B**	**SE**	**β**	**R^2**	**RMSE**	***p*-Value**
Diastolic blood pressure (mmHg)	−0.203	0.047	−0.242	0.058	11.203	−32.1	**<0.001**	−0.109	0.053	−0.130	0.099	11.038	**0.041**	−0.116	0.053	−0.138	0.106	11.0456	**0.030**
Non-fasting blood glucose (mmol·L)	−0.004	0.006	−0.137	0.019	1.365	−10.7	**0.017**	−0.004	0.006	−0.044	0.051	1.345	0.494	-	-	-	-	-	-
Total cholesterol (mmol·L)	0.005	0.006	−0.125	0.016	1.276	−19.9	**0.029**	0.005	0.006	0.050	0.114	1.212	0.428	-	-	-	-	-	-
Low-density lipoprotein cholesterol (mmol·L)	−0.006	0.004	−0.010	0.005	1.073	12.7	0.221	-	-	-	-	-	-	-	-	-	-	-	-
High-density lipoprotein (mmol·L)	0.002	0.002	0.090	0.007	0.385	0.5	0.141	-	-	-	-	-	-	-	-	-	-	-	-
Triglycerides (mmol·L)	−0.020	0.004	−0.254	0.065	1.072	−3.2	**<0.001**	−0.014	0.005	−0.176	0.131	1.037	**0.005**	−0.014	0.005	−0.179	0.143	1.035	**0.004**
Framingham risk score	−0.157	0.020	−0.411	0.169	4.838	−7.8	**<0.001**	−0.029	0.015	−0.075	0.675	3.023	**0.049**	−0.026	0.015	−0.068	0.679	3.010	0.074
Weekly MET minutes	28.654	11.864	0.138	0.019	2824.061	2.6	**0.016**	15.876	13.571	0.077	0.031	2825.378	0.243	-	-	-	-	-	-
Exploratory variable: Sit-ups																			
Systolic blood pressure (mmHg)	−0.237	0.084	−0.160	0.026	15.187	32.1	**0.005**	−0.114	0.091	−0.077	0.111	14.492	0.210	-	-		-		-
Diastolic blood pressure (mmHg)	−0.250	−0.270	−0.279	0.078	11.064	28.2	**<0.001**	−0.200	0.068	−0.179	0.116	10.899	**0.004**	−0.196	0.068	−0.176	0.122	10.913	**0.004**
Non-fasting blood glucose (mmol·L)	−0.021	0.008	−0.156	0.024	1.361	5.6	**0.007**	−0.010	0.008	−0.075	0.055	-	0.239	-	-	-	-	-	-
Total cholesterol (mmol·L)	−0.018	0.007	−0.146	0.021	1.269	8.8	**0.011**	0.001	0.008	0.006	0.101	-	0.925	-	-	-	-	-	-
Low-density lipoprotein cholesterol (mmol·L)	−0.008	0.006	−0.082	0.007	1.067	3.0	0.155	-	-	-	-	-	-	-	-	-	-	-	-
High-density lipoprotein (mmol·L)	0.003	0.002	0.074	0.006	0.385	2.2	0.198	-	-	-	-	-	-	-	-	-	-	-	-
Triglycerides (mmol·L)	−0.033	0.006	−0.305	0.093	1.056	7.6	**<0.001**	−0.026	0.006	−0.244	0.153	1.023	**<0.001**	−0.026	0.006	−0.241	0.163	1.022	**<0.001**
Framingham risk score	−0.198	0.027	−0.289	0.151	4.888	0.6	**<0.001**	−0.037	0.019	−0.073	0.674	3.028	0.051	-	-	-	-	-	-
Weekly MET minutes	02.154	15.844	0.073	0.005	2850.996	0.7	0.204	-	-	-	-	-	-	-	-	-	-	-	-
Exploratory variable: Age																			
ab$\dot{V}O_{2max}$ (L·min)	−0.009	0.001	−0.342	0.114	0.263	4.9	**<0.001**	−0.009	0.001	−0.344	0.138	0.261	**<0.001**	−0.009	0.001	−0.316	0.254	0.243	**<0.001**
rel$\dot{V}O_{2max}$ (mL·kg·min)	−0.328	0.028	−0.552	0.305	5.125	0.3	**<0.001**	−0.327	0.028	−0.550	0.328	5.049	**<0.001**	−0.328	0.027	−0.552	0.391	4.828	**<0.001**
Grip strength (kg)	−0.139	0.098	−0.081	0.007	17.463	0.3	0.157	-	-	-	-	-	-	-	-	-	-	-	-
Right grip strength (kg)	−0.070	0.051	−0.082	0.003	9.130	0.3	**0.051**	-	-	-	-	-	-	-	-	-	-	-	-
Left grip strength (kg)	−0.069	0.050	−0.080	0.003	8.909	0.2	0.170	-	-	-	-	-	-	-	-	-	-	-	-
Leg strength (kg)	−0.621	0.158	−0.221	0.049	28.162	7.1	**<0.001**	−0.629	0.143	−0.224	0.221	25.532	**<0.001**	−0.552	0.141	−0.196	0.277	24.692	**<0.001**
Push-ups (rpm)	−0.646	0.068	−0.482	0.232	12.076	1.2	**<0.001**	−0.647	0.067	−0.483	0.242	12.021	**<0.001**	−0.616	0.070	−0.451	0.233	12.351	**<0.001**
Sit-ups (rpm)	−0.455	0.052	−0.450	0.202	9.264	10.5	**<0.001**	−0.455	0.052	−0.450	0.210	9.235	**<0.001**	−0.457	0.053	−0.451	0.211	9.273	**<0.001**
Sit-and-reach (cm)	−0.186	0.050	−0.208	0.040	8.962	4.3	**<0.001**	−0.185	0.050	−0.207	0.067	8.864	**<0.001**	−0.178	0.050	−0.199	0.080	8.825	**<0.001**
Lean body Mass (kg)	0.153	0.053	0.163	0.024	9.719	0.9	**0.007**	0.146	0.044	0.156	0.330	7.125	**<0.001**	0.167	0.037	0.178	0.541	6.614	**<0.001**
Exploratory variable: body mass index																			
ab$\dot{V}O_{2max}$ (L·min)	0.026	0.003	0.440	0.191	0.252	−8.1	**<0.001**	0.038	0.003	0.640	0.500	0.199	**<0.001**	0.040	0.002	0.673	0.651	0.167	**<0.001**
rel$\dot{V}O_{2max}$ (mL·kg·min)	−1.025	0.047	−0.782	0.612	3.828	11.6	**<0.001**	−0.920	0.039	−0.702	0.764	0.299	**<0.001**	−0.955	0.030	−0.730	0.858	2.336	**<0.001**
Grip strength (kg)	0.113	0.215	0.030	0.001	17.514	0.5	0.525	-	-	-	-	-	-	-	-	-	-	-	-
Right grip strength (kg)	0.032	0.113	0.016	0.000	9.157	0.1	0.780	-	-	-	-	-	-	-	-	-	-	-	-
Left grip strength (kg)	0.081	0.110	0.043	0.002	8.929	0.8	0.459	-	-	-	-	-	-	-	-	-	-	-	-
Leg strength (kg)	0.800	0.352	0.130	0.017	28.632	4.3	**0.024**	1.705	0.319	0.277	0.289	24.432	**<0.001**	1.786	0.306	0.290	0.340	23.426	**<0.001**
Push-ups (rpm)	−0.860	0.162	−0.293	0.086	13.178	11.5	**<0.001**	−0.433	0.155	−0.147	0.261	11.178	**0.006**	−0.449	0.155	−0.153	0.267	11.888	**0.004**
Sit-ups (rpm)	−0.832	0.119	−0.375	0.140	9.317	−11.0	**<0.001**	−0.563	0.116	−0.254	0.267	8.908	**<0.001**	−0.560	0.117	−0.252	0.268	8.950	**<0.001**
Sit-and-reach (cm)	−0.489	0.109	−0.250	0.062	8.872	−17.7	**<0.001**	−0.445	0.113	−0.227	0.113	8.657	**<0.001**	−0.445	0.112	−0.233	0.128	8.606	**<0.001**
Lean body Mass (kg)	0.681	0.113	0.333	0.106	9.302	20.7	**<0.001**	0.818	0.094	0.389	0.464	7.122	**<0.001**	0.917	0.070	0.436	0.708	5.245	**<0.001**
Exploratory variable: body fat percentage																			
ab$\dot{V}O_{2max}$ (L·min)	0.006	0.002	0.211	0.044	0.270	3.8	**<0.001**	0.015	0.002	0.507	0.343	0.225	**<0.001**	0.016	0.001	0.569	0.496	0.199	**0.014**

http://etd.uwc.ac.za/

Table 4. *Cont.*

	Univariate Linear Models [a]							Multivariate Linear Models [b]											
	Model 1							Model 2 [c]						Model 3 [d]					
Variables	**B**	**SE**	**β**	R^2	**RMSE**	**CV** •	p	**B**	**SE**	**β**	R^2	**RMSE**	p	**B**	**SE**	**β**	R^2	**RMSE**	p**-Value**
relV̇ O_{2max} (mL·kg·min)	−0.315	0.032	−0.497	0.247	5.301	25.4	**<0.001**	−0.365	0.027	−0.575	0.588	3.936	**<0.001**	−0.400	0.024	−0.631	0.688	3.440	**<0.001**
Grip strength (kg)	−0.310	0.103	−0.170	0.029	17.251	2.3	**0.003**	0.178	0.104	0.098	0.271	15.000	0.089	-	-	-	-	-	-
Right grip strength (kg)	−0.168	0.054	−0.177	0.031	9.002	3.0	**0.002**	0.068	0.056	0.072	0.240	7.999	0.220	-	-	-	-	-	-
Left grip strength (kg)	−0.142	0.053	−0.153	0.023	8.831	1.6	**0.008**	0.109	0.053	0.118	0.269	7.668	**0.041**	0.148	0.051	0.160	0.342	7.307	**0.004**
Leg strength (kg)	−0.488	0.171	−0.163	0.027	28.536	7.1	**0.005**	0.319	0.176	0.106	0.235	25.378	0.072	-	-	-	-	-	-
Push-ups (rpm)	−0.464	0.078	−0.324	0.105	13.056	−15.7	**<0.001**	−0.306	0.082	−0.214	0.257	11.789	**<0.001**	−0.326	0.083	−0.228	0.283	11.769	**<0.001**
Sit-ups (rpm)	−0.434	0.057	−0.401	0.161	9.511	−14.1	**<0.001**	−0.369	0.061	−0.341	0.295	8.743	**<0.001**	−0.370	0.062	−0.341	0.296	8.785	**<0.001**
Sit-and-reach (cm)	−0.138	0.054	−0.145	0.021	9.036	−15.1	**0.011**	−0.214	0.060	−0.226	0.112	8.645	**<0.001**	−0.227	0.060	−0.240	0.128	8.581	**<0.001**
Lean body Mass (kg)	−0.151	0.057	−0.150	0.028	9.682	2.6	**0.003**	0.063	0.055	0.062	0.329	7.957	0.256	-	-	-	-	-	-

Note: Bold indicates statistical significance <0.05. CVHI—cardiovascular health index; V̇ O_{2max}—oxygen consumption; L·min—litres per min; mL·kg·min—millilitres per kilogram per minute; mmol·L—millimole per litre; mmHg—millimetres mercury; kg—kilogram; cm—centimetres; rpm—repetitions per minute; a—univariable linear regression; b—multivariable analysis; c—adjusted for age and sex; d—covariates adjusted for age, sex, weekly METs and height.; B—unstandardised beta coefficients; β—standardised beta coefficient; SE—standard error; R^2—R squared; RMSE—root mean square error; CV—cross-validation; •—percentage difference for R^2 between training and testing data.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 5 describes the association between physical fitness and CVHI in firefighters. Univariable analysis indicated that a one-unit increase in rel$\dot{V}O_{2max}$, push-ups, sit-ups, and sit-and-reach increased the odds of firefighters reporting intermediate CVHI rather than a poor CVHI by 1.14 (1.09, 1.20), 1.04 (1.02, 1.06), 1.05 (1.03, 1.08), and 1.04 (1.01, 1.07), respectively. One-unit increase in rel$\dot{V}O_{2max}$, push-ups, sit-ups, and sit-and-reach increased the odds of firefighters having a good CVHI rather than a poor CVHI by 1.41 (1.29, 1.55), 1.05 (1.02, 1.08), 1.08 (1.03, 1.12), and 1.06 (1.01, 1.11), respectively. In Model 2, after adjustment for age and sex, a one-unit increase in rel$\dot{V}O_{2max}$, push-ups, sit-ups, and sit-and-reach increased the odds of firefighters having an intermediate CVHI rather than a poor CVHI by a factor of 1.14 (1.08, 1.21), 1.03 (1.01, 1.05), 1.04 (1.01, 1.07), and 1.04 (1.01, 1.07), respectively. In addition, a one-unit increase in ab$\dot{V}O_{2max}$, rel$\dot{V}O_{2max}$, and sit-ups increased the odds of firefighters reporting a good CVHI by 0.09 (0.02, 0.51), 1.38 (1.24, 1.53), and 1.06 (1.01, 1.11). In Model 3, after weekly METs and years of experience were added to the model, a one-unit increase in rel$\dot{V}O_{2max}$, sit-ups, and sit-and-reach increased the odds of firefighters reporting intermediate health rather than poor CVHI by 1.19 (1.11, 1.28), 1.04 (1.01, 1.07), and 1.04 (1.01, 1.07), respectively. A one-unit increase in rel$\dot{V}O_{2max}$ and sit-ups increased the odds of firefighters reporting a good CVHI by 1.49 (1.33, 1.69) and 1.06 (1.01, 1.11), respectively.

Table 6 shows the relationship between measures of physical fitness and HRV in firefighters. Univariate regression found that ab$\dot{V}O_{2max}$ and rel$\dot{V}O_{2max}$ explained 26.8% and 9.3%, 27.3% and 22.8%, 25.9% and 22.5%, and 3.7% and 7.6% of the variation in HRV, SDNN, RMSSD, and LF/HF ratio, respectively. After adjustment for age, sex, weekly METs, and height, one standard deviation increases in ab$\dot{V}O_{2max}$ and rel$\dot{V}O_{2max}$ increased in HRV, SDNN, and RMSSD by 0.608 and 0.565, 0.478 and 0.522, and 0.516 and 0.559 standard deviations, respectively, and decreased LF/HF ratio by 0.254 and 0.303 standard deviations. Push-ups and sit-ups explained 8.4% and 6.3% of the variation in SDNN, and after adjustment for age, sex, weekly METs, and height, one standard deviation increase in push-up and sit-up capacity increased SDNN by 0.161 and 0.129 standard deviations, respectively.

Table 7 describes the LASSO results for key indicators of physical fitness associated with CVH in firefighters. The results of the LASSO regression reported that rel$\dot{V}O_{2max}$ and LBM were the most significant indicators of SBP in firefighters, with the highest predicted model accuracy (0.905 vs. 0.923). Rel$\dot{V}O_{2max}$ and sit-ups were significant indicators of DBP in firefighters, with the highest predicted model accuracy (0.903 vs. 0.930). Ab$\dot{V}O_{2max}$ and rel$\dot{V}O_{2max}$ were the most significant indicators of NFBG with the highest predicted model accuracy (0.954 vs. 0.969). Rel$\dot{V}O_{2max}$ was the most significant indicator of TC and LDL-C concentrations; however, model predictive accuracy was low for TC (0.965 vs. 0.602) and high for LDL-C (0.989 vs. 0.996). For HDL-C ab$\dot{V}O_{2max}$, rel$\dot{V}O_{2max}$, leg strength, and push-up capacity were the most significant indicators, with the highest predicted model accuracy (0.894 vs. 0.930). Rel$\dot{V}O_{2max}$ was the most significant indicator of triglycerides in firefighters, with the highest predicted model accuracy (0.871 vs. 0.901). Leg strength was the most significant indicator of MET minutes, with the highest predicted model accuracy (0.993 vs. 0.999). For CVHI, ab$\dot{V}O_{2max}$ was the most significant indicator of a good CVHI, with the highest predicted model accuracy (0.942 vs. 0.958). Ab$\dot{V}O_{2max}$, rel$\dot{V}O_{2max}$, and leg strength were the most significant indicators of HRV in firefighters; however, model predictive accuracy was low (0.635 vs. 0.649). Ab$\dot{V}O_{2max}$ and rel$\dot{V}O_{2max}$ were the most significant indicators for SDNN and RMSSD; however, the model predictive accuracy was low for both SDNN (0.476 vs. 0.479) and RMSSD (0.518 vs. 0.527). Leg strength was the most significant indicator of HF ratio in firefighters, with the highest predicted model accuracy (0.995 vs. 0.999). Ab$\dot{V}O_{2max}$ and rel$\dot{V}O_{2max}$ were the most significant indicators for LF/HF ratio, with the highest predicted model accuracy (0.911 vs. 0.943).

http://etd.uwc.ac.za/

Table 5. Multinomial logistic regression indicating the association between physical fitness and cardiovascular health index categories in firefighters.

	Univariable Model [a]				Multivariable Model [b]							
	Model 1				Model 2 [c]				Model 3 [d]			
	Intermediate CVHI		Good CVHI		Intermediate CVHI		Good CVHI		Intermediate CVHI		Good CVHI	
Model: CVHI (Poor CVHI)	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
ab$\dot{V}O_{2max}$ (L·min)	0.980 (0.41, 2.35)	0.719	0.34 (0.09, 1.37)	0.131	-	-	0.09 (0.02, 0.51)	**0.006**	-	-	-	-
rel$\dot{V}O_{2max}$ (mL·kg·min)	1.14 (1.09, 1.20)	**<0.001**	1.41 (1.29, 1.55)	**<0.001**	1.14 (1.08, 1.21)	**<0.001**	1.38 (1.24, 1.53)	**<0.001**	1.19 (1.11, 1.28)	**<0.001**	1.49 (1.33, 1.69)	**<0.001**
Grip strength (kg)	1.00 (0.99, 1.02)	0.602	0.97 (0.95, 0.99)	**0.009**	1.01 (0.99, 1.03)	0.687	0.98 (0.95, 1.01)	0.135	-	-	-	-
Right grip strength (kg)	1.01 (0.98, 1.03)	0.704	0.95 (0.91, 0.99)	**0.025**	1.01 (0.98, 1.05)	0.793	0.98 (0.92, 1.03)	0.271	-	-	-	-
Left grip strength (kg)	1.01 (0.98, 1.04)	0.390	0.94 (0.89, 0.98)	**0.006**	1.02 (0.98, 1.05)	0.608	0.95 (0.89, 1.01)	**0.074**	-	-	-	-
Leg strength (kg)	0.99 (0.99, 1.01)	0.501	0.99 (0.98, 1.01)	0.243	-	-	-	-	-	-	-	-
Push-ups (rpm)	1.04 (1.02, 1.06)	**<0.001**	1.05 (1.02, 1.08)	**0.003**	1.03 (1.01, 1.05)	**0.010**	1.03 (0.99, 1.07)	0.134	-	-	-	-
Sit-ups (rpm)	1.05 (1.03, 1.08)	**<0.001**	1.08 (1.03, 1.12)	**<0.001**	1.04 (1.01, 1.07)	**0.004**	1.06 (1.01, 1.11)	0.023	1.04 (1.01, 1.07)	**0.003**	1.06 (1.01, 1.11)	**0.023**
Sit-and-reach	1.04 (1.01, 1.07)	**0.004**	1.06 (1.01, 1.11)	**0.012**	1.04 (1.01, 1.07)	**0.020**	1.03 (0.98, 1.08)	0.236	1.04 (1.01, 1.07)	**0.016**	-	-

Note: Bold indicates statistical significance <0.05. CVHI—cardiovascular health index; $\dot{V}O_{2max}$—oxygen consumption; L·min—litres per min; mL·kg·min—millilitres per kilogram per minute; kg—kilogram; cm—centimetres; rpm—repetitions per minute; a—unadjusted univariable multinomial regression; b—multivariable model adjusted for age and sex; c—adjusted for age and sex; d—covariates adjusted for age, sex and weekly METs; OR—odds ratio, CI—confidence interval; *p*—significance level.

Table 6. Linear regression indicating the association between physical fitness and heart rate variability in firefighters.

	Univariable Linear Models [a]							Multivariable Linear Models [b]											
	Model 1							Model 2 [c]						Model 3 [d]					
	B	SE	β	R^2	RMSE	CV *	*p*-Value	B	SE	β	R^2	RMSE	*p*-Value	B	SE	β	R^2	RMSE	*p*-Value
Dependent variable: Heart rate variability																			
ab$\dot{V}O_{2max}$ (L·min)	269.929	25.75	0.517	0.268	125.078	5.4	**<0.001**	308.020	27.113	0.590	0.303	122.397	**<0.001**	317.504	29.285	0.608	0.316	125.283	**<0.001**
rel$\dot{V}O_{2max}$ (mL·kg·min)	7.312	1.31	0.306	0.093	135.329	−6.3	**0.001**	11.136	1.557	0.466	0.148	135.328	**<0.001**	13.513	1.551	0.565	0.240	121.839	**<0.001**
Grip strength (kg)	0.498	0.482	0.060	0.04	145.633	−5.6	0.302	-	-	-	-	-	-	-	-	-	-	-	-
Right grip strength (kg)	−0.092	0.293	0.023	0.00	145.859	−2.6	0.755	-	-	-	-	-	-	-	-	-	-	-	-
Left grip strength (kg)	1.178	0.611	0.094	0.012	145.234	−8.5	0.055	-	-	-	-	-	-	-	-	-	-	-	-
Leg strength (kg)	1.366	0.816	−0.018	0.009	145.929	0.5	0.095	-	-	-	-	-	-	-	-	-	-	-	-
Push-ups (rpm)	1.486	0.922	0.112	0.009	144.757	−15.6	0.108	-	-	-	-	-	-	-	-	-	-	-	-
Sit-ups (rpm)	1.085	0.865	0.097	0.005	145.150	−6.9	0.211	-	-	-	-	-	-	-	-	-	-	-	-
Dependent variable: SDNN																			
ab$\dot{V}O_{2max}$ (L·min)	40.363	3.797	0.522	0.273	18.445	21.7	**<0.001**	36.076	4.023	0.467	0.299	18.178	**<0.001**	37.626	4.312	0.487	0.321	17.954	**<0.001**
rel$\dot{V}O_{2max}$ (mL·kg·min)	1.685	0.179	0.478	0.228	19.003	−18.8	**<0.001**	1.594	0.216	0.452	0.247	18.834	**<0.001**	1.838	0.217	0.522	0.302	18.057	**<0.001**
Grip strength (kg)	0.179	0.071	0.144	0.021	21.439	−0.2	**0.039**	0.154	0.079	0.124	0.116	20.445	0.053	-	-	-	-	-	-
Right grip strength (kg)	0.120	0.043	0.114	0.026	21.525	−0.2	**0.036**	0.198	0.150	0.083	0.109	20.515	0.187	-	-	-	-	-	-
Left grip strength (kg)	0.455	0.087	0.166	0.084	21.365	−4.2	**<0.001**	0.373	0.154	0.154	0.112	20.373	**0.016**	0.325	0.159	0.134	0.155	20.060	**0.042**
Leg strength (kg)	0.525	0.118	0.160	0.25	21.346	−2.1	**<0.001**	0.068	0.047	0.090	0.110	20.467	0.148	-	-	-	-	-	-

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Table 6. *Cont.*

	Univariable Linear Models [a]							Multivariable Linear Models [b]											
	Model 1							Model 2 [c]						Model 3 [d]					
	B	SE	β	R^2	RMSE	CV •	*p*-Value	B	SE	β	R^2	RMSE	*p*-Value	B	SE	β	R^2	RMSE	*p*-Value
Push-ups (rpm)	0.455	0.087	0.291	0.84	20.658	−1.9	**<0.001**	0.266	0.098	0.170	0.128	20.212	**0.007**	0.251	0.097	0.161	0.166	-	**0.010**
Sit-ups (rpm)	0.525	0.118	0.250	0.063	24.533	5.7	**0.013**	0.271	0.130	0.129	0.116	24.274	**0.007**	0.270	0.127	0.129	0.142	20.082	**0.035**
Dependent variable: RMSSD																			
ab$\dot{V}O_{2max}$ (L·min)	46.006	4.486	0.508	0.259	21.795	19.6	**<0.001**	43.592	4.816	0.482	0.269	21.719	**<0.001**	46.728	5.124	0.516	0.301	21.834	**<0.001**
rel$\dot{V}O_{2max}$ (mL·kg·min)	1.956	0.209	0.473	0.225	22.294	−10.6	**<0.001**	2.049	0.255	0.516	0.234	22.239	**<0.001**	2.307	0.257	0.559	0.296	22.408	**<0.001**
Grip strength (kg)	0.115	0.084	508	0.006	25.267	−1.3	0.173	-	-	-	-		-	-	-	-	-	-	-
Right grip strength (kg)	0.068	0.051	0.022	0.006	25.317	−0.3	0.184	-	-	-	-		-	-	-	-	-	-	-
Left grip strength (kg)	0.432	0.104	0.106	0.056	25.205	−2.4	**<0.001**	0.278	0.185	0.098	0.070	24.521	0.134	-	-	-	-	-	-
Leg strength (kg)	0.447	0.14	0.077	0.033	25.235	−3.4	**0.002**	0.015	0.056	0.017	0.063	24.579	0.788	-	-	-	-	-	-
Push-ups (rpm)	0.441	0.159	0.235	0.025	24.533	−14.9	**<0.001**	0.266	0.118	0.016	0.082	24.274	**0.025**	0.243	0.116	0.133	0.118	23.893	**0.037**
Sit-ups (rpm)	−0.066	0.151	0.182	0.001	24.958	−6.0	0.664	-	-	-	-		-	-	-	-	-	-	-
Dependent variable: low-frequency																			
ab$\dot{V}O_{2max}$ (L·min)	0.011	0.005	0.123	0.123	0.026	0.5	**0.032**	0.001	0.005	0.016	0.087	0.025	0.792	-	-	-	-	-	-
rel$\dot{V}O_{2max}$ (mL·kg·min)	0.001	0.000	0.217	0.047	0.025	6.7	**<0.001**	0.001	0.000	0.124	0.097	0.025	0.065	-	-	-	-	-	-
Grip strength (kg)	0.000	0.000	0.070	0.005	0.026	−2.1	0.227	-	-	-	-		-	-	-	-	-	-	-
Right grip strength (kg)	0.000	0.000	0.081	0.042	0.026	−2.8	0.160	-	-	-	-		-	-	-	-	-	-	-
Left grip strength (kg)	0.000	0.000	0.054	0.05	0.026	−1.3	0.353	-	-	-	-		-	-	-	-	-	-	-
Leg strength (kg)	0.000	0.000	0.204	0.022	0.025	−7.2	**<0.001**	0.000	0.000	0.127	0.094	0.025	**0.041**	0.000	0.000	0.118	0.101	0.025	0.073
Push-ups (rpm)	0.000	0.000	0.225	0.005	0.025	−6.0	0.236	-	-	-	-		-	-	-	-	-	-	-
Sit-ups (rpm)	4.332	0.000	0.147	0.000	0.025	−0.6	0.977	-	-	-	-		-	-	-	-	-	-	-
Dependent variable: high-frequency																			
ab$\dot{V}O_{2max}$ (L·min)	−0.015	0.013	−0.066	0.004	0.063	−2.6	0.251	-	-	-	-		-	-	-	-	-		-
rel$\dot{V}O_{2max}$ (mL·kg·min)	0.001	0.001	0.122	0.015	0.062	8.7	**0.033**	0.002	0.001	0.163	0.032	0.062	**0.019**	0.002	0.001	0.163	0.042	0.062	**0.027**
Grip strength (kg)	−0.001	0.000	−0.152	0.023	0.062	−0.5	**0.008**	0.000	0.000	−0.125	0.026	0.062	0.066	-	-	-	-	-	-
Right grip strength (kg)	0.000	0.000	−0.154	0.031	0.062	0.6	**0.002**	−0.001	0.000	−0.126	0.027	0.062	0.057	-	-	-	-	-	-
Left grip strength (kg)	−2.858	0.000	−0.141	0.000	0.062	−1.5	0.914	-	-	-	-		-	-	-	-	-	-	-
Leg strength (kg)	0.000	0.000	−0.177	0.031	0.061	1.8	**0.002**	0.000	0.000	−0.163	0.035	0.062	**0.014**	0.000	0.000	−0.192	0.056	0.062	**0.005**
Push-ups (rpm)	0.000	0.000	−0.005	0.002	0.062	−5.6	0.495	-	-	-	-		-	-	-	-	-	-	-
Sit-ups (rpm)	−0.001	0.000	0.015	0.022	0.062	−14.5	**<0.001**	0.000	0.000	0.031	0.016	0.062	0.640	-	-	-	-	-	-
Dependent variable: low/high-frequency ratio																			
ab$\dot{V}O_{2max}$ (L·min)	−2.914	0.862	−0.191	0.037	4.159	−0.3	**<0.001**	−3.045	0.923	−0.200	0.055	4.133	**0.001**	−3.880	0.992	−0.254	0.083	4.092	**<0.001**
rel$\dot{V}O_{2max}$ (mL·kg·min)	−0.191	0.038	−0.276	0.076	4.073	6.4	**<0.001**	−0.210	0.047	−0.305	0.083	4.072	**<0.001**	−0.209	0.049	−0.303	0.092	4.072	**<0.001**
Grip strength (kg)	0.016	0.014	0.064	0.004	4.243	0.7	0.265	-	-	-	-		-	-	-	-	-	-	-
Right grip strength (kg)	0.010	0.009	0.068	0.004	4.240	0.5	0.265	-	-	-	-		-	-	-	-	-	-	-
Left grip strength (kg)	0.027	0.018	0.056	0.015	4.244	0.6	0.332	-	-	-	-		-	-	-	-	-	-	-

http://etd.uwc.ac.za/

Table 6. *Cont.*

	Univariable Linear Models [a]							Multivariable Linear Models [b]											
	Model 1							Model 2 [c]						Model 3 [d]					
	B	SE	β	R^2	RMSE	CV [•]	*p*-Value	B	SE	β	R^2	RMSE	*p*-Value	B	SE	β	R^2	RMSE	*p*-Value
Leg strength (kg)	−0.014	0.024	0.065	0.001	4.247	0.4	0.565	-	-	-	-		-	-	-	-	-	-	-
Push-ups (rpm)	−0.038	0.018	−0.123	0.015	4.221	−6.1	**0.034**	−0.035	0.021	−0.114	0.029	4.205	0.086	-	-	-	-	-	-
Sit-ups (rpm)	−0.014	0.024	−0.033	0.001	4.217	−5.9	0.565	-	-	-	-		-	-	-	-	-	-	-

Note: Bold indicates statistical significance <0.05. CVHI—cardiovascular health index; $\dot{V}O_{2max}$—oxygen consumption; L·min—litres per min; mL·kg·min—millilitres per kilogram per minute; mmol·L—millimole per litre; mmHg—millimetres mercury; kg—kilogram; cm—centimetres; rpm—repetitions per minute; SDNN—standard deviation of N-N intervals; RMSSD—root mean square of successive differences between normal heartbeats; a—univariable linear regression; b—multivariable analysis; c—adjusted for age and sex; d—covariates adjusted for age, sex, weekly METs and height. B—unstandardised beta coefficients; β—standardised beta coefficient; SE—standard error; R^2—R squared; RMSE—root mean square error; CV—cross-validation; [•]—percentage difference for R^2 between training and testing data.

Table 7. LASSO-derived multivariable linear regression coefficients to discern key physical fitness parameters most associated with CVH in firefighters.

				LASSO Coefficients							
				Physical Fitness							
	Prediction	Estimate	RMSE	ab$\dot{V}O_{2max}$	rel$\dot{V}O_{2max}$	GS	LS	PU	SU	SaR	LBM
Systolic blood pressure	0.905	0.923	0.941	-	−0.086	-	-	-	-	-	0.085
Diastolic blood pressure	0.903	0.930	0.951	-	−0.172	-	-	-	−0.007	-	-
Non-fasting blood glucose	0.954	0.969	0.978	−0.001	−0.100	-	-	-	-	-	-
Total cholesterol	0.965	0.602	0.986	-	−0.064	-	-	-	-	-	-
Low-density lipoprotein cholesterol	0.989	0.996	1.000	-	0.004	-	-	-	-	-	-
High-density lipoprotein cholesterol	0.894	0.930	0.804	−0.062	0.148	-	−0.134	0.067	-	-	-
Triglycerides	0.871	0.901	0.936	-	−0.184	-	-	-	-	-	-
MET minutes	0.993	0.999	1.000	-	-	-	0.007	-	-	-	-
Cardiovascular health index	0.942	0.958	0.992	-	0.64	-		-	-	-	-
HRV	0.635	0.649	0.791	0.437	0.213	-	−0.003	-	-	-	-
SDNN	0.476	0.479	0.686	0.457	0.397	-	-	-	-	-	-
RMSSD	0.518	0.527	0.715	0.438	0.372	-	-	-	-	-	-
LF	0.984	0.998	0.987	-	-	-	0.013	0.028	-	-	-
HF	0.995	0.999	0.994	-	-	-	−0.004	-	-	-	-
LF/HF ratio	0.911	0.943	0.948	−0.089	−0.150	-	-	-	-	-	-

Note: RMSE—root-mean-square error; abCRF—absolute cardiorespiratory fitness; relCRF—relative cardiorespiratory fitness; GS—grip strength; LS—leg strength; PU—push-ups; SU—sit-ups; SaR—sit-and-reach; LBM—lean body mass; "-"—indicates coefficients of zero; HRV—heart rate variability; SDNN—standard deviation of N-N intervals; RMSSD—root mean square of successive differences between normal heartbeats; LF—low frequency; HF—high frequency; LF/HF ratio—low-frequency/high-frequency ratio.

http://etd.uwc.ac.za/

4. Discussion

The results of this present study indicated that higher cardiorespiratory fitness, muscular strength and endurance, and body composition were associated with CVH status, particularly, blood pressure, and blood lipid concentrations in firefighters. In addition, age and obesity were inversely related to all measures of physical fitness in firefighters. Firefighters with higher cardiorespiratory fitness had a better HRV. Moreover, after LASSO regression was performed, relative cardiorespiratory fitness was the most significant indicator of better overall CVH in firefighters. The results support earlier research that found a relationship between physical fitness and CVH [30–32]. Moreover, physical fitness and CVH were modestly associated, where a decrease in one, may, present as a decline in the other. This becomes more prominent as firefighters age, which has been associated with a reduction in both physical fitness and CVH in firefighters [30–32]. The results are consistent with previous studies that indicated that aged and obese firefighters are more likely to have poor levels of physical fitness, and firefighters with higher levels of physical fitness had more favourable CVH parameters, such as body composition, blood pressure, blood lipid, and blood glucose concentrations [30–33].

The current results found that physical fitness was inversely associated with cholesterol concentrations and blood pressure. This is supported by previous studies, where it had been reported that HDL-C, SBP, and DBP were significantly associated with most measures of physical fitness [51–55]. The opposite holds true as well, as improvements in physical fitness would improve overall cardiovascular health, which has been shown in previous studies [7,30–32]. This relationship between physical fitness and CVH may be bidirectional and suggests that physical fitness influences CVH and, in turn, CVH influences physical fitness [51,52,55]. This is seen in the present results, where, collectively, increased adiposity and blood pressure and worsened blood cholesterol concentrations were most likely to be attributed to lower levels of physical fitness in firefighters. These observations are supported by a recently published systematic review, which indicated that adiposity, blood pressure, and cholesterol concentrations were bi-directionally associated with physical fitness [56].

The results indicated that relVO_{2max} and abVO_{2max} were significantly and negatively associated with blood pressure, NFBG, lipid profile, Framingham risk score, and CVHI. In addition, LASSO results indicated that relVO_{2max} was consistently a key indicator of good CVH parameters in firefighters. This is consistent with previous studies, which showed that firefighters with higher cardiorespiratory fitness levels had better overall cardiovascular health compared to less fit firefighters [7,30,31]. Regular physical activity is a prerequisite to improving cardiorespiratory fitness. Moreover, DeFina et al. [57] reported that cardiorespiratory fitness was a reliable marker of cardiovascular health and functioning, indicating good oxygen transport and absorption. This suggests that firefighters with favourable cardiorespiratory fitness had better cardiovascular functioning, which is shown by a favourable CVHI and risk profile. The added benefits of regular physical activity would be the positive effect exercise has on blood pressure, blood glucose and lipid concentrations, especially associated with reductions in LDL-C and increases in HDL-C [30,31,34].

We found that grip strength was significantly and negatively associated with HDL-C. Leg strength was significantly associated with SBP, HDL-C, triglycerides, and weekly MET minutes. After adjustment for covariates, leg strength remained significantly associated with SBP, HDL-C, and MET minute. In addition, leg strength remained a significant indicator for HDL-C and weekly MET minutes. Gubelmann et al. [54] noted that grip strength was significantly correlated with blood pressure, LDL-C, triglycerides, and blood glucose. Although grip strength was only associated with HDL-C in this current study, leg strength reported similar associations as Gubelmann et al. [54]. Similarly, Yamada et al. [58] reported that grip strength was significantly correlated with HDL-C. Carter et al. [59] found that resistance training reduced arterial blood pressure in healthy adults. This was supported by a study that reported in hypertensive older adults, strength training normalised their blood pressure [60]. Singh et al. [61] reported that leg strength was associated with cardiovascular

http://etd.uwc.ac.za/

disease mortality. This suggests that maintaining strength levels in adults may have a positive effect on all cardiovascular parameters, which is particularly important for firefighters, given the physically strenuous nature of their occupations [1]. Studies indicated that firefighters that participated in regular physical activity were significantly stronger than those who were sedentary or participated in lower levels of physical activity [2,62,63].

Push-ups and sit-ups were significantly and inversely associated with SBP, DBP, NFBG, TC, triglycerides, Framingham risk score, and CVHI and positively associated with weekly MET minutes. Moreover, in the LASSO analysis, push-ups remained a key indicator of HDL-C, and sit-ups remained a key indicator of DBP. Lin et al. [53] reported that push-up capacity was significantly associated with average variability in SBP, but push-ups were not significantly associated with any measures of blood pressure in military personnel. This is supported by Vaara et al. [51], who reported that muscular endurance was associated with triglycerides, LDL-C, glucose, blood pressure, and HDL-C. Similarly, Shina and Ha [52] reported that sit-ups were significantly correlated to SBP and DBP. Yang et al. [55] reported that push-up capacity was significantly related to future cardiovascular events in male firefighters, supporting that firefighters that focused on increasing their muscular stamina may have an improved CVH. Firefighters that have higher levels of muscular endurance are likely, to participate in regular physical activity that is of moderate intensity [16,34], contributing to higher muscular endurance and better cardiovascular health status. Nonetheless, higher muscular endurance seems to be a good marker of better cardiovascular health in firefighters.

We found that age and obesity had significant linear and negative associations of all measures of physical fitness, except grip strength, and remained significant after adjustment of covariates. This was reported to be similar among previous studies, where it was consistently reported that all measures of physical fitness decreased as firefighters aged and fat mass increased [24,25,29,64]. Moreover, overeating while on duty and physical inactivity may compound this issue, as physical fitness is essential in maintaining body composition, musculoskeletal health, muscular strength and endurance, especially as firefighters age [16,34,65]. Ageing has been associated with a progressive decrease in muscle mass and bone mineral density, which has a negative effect on physical fitness in firefighters [25,29,66]. This is supported by studies which reported muscular endurance and force production decreased as firefighters aged [25,67], explaining why, in this current study, aged firefighters performed significantly worse on all physical fitness tests. Furthermore, a progressive decrease in vascular elasticity increases blood pressure, therefore, the afterload that the heart is required to overcome, ultimately negatively affecting cardiac output and reducing cardiovascular fitness [68–70]. Obesity compounds this for all aspects of physical fitness, as it increases the non-functional mass firefighters are required to carry [70,71]. This places an additional strain on the cardiorespiratory system, reducing cardiac output [72]. Similarly, increased fat mass increases the amount of weight firefighters are required to move during bodyweight movements, such as push-ups and sit-ups [25,73]. This was seen in the tests for lower body strength as well, where firefighters that had a higher BMI and BF% had a lower level of leg strength. Obese firefighters, or those with higher fat mass, force them to overcome more non-functional mass, reducing their absolute leg strength [25,64].

The results showed that HRV, SDNN, RMSSD, and LF/HF ratio were significantly associated with cardiorespiratory fitness, muscular strength, and endurance in firefighters. In addition, leg strength, push-ups, and sit-ups were significant indicators in the LASSO regression of HRV, LF, and HF in firefighters. Porto et al. [74] found that RMSSD and LF/HF ratio were significantly related to cardiorespiratory fitness in firefighters. In contrast, Lesniak et al. [75] found that there were no measures of HRV that were significantly related to cardiorespiratory fitness in firefighters. However, the study noted that LF, HF, and LF/HF ratio were significantly related to deadlift strength in firefighters. Grant et al. [76] reported that HRV, RMSSD, and LF significantly improved after military personnel engaged in an exercise intervention. Engaging in regular physical activity may promote parasympathetic dominance and decrease sympathetic cardiac control, significantly improving cardiac

http://etd.uwc.ac.za/

functioning in firefighters [50,74,76]. Firefighters who have higher cardiorespiratory fitness may have a lower heart rate, thus, higher variability in their normal-to-normal intervals, increasing their HRV metrics [50,75,77]. Moreover, firefighters with better HRV indices are likely fitter, stronger, and less stressed than those with worse HRV indices [50,74,77]. These findings highlight the potential use of measures such as HRV to assess the CVH, cardiorespiratory functioning, and stress states of firefighters; however, more studies are needed in this area.

Strengths and Limitations

This was the first study investigating the association between physical fitness and cardiovascular health in firefighters in the CoCTFRS. The measures for physical fitness and cardiovascular health were objectively measured by trained researchers using standardised and validated instruments [34]. Furthermore, this paper adds novel information on physical fitness and CVH in firefighters in an area that is understudied, particularly in a South African context. There are, however, several limitations of this present study. First, the cross-sectional study design limits our ability to infer causal relationships. Secondly, female firefighters were under-represented, limiting the generalizability of our results to the female firefighter population. Lastly, cardiorespiratory fitness was measured using a non-exercise estimation, not using lab or field testing.

5. Conclusions

This present study provides evidence that multiple components of physical fitness and cardiovascular health are significantly associated with this population of firefighters. Overall, cardiorespiratory fitness, muscular strength, and endurance were significantly related to a better overall cardiovascular health profile. However, cardiorespiratory fitness may be the key physical fitness parameter to ensure good CVH in firefighters. Moreover, aged and obese firefighters have the poorest overall level of physical fitness and CVH. Ageing, accumulated body fat, and physical inactivity likely serve as catalysts that lead to an increase in body fat and a decline in physical fitness and, subsequently, a reduction in CVH. This study adds novel research results into a scarcely studied research area, especially in a South African context and highlights the importance of physical fitness in maintaining cardiovascular health and vice versa. In particular, the impact of ageing and obesity on physical fitness and all measures of physical fitness on CVH among firefighters is highlighted. Implementing regular physical activity, with a combination of aerobic and resistance training, may improve and maintain the cardiovascular health and well-being of firefighters, which is increasingly important as firefighters age.

Recommendations

Intervention studies are warranted to examine the effect of maintenance or the improvement of key physical fitness parameters on cardiovascular health. A more representative sample of female firefighters should be included to assess the validity and generalizability of study findings to the entire population of firefighters in the CoCTFRS. In addition, a larger sample to increase the strength of the analysis and model prediction accuracy is warranted.

Author Contributions: Conceptualization, J.R. and L.L.; methodology, J.R. and A.P.K.; software, J.R.; validation, J.R., L.L., A.P.K., D.L.S. and E.S.S.; formal analysis, J.R.; investigation, J.R. and resources, J.R.; data curation, J.R.; writing—original draft preparation, J.R.; writing—review and editing, J.R., L.L., A.P.K., D.L.S. and E.S.S.; visualization, J.R., L.L., A.P.K., D.L.S. and E.S.S.; supervision, L.L., A.P.K., D.L.S. and E.S.S.; project administration, J.R., L.L., A.P.K., D.L.S. and E.S.S.; funding acquisition, J.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Research Foundation (NRF), grant number 141282 and The Ryoichi Sasakawa Young Leaders Fellowship Fund (SLYFF).

http://etd.uwc.ac.za/

Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the BIOMEDICAL RESEARCH ETHICS COMMITTEE (BMREC) of THE UNIVERSITY OF THE WESTERN CAPE (BM21/10/19) for studies involving humans.

Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to this being an ongoing study and the POPIA Act, which restricts access to private information being made publicly available.

Acknowledgments: We would like to thank every firefighter that agreed to participate in this study. We also thank the Chief Fire Officer and the City of Cape Town for granting approval for this present study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Smith, D.L.; Haller, J.M.; Korre, M.; Sampani, K.; Porto, L.G.G.; Fehling, P.C.; Christophi, C.A.; Kales, S.N. The Relation of Emergency Duties to Cardiac Death Among US Firefighters. *Am. J. Cardiol.* **2019**, *123*, 736–741. [CrossRef] [PubMed]
2. Chizewski, A.; Box, A.; Kesler, R.; Petruzzello, S.J. Fitness Fights Fires: Exploring the Relationship between Physical Fitness and Firefighter Ability. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11733. [CrossRef] [PubMed]
3. Park, K.; Rosengren, K.S.; Horn, G.P.; Smith, D.L.; Hsiao-Wecksler, E.T. Assessing Gait Changes in Firefighters Due to Fatigue and Protective Clothing. *Saf. Sci.* **2011**, *49*, 719–726. [CrossRef]
4. Taylor, N.A.S.; Lewis, M.C.; Notley, S.R.; Peoples, G.E. A Fractionation of the Physiological Burden of the Personal Protective Equipment Worn by Firefighters. *Eur. J. Appl. Physiol.* **2012**, *112*, 2913–2921. [CrossRef]
5. Henderson, N.; Berry, M.; Matic, T. Field Measures of Strength and Fitness Predict Firefighter Performance on Physically Demanding Tasks. *Pers. Psychol.* **2007**, *60*, 431–473. [CrossRef]
6. Sothmann, M.S.; Gebhardt, D.L.; Baker, T.A.; Kastellos, G.M.; Sheppard, V.A. Performance Requirements of Physically Strenuous Occupations: Validating Minimum Standards for Muscular Strength and Endurance. *Ergonomics* **2004**, *47*, 864–875. [CrossRef]
7. Baur, D.M.; Christophi, C.A.; Tsismenakis, A.J.; Cook, E.F.; Kales, S.N. Cardiorespiratory Fitness Predicts Cardiovascular Risk Profiles in Career Firefighters. *J. Occup. Environ. Med.* **2011**, *53*, 1155–1160. [CrossRef]
8. Smith, D.L.; Haller, J.M.; Korre, M.; Fehling, P.C.; Sampani, K.; Grossi Porto, L.G.; Christophi, C.A.; Kales, S.N. Pathoanatomic Findings Associated with Duty-Related Cardiac Death in US Firefighters: A Case–Control Study. *J. Am. Heart Assoc.* **2018**, *7*, e009446. [CrossRef]
9. Dorman, L.E.; Havenith, G. The Effects of Protective Clothing on Energy Consumption during Different Activities. *Eur. J. Appl. Physiol.* **2009**, *105*, 463–470. [CrossRef]
10. Elsner, K.L.; Kolkhorst, F.W. Metabolic Demands of Simulated Firefighting Tasks. *Ergonomics* 2008, *51*, 1418–1425. [CrossRef]
11. Frost, D.M.; Beach, T.A.C.; Crosby, I.; McGill, S.M. The Cost and Distribution of Firefighter Injuries in a Large Canadian Fire Department. *Work* **2016**, *55*, 497–504. [CrossRef]
12. von Heimburg, E.D.; Rasmussen, A.K.R.; Medbø, J.I. Physiological Responses of Firefighters and Performance Predictors during a Simulated Rescue of Hospital Patients. *Ergonomics* **2006**, *49*, 111–126. [CrossRef]
13. Ras, J.; Kengne, A.P.; Smith, D.; Soteriades, E.S.; Leach, L. Effects of Cardiovascular Health, Musculoskeletal Health and Physical Fitness on Occupational Performance of Firefighters: Protocol for a Systematic Review and Meta-Analysis. *BMJ Open* **2022**, *12*, e061435. [CrossRef]
14. Rhea, M.R.; Alvar, B.A.; Gray, R. Physical Fitness and Job Performance of Firefighters. *J. Strength Cond. Res.* **2004**, *18*, 348–352. [CrossRef]
15. Michaelides, M.A.; Parpa, K.M.; Thompson, J.; Brown, B. Predicting Performance on a Firefghter's Ability Test from Fitness Parameters. *Res. Q. Exerc. Sport* **2008**, *79*, 468–475. [CrossRef]
16. Yu, C.C.W.; Au, C.T.; Lee, F.Y.F.; So, R.C.H.; Wong, J.P.S.; Mak, G.Y.K.; Chien, E.P.; McManus, A.M. Association between Leisure Time Physical Activity, Cardiopulmonary Fitness, Cardiovascular Risk Factors, and Cardiovascular Workload at Work in Firefighters. *Saf. Health Work* **2015**, *6*, 192–199. [CrossRef]
17. Mehrdad, R.; Movasatian, F.; Momenzadeh, A.S. Fitness for Work Evaluation of Firefighters in Tehran. *Acta Med. Iran.* **2013**, *51*, 265–269.
18. Ras, J.; Mosie, D.; Strauss, M.; Leach, L. Knowledge of and Attitudes toward Health and Cardiovascular Disease Risk Factors among Firefighters in Cape Town, South Africa. *J. Public Health Res.* **2021**, *11*, 2307. [CrossRef]
19. Muegge, C.M.; Zollinger, T.W.; Song, Y.; Wessel, J.; Monahan, P.O.; Moffatt, S.M. Barriers to Weight Management among Overweight and Obese Firefighters. *J. Occup. Environ. Med.* **2020**, *62*, 37–45. [CrossRef]
20. Ras, J.; Leach, L. Firefighters' Health Knowledge, Cardiovascular Disease Risk Factors and Sociodemographic Characteristics as Predictors of Firefighters Attitudes Toward Health. *J. Occup. Environ. Med.* **2022**, *64*, e705–e713. [CrossRef]
21. Dobson, M.; Choi, B.; Schnall, P.L.; Wigger, E.; Garcia-Rivas, J.; Israel, L.; Baker, D.B. Exploring Occupational and Health Behavioral Causes of Firefighter Obesity: A Qualitative Study. *Am. J. Ind. Med.* **2013**, *56*, 776–790. [CrossRef] [PubMed]

http://etd.uwc.ac.za/

22. Kirlin, L.K.; Nichols, J.F.; Rusk, K.; Parker, R.A.; Rauh, M.J. The Effect of Age on Fitness among Female Firefighters. *Occup. Med.* **2017**, *67*, 528–533. [CrossRef] [PubMed]
23. Kiss, P.; de Meester, M.; Maes, C.; de Vriese, S.; Kruse, A.; Braeckman, L. Cardiorespiratory Fitness in a Representative Sample of Belgian Firefighters. *Occup. Med.* **2014**, *64*, 589–594. [CrossRef] [PubMed]
24. Walker, A.; Driller, M.; Argus, C.; Cooke, J.; Rattray, B. The Ageing Australian Firefighter: An Argument for Age-Based Recruitment and Fitness Standards for Urban Fire Services. *Ergonomics* **2014**, *57*, 612–621. [CrossRef] [PubMed]
25. Perroni, F.; Guidetti, L.; Cignitti, L.; Baldari, C. Age-Related Changes in Upper Body Strength and Lower Limb Power of Professional Italian Firefighters. *Sport Sci. Health* **2015**, *11*, 279–285. [CrossRef]
26. Ras, J.; Leach, L. Prevalence of Coronary Artery Disease Risk Factors in Firefighters in the City of Cape Town Fire and Rescue Service—A Descriptive Study. *J. Public Health Res.* **2021**, *10*, 2000. [CrossRef]
27. Martin, Z.T.; Schlaff, R.A.; Hemenway, J.K.; Coulter, J.R.; Knous, J.L.; Lowry, J.E.; Ode, J.J. Cardiovascular Disease Risk Factors and Physical Fitness in Volunteer Firefighters. *Int. J. Exerc. Sci.* **2019**, *12*, 764–776.
28. Savall, A.; Charles, R.; Bertholon, A.; Gramont, B.; Trombert, B.; Barthélémy, J.C.; Roche, F. Volunteer and Career French Firefighters: Cardiovascular Risk Factors and Cardiovascular Risk Assessment. *Eur. J. Prev. Cardiol.* **2020**, *27*, 107–109. [CrossRef]
29. Baur, D.M.; Christophi, C.A.; Cook, E.F.; Kales, S.N. Age-Related Decline in Cardiorespiratory Fitness among Career Firefighters: Modification by Physical Activity and Adiposity. *J. Obes.* **2012**, *2012*, 710903. [CrossRef]
30. Seyedmehdi, S.M.; Attarchi, M.; Cherati, A.S.; Hajsadeghi, S.; Tofighi, R.; Jamaati, H. Relationship of Aerobic Fitness with Cardiovascular Risk Factors in Firefighters. *Work* **2016**, *55*, 155–161. [CrossRef]
31. Strauss, M.; Foshag, P.; Jehn, U.; Brzęk, A.; Littwitz, H.; Leischik, R. Higher Cardiorespiratory Fitness Is Strongly Associated with Lower Cardiovascular Risk Factors in Firefighters : A Cross-Sectional Study in a German Fire Brigade. *Sci. Rep.* **2021**, *11*, 2445. [CrossRef]
32. Espinoza, F.; Delgado-Floody, P.; Martínez-Salazar, C.; Jerez-Mayorga, D.; Guzmán-Guzmán, I.P.; Caamaño-Navarrete, F.; Ramirez-Campillo, R.; Chamorro, C.; Campos-Jara, C. The Influence of Cardiometabolic Risk Factors on Cardiorespiratory Fitness in Volunteer Chilean Firefighters. *Am. J. Hum. Biol.* **2019**, *31*, e23280. [CrossRef]
33. McAllister, M.J.; Gonzalez, D.E.; Leonard, M.; Martaindale, M.H.; Bloomer, R.J.; Pence, J.; Martin, S.E. Firefighters with Higher Cardiorespiratory Fitness Demonstrate Lower Markers of Cardiovascular Disease Risk. *J. Occup. Environ. Med.* **2022**, *64*, 1036–1040. [CrossRef]
34. Durand, G.; Tsismenakis, A.J.; Jahnke, S.A.; Baur, D.M.; Christophi, C.A.; Kales, S.N. Firefighters' Physical Activity: Relation to Fitness and Cardiovascular Disease Risk. *Med. Sci. Sport. Exerc.* **2011**, *43*, 1752–1759. [CrossRef]
35. Ras, J.; Smith, D.L.; Kengne, A.P.; Soteriades, E.E.; Leach, L. Cardiovascular Disease Risk Factors, Musculoskeletal Health, Physical Fitness, and Occupational Performance in Firefighters: A Narrative Review. *J. Environ. Public Health* **2022**, *2022*, 7346408. [CrossRef]
36. Ras, J.; Leach, L. Relationship between Physical Activity, Coronary Artery Disease Risk Factors and Musculoskeletal Injuries in the City of Cape Town Fire and Rescue Service. *INQUIRY J. Health Care Organ. Provis. Financ.* **2022**, *59*, 00469580221084485. [CrossRef]
37. Bode, E.D.; Mathias, K.C.; Stewart, D.F.; Moffatt, S.M.; Jack, K.; Smith, D.L. Cardiovascular Disease Risk Factors by BMI and Age in United States Firefighters. *Obesity* **2021**, *29*, 1186–1194. [CrossRef]
38. Ras, J.; Smith, D.L.; Soteriades, E.S.; Kengne, A.P.; Leach, L. A Pilot Study on the Relationship between Cardiovascular Health, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters. *Eur. J. Investig. Health Psychol. Educ.* **2022**, *12*, 1703–1718. [CrossRef]
39. Liguori, G.; Medicine, A.C.; Fountaine, C.J. *ACSM's Guidelines for Exercise Testing and Prescription*; American College of Sports Medicine Series; Wolters Kluwer: Alphen aan den Rijn, The Netherlands, 2021; ISBN 9781975150181.
40. Bianco, A.; Lupo, C.; Alesi, M.; Spina, S.; Raccuglia, M.; Thomas, E.; Paoli, A.; Palma, A. The Sit up Test to Exhaustion as a Test for Muscular Endurance Evaluation. *Springerplus* **2015**, *4*, 309. [CrossRef]
41. Lloyd-Jones, D.M.; Hong, Y.; Labarthe, D.; Mozaffarian, D.; Appel, L.J.; van Horn, L.; Greenlund, K.; Daniels, S.; Nichol, G.; Tomaselli, G.F.; et al. Defining and Setting National Goals for Cardiovascular Health Promotion and Disease Reduction. *Circulation* **2010**, *121*, 586–613. [CrossRef]
42. Kim, S.; Chang, Y.; Cho, J.; Hong, Y.S.; Zhao, D.; Kang, J.; Jung, H.-S.; Yun, K.E.; Guallar, E.; Ryu, S.; et al. Life's Simple 7 Cardiovascular Health Metrics and Progression of Coronary Artery Calcium in a Low-Risk Population. *Arter. Thromb. Vasc. Biol.* **2019**, *39*, 826–833. [CrossRef] [PubMed]
43. Ketelaar, E.J.; Vos, A.G.; Godijk, N.G.; Scheuermaier, K.; Devillé, W.; Tempelman, H.; Coutinho, R.A.; Venter, W.D.F.; Grobbee, D.E.; Klipstein-Grobusch, K. Ideal Cardiovascular Health Index and Its Determinants in a Rural South African Population. *Glob. Heart* **2020**, *15*, 76. [CrossRef] [PubMed]
44. Lloyd-Jones, D.M.; Leip, E.P.; Larson, M.G.; D'Agostino, R.B.; Beiser, A.; Wilson, P.W.F.; Wolf, P.A.; Levy, D. Prediction of Lifetime Risk for Cardiovascular Disease by Risk Factor Burden at 50 Years of Age. *Circulation* **2006**, *113*, 791–798. [CrossRef] [PubMed]
45. Jones, N.R.; McCormack, T.; Constanti, M.; McManus, R.J. Diagnosis and Management of Hypertension in Adults: NICE Guideline Update 2019. *Br. J. Gen. Pract.* **2020**, *70*, 90. [CrossRef] [PubMed]
46. Kaleta, D.; Makowiec-Dąbrowska, T.; Dziankowska-Zaborszczyk, E.; Fronczak, A. Determinants of Heavy Smoking: Results from the Global Adult Tobacco Survey in Poland (2009–2010). *Int. J. Occup. Med. Environ. Health* **2012**, *25*, 66–79. [CrossRef]

http://etd.uwc.ac.za/

47. D'Agostino, R.B.; Vasan, R.S.; Pencina, M.J.; Wolf, P.A.; Cobain, M.; Massaro, J.M.; Kannel, W.B. General Cardiovascular Risk Profile for Use in Primary Care. *Circulation* **2008**, *117*, 743–753. [CrossRef]
48. Arnett, D.K.; Blumenthal, R.S.; Albert, M.A.; Buroker, A.B.; Goldberger, Z.D.; Hahn, E.J.; Himmelfarb, C.D.; Khera, A.; Lloyd-Jones, D.; McEvoy, J.W.; et al. 2019 ACC/AHA Guideline on the Primary Prevention of Cardiovascular Disease: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Circulation* **2019**, *140*, e596–e646. [CrossRef]
49. Billman, G.E.; Huikuri, H.V.; Sacha, J.; Trimmel, K. An Introduction to Heart Rate Variability: Methodological Considerations and Clinical Applications. *Front. Physiol.* **2015**, *6*, 2013–2015. [CrossRef]
50. Tomes, C.; Schram, B.; Orr, R. Relationships between Heart Rate Variability, Occupational Performance, and Fitness for Tactical Personnel: A Systematic Review. *Front. Public Health* **2020**, *8*, 583336. [CrossRef]
51. Vaara, J.P.; Fogelholm, M.; Vasankari, T.; Santtila, M.; Häkkinen, K.; Kyröläinen, H. Associations of Maximal Strength and Muscular Endurance with Cardiovascular Risk Factors. *Int. J. Sport. Med.* **2014**, *35*, 356–360. [CrossRef]
52. Shin, J.Y.; Ha, C.H. Relationships between Blood Pressure and Health and Fitness-Related Variables in Obese Women. *J. Phys. Ther. Sci.* **2016**, *28*, 2933–2937. [CrossRef]
53. Lin, G.-M.; Tsai, K.-Z.; Lin, C.-S.; Han, C.-L. Physical Fitness and Long-Term Blood Pressure Variability in Young Male Military Personnel. *Curr. Hypertens. Rev.* **2019**, *16*, 156–160. [CrossRef]
54. Gubelmann, C.; Vollenweider, P.; Marques-Vidal, P. Association of Grip Strength with Cardiovascular Risk Markers. *Eur. J. Prev. Cardiol.* **2017**, *24*, 514–521. [CrossRef]
55. Yang, J.; Christophi, C.A.; Farioli, A.; Baur, D.M.; Moffatt, S. Association between Push-up Exercise Capacity and Future Cardiovascular Events among Active Adult Men. *JAMA Netw. Open* **2019**, *2*, e188341. [CrossRef]
56. Ras, J.; Kengne, A.P.; Smith, D.L.; Soteriades, E.S.; Leach, L. Association between Cardiovascular Disease Risk Factors and Cardiorespiratory Fitness in Firefighters: A Systematic Review and Meta-Analysis. *Int. J. Environ. Res. Public Health* **2023**, *20*, 2816. [CrossRef]
57. DeFina, L.F.; Haskell, W.L.; Willis, B.L.; Barlow, C.E.; Finley, C.E.; Levine, B.D.; Cooper, K.H. Physical Activity Versus Cardiorespiratory Fitness: Two (Partly) Distinct Components of Cardiovascular Health? *Prog. Cardiovasc. Dis.* **2015**, *57*, 324–329. [CrossRef]
58. Yamada, E.; Takeuchi, M.; Kurata, M.; Tsuboi, A.; Kazumi, T.; Fukuo, K. Low Haemoglobin Levels Contribute to Low Grip Strength Independent of Low-Grade Inflammation in Japanese Elderly Women. *Asia Pac. J. Clin. Nutr.* **2015**, *24*, 444–451. [CrossRef]
59. Carter, J.R.; Ray, C.A.; Downs, E.M.; Cooke, W.H. Strength Training Reduces Arterial Blood Pressure but Not Sympathetic Neural Activity in Young Normotensive Subjects. *J. Appl. Physiol.* **2003**, *94*, 2212–2216. [CrossRef]
60. Martel, G.F.; Hurlbut, D.E.; Lott, M.E.; Lemmer, J.T.; Ivey, F.M.; Roth, S.M.; Rogers, M.A.; Fleg, J.L.; Hurley, B.F. Strength Training Normalizes Resting Blood Pressure in 65- to 73-Year-Old Men and Women with High Normal Blood Pressure. *J. Am. Geriatr. Soc.* **1999**, *47*, 1215–1221. [CrossRef]
61. Singh, N.; Liu, K.; Tian, L.; Criqui, M.H.; Guralnik, J.M.; Ferrucci, L.; Liao, Y.; McDermott, M.M. Leg Strength Predicts Mortality in Men but Not in Women with Peripheral Arterial Disease. *J. Vasc. Surg.* **2010**, *52*, 624–631. [CrossRef]
62. Taylor, P.; Beach, T.A.C.; Frost, D.M.; Mcgill, S.M.; Callaghan, J.P. Physical Fitness Improvements and Occupational Low- Back Loading—An Exercise Intervention Study with Firefighters. *Ergonomics* **2014**, *57*, 744–763. [CrossRef]
63. Andrews, K.L.; Gallagher, S.; Herring, M.P. The Effects of Exercise Interventions on Health and Fitness of Firefighters: A Meta-Analysis. *Scand. J. Med. Sci. Sport.* **2019**, *29*, 780–790. [CrossRef] [PubMed]
64. Findley, B.W.; Brown, L.E.; Whitehurst, M.; Gilbert, R.; Apold, S.A. Age-Group Performance and Physical Fitness in Male Firefighters. *J. Strength Cond. Res.* **1995**, *9*, 259–260.
65. Nowak, A.; Molik, B.; Wójcik, A.; Rutkowska, I.; Nowacka-Dobosz, S.; Kowalczyk, M.; Marszałek, J. Physical Activity and Injuries Relating to Physical Fitness of Professional Firefighters. *Adv. Rehabil.* **2018**, *32*, 13–22. [CrossRef]
66. Perroni, F.; Cignitti, L.; Cortis, C.; Capranica, L. Physical Fitness Profile of Professional Italian Firefighters: Differences among Age Groups. *Appl. Ergon.* **2014**, *45*, 456–461. [CrossRef]
67. Gerstner, G.R.; Giuliani, H.K.; Mota, J.A.; Ryan, E.D. Influence of Muscle Quality on the Differences in Strength from Slow to Fast Velocities in Career Firefighters. *J. Strength Cond. Res.* **2018**, *32*, 2982–2986. [CrossRef]
68. Álvarez, C.; Cadore, E.; Gaya, A.R.; Mello, J.B.; Reuter, C.P.; Delgado-Floody, P.; Ramos-Sepúlveda, J.A.; Carrillo, H.A.; Devia, D.G.; Ramírez-Vélez, R. Associations of Cardiorespiratory Fitness and Obesity Parameters with Blood Pressure: Fitness and Fatness in Youth Latin-American Ethnic Minority. *Ethn. Health* **2022**, *27*, 1058–1074. [CrossRef]
69. Macdonald, H.V.; Pescatello, L.S. *Cardiorespiratory Fitness in Cardiometabolic Diseases*; Springer Nature Publications: Cham, Switzerland, 2019; ISBN 9783030048167.
70. Davison, K.; Bircher, S.; Hill, A.; Coates, A.M.; Howe, P.R.C.; Buckley, J.D. Relationships between Obesity, Cardiorespiratory Fitness, and Cardiovascular Function. *J. Obes.* **2010**, *2010*, 191253. [CrossRef]
71. Poston, W.S.C.; Haddock, C.K.; Jahnke, S.A.; Jitnarin, N.; Tuley, B.C.; Kales, S.N. The Prevalence of Overweight, Obesity, and Substandard Fitness in a Population-Based Firefighter Cohort. *J. Occup. Environ. Med.* **2011**, *53*, 266–273. [CrossRef]
72. Oktay, A.A.; Lavie, C.J.; Kokkinos, P.F.; Parto, P.; Pandey, A.; Ventura, H.O. The Interaction of Cardiorespiratory Fitness with Obesity and the Obesity Paradox in Cardiovascular Disease. *Prog. Cardiovasc. Dis.* **2017**, *60*, 30–44. [CrossRef]

http://etd.uwc.ac.za/

73. Mayer, J.M.; Nuzzo, J.L.; Chen, R.; Quillen, W.S.; Verna, J.L.; Miro, R.; Dagenais, S. The Impact of Obesity on Back and Core Muscular Endurance in Firefighters. *J. Obes.* **2012**, *2012*, 729283. [CrossRef]
74. Porto, L.G.G.; Schmidt, A.C.B.; de Souza, J.M.; Nogueira, R.M.; Fontana, K.E.; Molina, G.E.; Korre, M.; Smith, D.L.; Junqueira, L.F.; Kales, S.N. Firefighters' Basal Cardiac Autonomic Function and Its Associations with Cardiorespiratory Fitness. *Work* **2019**, *62*, 485–495. [CrossRef]
75. Lesniak, A.Y.; Sell, K.M.; Morris, C.; Abel, M.G. Relationship between Heart Rate Variability vs. Occupational Performance, Physical Activity and Fitness Measures in Structural Firefighters. *J. Sport Hum. Perform.* **2022**, *10*, 56–72. [CrossRef]
76. Grant, C.C.; Mongwe, L.; Janse Van Rensburg, D.C.; Fletcher, L.; Wood, P.S.; Terblanche, E.; du Toit, P.J. The Difference between Exercise-Induced Autonomic and Fitness Changes Measured after 12 and 20 Weeks of Medium-to-High Intensity Military Training. *J. Strength Cond. Res.* **2016**, *30*, 2453–2459. [CrossRef]
77. Ras, J.; Leach, L. Use of Mobile Technology in Assessing Occupational Performance and Stress in Firefighters. In *Handbook of Research on New Media, Training, and Skill Development for the Modern Workforce*; Mentor, D., Ed.; IGI Global: Hershey, PA, USA, 2022; pp. 150–186, ISBN 9781668439968.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

CHAPTER TEN: PUBLICATION NINE − ORINGIAL RESEARCH ARTICLE FIVE

Association between Physical Fitness and Musculoskeletal Health in Firefighters

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

frontiers | Frontiers in Physiology

TYPE Original Research
PUBLISHED 04 July 2023
DOI 10.3389/fphys.2023.1210107

Association between physical fitness and musculoskeletal health in firefighters

Jaron Ras[1]*, Elpidoforos S. Soteriades[2,3], Denise L. Smith[4], Andre P. Kengne[5] and Lloyd Leach[1]

[1]Department of Sport, Recreation and Exercise Science, Faculty of Community and Health Sciences, University of the Western Cape, Cape Town, South Africa, [2]Healthcare Management Program, School of Economics and Management, Open University of Cyprus, Nicosia, Cyprus, [3]Environmental and Occupational Medicine and Epidemiology (EOME), Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston, MA, United States, [4]Health and Human Physiological Sciences, Skidmore College, Saratoga Springs, NY, United States, [5]Non-Communicable Diseases Research Unit, South African Medical Research Council, Cape Town, South Africa

Check for updates

OPEN ACCESS

EDITED BY
Filip Kukic,
Abu Dhabi Police, United Arab Emirates

REVIEWED BY
Marcos Michaelides,
University of Central Lancashire, Cyprus
Antonio Roberto Zamunér,
Catholic University of Maule, Chile

*CORRESPONDENCE
Jaron Ras,
3405618@myuwc.ac.za

RECEIVED 25 April 2023
ACCEPTED 19 June 2023
PUBLISHED 04 July 2023

CITATION
Ras J, Soteriades ES, Smith DL, Kengne AP and Leach L (2023), Association between physical fitness and musculoskeletal health in firefighters.
Front. Physiol. 14:1210107.
doi: 10.3389/fphys.2023.1210107

COPYRIGHT
© 2023 Ras, Soteriades, Smith, Kengne and Leach. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Introduction: Firefighters are often placed in situations that require high levels of physical exertion, leading to significant strain on firefighters' musculoskeletal system, predisposing them to musculoskeletal discomfort (MSD) and/or musculoskeletal injury (MSI). Physical fitness programs are often recommended and justified, in part, to prevent injuries. The aim of this study was to determine the association between physical fitness and musculoskeletal health (MSH) in firefighters.

Methods: A total of 308 full-time firefighters took part in the study conducted in Cape Town, South Africa. Physical fitness tests encompassed a non-exercise estimation for cardiorespiratory fitness, grip and leg strength for upper and lower body strength, push-ups and sit-ups for muscular endurance, and sit-and-reach for flexibility. The Nordic Musculoskeletal Questionnaire and Cornell Musculoskeletal Discomfort Questionnaire were used to determine MSIs and MSD, respectively. A p-value <0.05 indicated statistical significance.

Results: Every one-unit increase in AbVO2max, push-ups, sit-ups, and sit-and-reach decreased the odds of firefighters reporting MSIs by 5% ($p = 0.005$), 3% ($p = 0.017$), 3% ($p = 0.006$), and 3% ($p = 0.034$), respectively. Every one repetition increase in push-up capacity increased the odds of firefighters reporting neck, elbow and forearm, wrist and hand, and thigh discomfort by 3% ($p = 0.039$), 4% ($p = 0.031$), 5% ($p = 0.002$), and 5%` ($p = 0.007$), respectively. Every one repetition increase in sit-up capacity increased the odds of firefighters reporting upper back discomfort and thigh discomfort by 5% ($p = 0.045$) and 7% ($p = 0.013$), respectively.

Conclusion: Maintenance of physical fitness is likely beneficial in reducing MSIs, which, however, may increase the feeling of MSD in firefighters. In addition, it may be noticed that there is an ideal level of physical fitness that is conducive to the reduction of MSIs and should be studied further.

KEYWORDS

firefighting, discomfort, injury, workload, physical activity, strength, endurance, cardiorespiratory

http://etd.uwc.ac.za/

1 Introduction

Firefighting is globally acknowledged to be a dangerous occupation, routinely placing firefighters in hazardous situations that often require high levels of physical exertion, such as fire suppression, victim rescue, and door breaches (Smith et al., 2013; Smith et al., 2019). These workplace stressors place firefighters at high risk for sustaining serious and, sometimes, career-ending injuries (Poston et al., 2011; Orr et al., 2019). In addition, firefighters are regularly exposed to hazardous chemicals and fumes and high temperatures (Frost et al., 2015a; Smith et al., 2019; Nazari et al., 2020a). Due to the hazards of the profession, firefighters are required to wear heavy and insulated personal protective equipment (PPE) that places additional strain on an already burdened musculoskeletal system (Smith et al., 2013; Smith et al., 2016). As a consequence of the physically exhaustive nature of the profession, which often challenges their abilities to perform their work safely, fire departments have recommended firefighters to engage in regular and structured physical activity to manage these various stressors and workplace hazards (Poplin et al., 2013; Poplin et al., 2016; Nowak et al., 2018).

Frost et al. (2015a) reported that injuries occurring at the fire station (37.9%), during physical training (26.6%), during fire emergencies (14.7%), and non-fire emergencies (12.1%) were the most frequent ones. In addition, injuries and injury-related absenteeism are costly to fire departments and municipalities (Poston et al., 2011). Furthermore, a study reported that only 1%–5% of duty time was spent in fire suppression activities (Kales et al., 2007). However, injuries of higher severity occurred more frequently on the fireground (Poplin et al., 2012). Moreover, higher total number of hours worked by firefighters showed a higher incidence rate of injuries (Poplin et al., 2012). To perform their duties aptly, firefighters are required to maintain all aspects of physical fitness (Williford et al., 1999; Rhea et al., 2004; Michaelides et al., 2008; Chizewski et al., 2021), often through occupational specific exercise interventions (Andrews et al., 2019; Chizewski et al., 2021). Previous studies have indicated that a linear relationship existed between physical fitness and work performance (Williford et al., 1999; Rhea et al., 2004; Chizewski et al., 2021). Injury incidence has been related to increasing age and more years of experience as firefighters (Hong et al., 2012; Frost et al., 2016; Yoon et al., 2016). Studies have shown that firefighters tend to become less active as they age and, along with the attrition of the musculoskeletal system, which is associated with both an increase in age and years of experience, as a product of their work, are significantly predisposed to injuries (Hong et al., 2012; Frost et al., 2015a; Yu et al., 2015). Injuries, particularly moderate-to-severe injuries, result in substantial loss of time from work and, due to medical expenses, become costly to fire departments (Poston et al., 2011; Frost et al., 2016). To reduce the incidence of injuries, it is suggested that firefighters remain physically active in their leisure time or when off-duty (Poplin et al., 2013; Frost et al., 2015a; Nowak et al., 2018), and many fire departments schedule prescribed exercise programs when firefighters are on duty (Vaulerin et al., 2016), though studies have shown that higher overload in workload may predispose firefighters to injury (Vaulerin et al., 2016; Ras and Leach, 2022). This suggests that monitoring the overall weekly workload may be beneficial for firefighters, given the physical nature of their occupation (Poplin et al., 2013; Yu et al., 2015).

Physical fitness has been related to lower the incidence of musculoskeletal injuries (MSIs) in firefighters (Poplin et al., 2013; Poplin et al., 2016). Systematic reviews support the aforementioned finding, where it has been reported that cardiorespiratory fitness, muscle strength, muscular endurance, and flexibility were significantly related to reduction in injuries (de la Motte et al., 2017; Lisman et al., 2017; de la Motte et al., 2019). On the other hand, high weekly duty workloads may be related to insufficient time for recovery among firefighters (Vaulerin et al., 2016; Ras et al., 2022a; Ras and Leach, 2022). Monitoring of overall workload may allow fire departments to adjust the level of total physical activity firefighters are engaged in, either occupational activity or recreational activity, adjusting the workload to allow for more time for rest and recovery, thus reducing the likelihood of overload-related musculoskeletal discomfort (MSD) and/or MSIs (Yu et al., 2015; Bustos et al., 2022; Giuliani-Dewig et al., 2022). It is plausible that higher physical fitness would relate to lower feelings of MSD and pain in firefighters (Azmi and Masuri, 2019; Kodom-Wiredu, 2019; Nazari et al., 2020a). However, it is also possible that higher levels of physical fitness may cause firefighters to exert themselves more vigorously during emergency operations, thereby triggering workload-related feeling of MSD and chronic pain, and this may be exacerbated by repetitive movements (Rintala et al., 2015). Higher physical fitness has been shown to be related to improved occupational performance in firefighters, and it is logical to assume that increased levels of physical activity and physical fitness would also provide an additional benefit of better musculoskeletal health (MSH) (Ras et al., 2022a; Ras et al., 2022b).

It has been reported that firefighters in South Africa have high workloads while on duty, while many firefighters are physically inactive during their leisure time (Ras and Leach, 2022). However, there are firefighters in South Africa who are remarkably physically active both on-duty and off-duty (Ras et al., 2022c; Ras and Leach, 2022), which could place this population at an increased risk of reporting MSD or sustaining MSIs while on duty. It is plausible that firefighters who engage in high levels of duty-related physical activity, but are insufficiently active in their leisure time, (Frost et al., 2015a; Poplin et al., 2016) and those who engage in high levels of both duty-related physical activity and leisure time physical activity could be equally predisposed to MSIs (Vaulerin et al., 2016; Ras and Leach, 2022), possibly due to the mismatch between physical fitness and job tasks, and also due to overload of the musculoskeletal system. There has been insufficient research on the association between physical fitness and MSH in firefighters, particularly in South Africa. The South African Fire and Rescue Services policy on physical fitness is devoid of established guidelines requiring firefighters to remain physically active or maintain a fitness standard, perhaps, in part, due to the lack of research on this population. Therefore, the aim of this study was to determine the association between physical fitness and MSH (MSIs and MSD) in firefighters in the City of Cape Town Fire and Rescue Service (CoCTFRS).

2 Methods

2.1. Study design and population

This cross-sectional study recruited 308 firefighters from the CoCTFRS between June and August 2022. Physical testing was used

http://etd.uwc.ac.za/

TABLE 1 Physical fitness parameters, musculoskeletal disorders, and musculoskeletal injuries according to age groups in firefighters.

	Age group								P	Age	Sex	BMI	TWMETM
	20–29		30–39		40–49		50+						
	N	X±SD	N	X±SD	N	X±SD	N	X±SD		r	rpb	r	r
Height (cm)	72	173.1 ± 7.4	95	173.1 ± 7.6	83	171.3 ± 8.2	58	174.7 ± 7.4	0.067	—	—	—	—
Weight (kg)	72	76.7 ± 12.5	95	80.6 ± 15.2	83	84.2 ± 14.3	58	91.1 ± 14.8	<0.001**	—	—	—	—
Body mass index (kgm-2)	72	25.5 ± 3.6	95	26.9 ± 4.9	83	28.7 ± 4.5	58	29.5 ± 4.7	<0.001**	—	—	—	—
Weekly MET minutes	72	3972.2 ± 2887.7	95	3224.7 ± 2955.3	83	2564.1 ± 2624.6	58	2759.9 ± 2756.7	0.014*	—	—	—	—
abVO₂max (L•min)	72	3.5 ± 0.3	95	3.5 ± 0.3	83	3.3 ± 0.2	58	3.3 ± 0.3	<0.001**	−0.342**	0.138*	0.440**	0.172**
relVO₂max (mL•kg•min)	72	46.8 ± 5.0	95	43.8 ± 5.7	83	40.4 ± 5.1	58	37.0 ± 4.1	<0.001**	−0.522**	−0.185**	−0.782**	0.102
Grip strength (kg)	72	89.6 ± 17.5	95	89.6 ± 17.5	82	84.8 ± 18.8	56	89.9±12.3	0.008**	−0.079	0.526**	0.016	0.024
Right grip strength (kg)	72	45.3 ± 9.0	95	47.3 ± 9.4	82	42.2 ± 9.9	56	45.7 ± 6.4	0.003**	−0.079	0.499**	0.043	0.051
Left grip strength (kg)	72	44.3 ± 8.9	95	46.6 ± 9.4	82	42.6 ± 9.4	56	44.2 ± 6.7	0.026*	−0.081	0.522**	0.030	0.039
Leg strength (kg)	72	124.1 ± 29.2	95	121.2 ± 27.8	82	106.4 ± 28.4	56	111.7 ± 28.8	<0.001**	−0.221**	0.406**	0.130*	0.225**
Push-ups (rpm)	72	38.9 ± 10.5	95	33.7 ± 11.9	82	27.5 ± 15.0	56	20.2 ± 9.9	<0.001**	−0.482**	0.099	−0.293**	0.138*
Sit-ups (rpm)	72	33.9 ± 6.9	95	30.9 ± 8.8	82	25.7 ± 11.3	56	20.5 ± 9.4	<0.001**	−0.450**	0.071	−0.375**	0.073
Sit-and-reach (cm)	72	45.6 ± 8.2	95	42.5 ± 9.3	82	43.6 ± 8.8	56	38.9 ± 9.4	<0.001**	−0.208**	−0.184**	−0.250**	0.116*
Lean body mass (kg)	72	58.6 ± 8.2	95	59.3 ± 9.5	83	60.4 ± 10.1	57	64.6 ± 9.9	0.002**	−0.163**	0.534**	0.333**	0.050
	Sex								P				
		Males		Females									
	N	X ± SD	N	X ± SD									
Height (cm)	275	174.3 ± 6.5	34	161.7 ± 7.4	—	—	—	—	<0.001**	—	—	—	—
Weight (kg)	275	83.3 ± 14.2	34	75.8 ± 18.8	—	—	—	—	0.005**	—	—	—	—
Body mass index (kgm-2)	275	27.4 ± 4.4	34	28.9 ± 6.4	—	—	—	—	0.064	—	—	—	—
Weekly MET minutes	275	3141.9 ± 2859.4	34	2991.2 ± 2800.9	—	—	—	—	0.772	—	—	—	—
abVO₂max (L•min)	275	3.4 ± 0.3	34	3.3 ± 0.3	—	—	—	—	0.014*	—	—	—	—
relVO₂max (mL•kg•min)	275	41.9 ± 5.9	34	45.1 ± 7.4	—	—	—	—	0.005**	—	—	—	—
Grip strength (kg)	270	92.9 ± 15.4	34	64.6 ± 12.0	—	—	—	—	<0.001**	—	—	—	—
Right grip strength (kg)	270	46.7 ± 8.2	34	32.7 ± 6.3	—	—	—	—	<0.001**	—	—	—	—

(Continued on following page)

UNIVERSITY of the WESTERN CAPE

10.3389/fphys.2023.1210107

http://etd.uwc.ac.za/

TABLE 1 (*Continued*) Physical fitness parameters, musculoskeletal disorders, and musculoskeletal injuries according to age groups in firefighters.

	Age group								P	Age	Sex	BMI	TWMETM
	20–29		30–39		40–49		50+						
	N	X±SD	N	X±SD	N	X±SD	N	X±SD		r	rpb	r	r
Left grip strength (kg)	270	46.1 ± 7.9	34	31.9 ± 6.1	—	—	—	—	<0.001**	—	—	—	—
Leg strength (kg)	270	120.6 ± 26.9	34	82.0 ± 23.9	—	—	—	—	<0.001**	—	—	—	—
Push-ups (rpm)	270	31.4 ± 14.3	34	26.7 ± 10.1	—	—	—	—	0.105	—	—	—	—
Sit-ups (rpm)	270	28.4 ± 10.4	34	25.9 ± 9.9	—	—	—	—	0.140	—	—	—	—
Sit-and-reach (cm)	270	42.3 ± 9.1	34	25.9 ± 9.9	—	—	—	—	0.006**	—	—	—	—
Lean body mass (kg)	275	62.4 ± 8.1	34	43.8 ± 5.7	—	—	—	—	<0.001**	—	—	—	—
Musculoskeletal health	N	%	N	%	N	%	N	%	p §	rpb	rpb	rpb	rpb
Musculoskeletal injury	19	14.6	39	31.0	41	31.5	31	23.8	0.008**	0.167*	0.119*	0.191*	-0.029
Upper limb	5	8.1	20	32.3	23	37.1	14	22.6	0.010*	0.149*	0.006	0.124*	0.033
Lower body	14	18.9	18	24.3	23	31.1	19	25.7	0.148	0.078	0.118*	0.137*	−0.019
Shoulder	1	5.9	4	23.5	6	35.3	6	35.3	0.124	0.132*	0.023	153*	−0.064
Lower back	1	4.2	10	41.7	8	33.3	5	20.8	0.139	0.080	0.015	0.082	−0.011
Ankle and foot	5	12.8	9	23.1	16	41.0	9	23.1	0.079	0.121*	-0.115*	0.154*	−0.026
Musculoskeletal discomfort	27	20.8	39	30.0	39	30.0	25	19.2	0.671	0.025	0.093	0.062	−0.015
Neck	6	18.2	11	33.3	11	33.3	5	15.2	0.727	0.014	0.002	−0.008	−0.026
Shoulder	6	14.3	16	38.1	12	28.6	8	19.0	0.471	0.042	0.105	−0.024	−0.028
Upper back	8	33.3	6	25.0	9	37.5	1	4.2	0.140	−0.071	−0.031	−0.083	0.010
Elbow	5	21.7	5	21.7	8	34.8	5	21.7	0.701	0.022	0.056	−0.034	0.029
Wrist and hand	5	16.1	10	32.3	13	41.9	3	9.7	0.157	−0.001	0.031	−0.004	0.098
Lower back	11	15.5	22	31.0	25	35.2	13	18.3	0.186	0.068	-0.014	0.135*	−0.007
Hip	4	21.1	6	31.6	6	31.6	3	15.8	0.959	0.005	−0.011	−0.061	−0.011
Thigh	4	22.2	5	27.8	7	38.9	2	11.1	0.636	−0.013	0.086	−0.027	−0.005
Ankle and foot	6	20.7	10	34.5	8	27.6	5	17.2	0.967	−0.002	−0.016	0.036	0.073

Note: * indicates statistical significance <0.05 and ** indicates statistical significance <0.01.
Correlations between physical fitness parameters and musculoskeletal health and age, sex, body mass index, and weekly MET minutes.
kg•m-2—kilogram per meter squared; L•min—liters per minute; mL•kg•min—milliliters per minute; kg—kilogram; rpm—repetitions per minute; X¯—mean; SD—standard deviation; p—significance level; %—percentage; r—Pearson's correlation.; BMI—body mass index; TWMETM—total weekly metabolic equivalent minutes; ANOVA—indicates analysis of variance; §—indicates Chi-squared; rpb—point biserial correlation coefficient; rτ—Kendall's tau coefficient.

UNIVERSITY of the WESTERN CAPE

10.3389/fphys.2023.1210107

http://etd.uwc.ac.za/

to acquire information on physical fitness (cardiorespiratory fitness, muscular strength and endurance, flexibility, and body composition), and a researcher-generated questionnaire, which included two validated questionnaires, was used to acquire information on MSH (MSIs and MSD). All volunteers for this study provided written informed consent before inclusion. Due to injury or inability to perform the physical fitness tests, the total number of firefighters who completed the physical fitness assessment was reduced to 304 for the grip strength, leg strength, push-up, sit-up, and sit-and-reach tests. The study was approved by the University of the Western Cape Biomedical Research Ethics Committee (BM21/10/9) and authorized by the Chief Fire Officer and the Department of Policy and Strategy. A detailed description of the methods used is available in Ras et al. (2022c).

2.2 Sampling and participant recruitment

Data collection took place at a standardized fire station in the metropolitan area of the City of Cape Town during the CoCTFRS's yearly physical fitness evaluation. Every third firefighter from the 96 platoons (32 fire stations) was selected to participate. Each of the 96 firefighting platoons was made up of eight–twelve firefighters. All full-time firefighters between the ages of 20 and 65 who were on active duty during the time of testing were considered. Firefighters who were on administrative duty or sick leave, firefighters who were removed from active duty due to injury, and those who worked part-time or seasonally were disqualified from participating in the study.

2.3 Physical fitness measures summary

Physical fitness was measured in accordance with the American College of Sports Medicine (ACSM) guidelines (Liguori et al., 2021). Cardiorespiratory capacity was calculated using a validated non-exercise calculation (Rexhepi and Brestovci, 2014; Ras et al., 2022c) to estimate oxygen consumption (VO_2). The push-up and sit-up tests were used to assess muscular endurance; handgrip and leg strength tests were used to assess upper and lower body muscle strength, respectively; and the sit-and-reach (YMCA sit-and-reach protocol (Liguori et al., 2021)) test was used to assess flexibility. Body mass and lean body mass (LBM) were used as a measure for body composition and assessed using a Tanita© (Tanita©, Tokyo, Japan) BC-1000 Plus bioelectrical impedance (BIA) analyzer. Briefly, for the push-up and sit-up tests, firefighters were required to perform as many push-ups and sit-ups within a minute until volitional fatigue or failure (Liguori et al., 2021). Grip strength was measured using a Takei® 5401-C handgrip dynamometer and leg strength using a Takei® back and leg strength dynamometer, following standardized protocols and with three attempts, with the highest value being recorded (Liguori et al., 2021). The sit-and-reach test required firefighters to reach as forward as far as possible on the ruler of a standardized sit-and-reach box. Cardiorespiratory fitness was estimated using the non-exercise method, using the following formula: oxygen consumption (VO_{2max}) = 3.542 + (−0.014 × Age) + [0.015 × Body Mass (kg)] + (−0.011 × Resting Heart Rate) (Rexhepi and Brestovci, 2014). Relative VO_{2max} ($relVO_{2max}$) was then calculated from the generated absolute VO_{2max} value. The estimated VO_{2max} formula was reported to be a moderately correlated predictor of VO_{2max} ($r = 0.688$, $p < 0.001$; $\bar{X}$ SD = 3.5420.314 vs. 3.5440.218). This was validated by Sun et al. (2022), who noted the formula was reliable in estimating VO_{2max} in men ($R^2 = 0.258$; RMSE = 2.657; SEE = 0.051) and women ($R^2 = 0.213$; RMSE = 2.202; SEE = 0.076), in the general population.

2.4 Musculoskeletal health measure summary

MSH encompassed MSIs and MSD. For MSIs, the Nordic Musculoskeletal Questionnaire (Crawford, 2007; Chairani, 2020) was used to acquire information on injuries and their location. The Cornell Musculoskeletal Discomfort Questionnaire (Hedge et al., 1999) was used to assess information on the location of discomfort.

2.5 Physical activity measures

Physical activity was assessed using the International Physical Activity Questionnaire (IPAQ) and using the questionnaire converted to weekly metabolic equivalent (MET) minutes (Bohlmann et al., 2001). Using the IPAQ cut-off values for physical activity levels, firefighters were further classified into highly active, which included firefighters who accumulated ≥3000 MET minutes a week of low-, moderate-, and vigorous-intensity MET minutes a week or ≥1,500 of vigorous-intensity MET minutes, only, a week (Bohlmann et al., 2001). Minimally active firefighters were classified as those who accumulated ≥600 MET minutes of low-, moderate-, and vigorous- intensity MET minutes a week. Insufficiently active firefighters were classified as those with <600 MET minutes a week (Bohlmann et al., 2001). In addition, physical activity was classified into total weekly MET minutes, total low-intensity physical activity minutes, total moderate-intensity physical activity minutes, and total vigorous- intensity physical activity minutes.

2.6 Statistical analysis

The data were analyzed using SPSS® software, version 28 (Chicago, Illinois, United States). The Shapiro–Wilk test was used to determine the distribution of the data, and the assumption of normal distribution was retained for the continuous variables of physical fitness and not normally distributed for measures of physical activity. Continuous variables of physical fitness are summarized as means and standard deviations, and continuous variables of physical activity are summarized as medians and 25th to 75th percentiles. Firefighters were classified into the following groups: those with 10-year age intervals, those with MSIs or those uninjured and injury location, and those with or without discomfort and location of discomfort. Group comparisons were based on independent t-tests and analysis of variance (ANOVA) for physical fitness parameters, and the Mann–Whitney U test for physical activity parameters. For the ANOVA analysis, Bonferroni correction was applied. Pearson's correlation analysis was performed to determine the correlation

http://etd.uwc.ac.za/

between physical fitness and age, sex [point-biserial correlation (0 = males and 1 = females)], body mass index (BMI), and weekly MET minutes. Point-biserial correlations were also performed for dichotomous measures of MSH and continuous variables of age, BMI, and weekly MET minutes. In addition, chi-squared test was used to compare MSIs and MSD according to age groups. Univariable and multivariable logistic regressions were performed to determine the association between MSH parameters, which were treated as the outcome/dependent variable, and physical fitness, which designated the exploratory/independent variables. As exploratory variables, physical fitness was used as a continuous measure of physical fitness ($abVO_{2max}$, $relVO_{2max}$, grip and leg strength, push-ups, sit-ups, sit-and-reach, and lean body mass). Selection of exploratory variables used as covariates was evidence- based and based on a previous research study that consistently reported an association between MSIs and MSD in firefighters. Collinearity was assessed using the variance inflation factor (VIF) between the exploratory variables used in the adjusted models and deemed acceptable with a VIF of <5. In addition, to ensure autocorrelation was not present between independent variables, a correlation coefficient of <0.8 was used. Due to collinearity between age and years of experience, two separate multivariable models were used. Attributes adjusted for in model 2 included age, sex, BMI, and weekly MET minutes, and in model 3, years of experience was favored over age. A p-value of <0.05 was used to indicate statistical significance.

3 Results

Table 1 presents the physical fitness measures according to sex and age groups in firefighters. Weight ($p < 0.001$), BMI ($p < 0.001$), and weekly MET ($p < 0.05$) minutes were significantly different between age groups. All physical fitness measures were significantly different between the age groups, particularly $abVO_{2max}$, $relVO_{2max}$, sit-ups, push-ups, and sit-and-reach scores ($p < 0.001$). After Bonferroni correction, $abVO_{2max}$, $relVO_{2max}$, grip strength, leg strength sit-ups, push-ups, sit-and-reach, and LBM remained robust to adjustment. According to sex, male firefighters were taller, heavier, and stronger and had a higher $abVO_{2max}$ and LBM. Female firefighters had a higher $relVO_{2max}$ and were more flexible. Age was negatively correlated with $abVO_{2max}$, $relVO_{2max}$, leg strength, push-ups, sit-ups, sit-and-reach, and LBM (all $p < 0.01$). $AbVO_2max$, grip strength, leg strength, and LBM were lower in female firefighters (all $p < 0.01$). BMI was negatively correlated with $abVO_{2max}$, $relVO_{2max}$, push-ups, sit-ups, and sit-and-reach and positively correlated with LBM (all $p < 0.01$). Weekly MET minutes were positively correlated to $abVO_{2max}$, leg strength, and sit-and-reach (all $p < 0.05$). Most MSIs were reported in firefighters aged between 30 and 49 ($p = 0.008$), which was predominantly upper limb injuries ($p = 0.010$).

Table 2 describes the MSH of firefighters according to demographic characteristics and physical activity classification in firefighters. Firefighters who were heavier ($p = 0.006$), older ($p = 0.002$), longer in service ($p < 0.001$), and with a higher BMI ($p = 0.004$) were more likely to report MSIs. Female firefighters were more likely to be injured ($p = 0.038$) than firefighters who were moderately active ($p = 0.016$).

Table 3 presents the physical activity levels of firefighters according to age, years of experience, BMI, and weekly MET minutes and the physical activity level according to MSIs and MSD. Age ($p = 0.049$) and weekly MET minutes ($p < 0.001$) were significantly different between activity levels in firefighters. Firefighters who reported MSIs participated in less vigorous-intensity physical activity than those who never reported an injury (p = 0.004). Firefighters who reported more upper-body injures participated in less low-intensity physical activity ($p = 0.044$). Firefighters who experienced increased lower back discomfort participated in more low-intensity weekly physical activity ($p = 0.002$).

Table 4 describes the MSI information according to physical fitness in firefighters. $RelVO_{2max}$ ($p = 0.002$), push-up ($p = 0.008$) and sit-up ($p = 0.005$) capacity, and sit-and-reach ($p = 0.015$) were significantly different between firefighters who experienced an MSI. Grip strength was significantly different according to the location of injury ($p = 0.044$). $RelVO_{2max}$ ($p = 0.002$), push-ups ($p = 0.009$), and sit-ups ($p = 0.011$) were significantly lower in firefighters who reported sustaining a shoulder injury. Grip strength ($p = 0.021$), sit-ups ($p = 0.022$), and sit-and-reach ($p = 0.049$) were significantly lower in firefighters who sustained ankle and foot injuries.

Table 5 shows MSD and physical fitness parameters at various sites in firefighters. Higher levels of cardiorespiratory fitness, muscular endurance, and strength were related to firefighters reporting MSD. $AbVO_{2max}$ was significantly different between those experiencing MSD and those without MSD ($p = 0.038$). A higher push-up capacity was related to neck discomfort ($p = 0.019$), shoulder discomfort ($p = 0.047$), upper back discomfort ($p = 0.036$), elbow and forearm discomfort ($p = 0.015$), wrist and hand discomfort ($p < 0.001$), hip discomfort ($p = 0.043$), thigh discomfort ($p = 0.003$), and ankle and foot discomfort ($p = 0.039$). Higher sit-up capacity was related to neck discomfort ($p = 0.045$), elbow and forearm discomfort ($p = 0.022$), wrist and hand discomfort ($p = 0.027$), and thigh discomfort ($p = 0.006$). Higher sit-and-reach score was related to lower neck discomfort ($p = 0.029$), elbow discomfort ($p = 0.044$), and thigh discomfort ($p = 0.028$).

Table 6 presents the association between physical fitness and MSIs in firefighters. Univariate analysis indicated that a higher $abVO_{2max}$ ($p = 0.005$), push-up ($p = 0.017$) and sit-up capacity ($p = 0.006$), and sit-and-reach ($p = 0.034$) were negatively associated with firefighters reporting MSIs. $RelVO_{2max}$ ($p = 0.007$) and sit-up capacity ($p = 0.032$) were negatively associated with firefighters reporting upper body MSIs. An increase in grip strength ($p = 0.048$) and sit-and-reach ($p = 0.041$) was negatively associated with firefighters reporting lower body MSIs. None of the variables was associated with MSIs after adjustment for covariates. An increase in $relVO_{2max}$ ($p = 0.003$), push-ups ($p = 0.011$), and sit-ups ($p = 0.013$) was negatively associated with firefighters reporting a shoulder injury. Push-ups were significantly and negatively associated with lower back injuries ($p = 0.039$). An increase in grip strength ($p = 0.022$), sit-ups ($p = 0.024$), and sit-and-reach ($p = 0.048$) was negatively associated with firefighters reporting ankle and foot injuries. After adjustment for covariates, none of the exploratory variables remained significant.

Table 7 presents the association between physical fitness and MSD in firefighters. A higher push-up capacity was positively associated with neck discomfort ($p = 0.038$), elbow and forearm discomfort ($p = 0.031$), wrist and hand discomfort ($p = 0.002$), and thigh discomfort ($p = 0.007$). A higher sit-up capacity was positively associated with upper back discomfort ($p = 0.045$) and thigh discomfort ($p = 0.013$). In model 2,

http://etd.uwc.ac.za/

TABLE 2 Musculoskeletal injuries and musculoskeletal discomfort according to demographic characteristics in firefighters.

	Injured		Never injured		p †	Musculoskeletal discomfort		Without musculoskeletal discomfort		p †
	N	X̃(p25th-p75th)	N	X̃(p25th-p75th)		N	X̃(p25th-p75th)	N	X̃(p25th-p75th)	
Height (cm)	130	172.9 (167.5, 178.0)	178	173.5 (169.0, 177.9)	0.512	130	173.0 (168.4, 178.0)	179	173.3 (168.0, 177.9)	0.942
Weight (kg)	130	82.4 (74.0, 95.9)	178	80.8 (72.1, 87.5)	0.006**	130	80.7 (71.9, 91.6)	179	82.0 (73.0, 90.1)	0.707
Age (years)	130	42.0 (32.0, 49.0)	180	36.0 (29.0, 46.0)	0.002**	130	39.0 (32.0, 46.5)	179	37.0 (29.0, 48.0)	0.478
Years of experience (years)	130	17.0 (7.0, 25.0)	178	11.0 (4.0, 19.0)	<0.001**	130	15.0 (6.8, 22.3)	179	13.0 (5.0, 22.0)	0.219
Body mass index (kg•m-2)	130	27.6 (25.1, 31.7)	178	26.8 (23.0, 29.6)	0.004**	130	27.0 (24.5, 31.1)	179	27.2 (23.9, 30.2)	0.469
Total weekly MET minutes	130	2000.5 (1176.8, 3600.0)	178	2348.5 (1073.3, 4819.5)	0.408	130	2009.5 (1167.0, 3743.0)	179	2400.0 (1160.0, 44.97.0)	0.474
	N	%	N	%	p §	N	%	N	%	p §
Sex										
Male	110	40.0	164	59.9	0.038*	112	40.7	163	59.3	0.174
Female	20	58.8	14	41.2		18	52.9	16	47.1	
Physical activity classification										
Vigorously active	15	29.4	36	70.6	0.016*	17	33.3	34	66.7	0.067
Moderately active	72	50.3	71	49.7		70	49.0	73	51	
Low active	43	37.7	71	62.3		43	37.4	72	62.6	

Note: * indicates statistical significance <0.05; ** indicates statistical significance <0.01.
cm—centimeter; kg—kilogram; kg•m-2—kilogram per meter squared; X~—median; p25th-p75th—25th percentile to 75th percentile; %—percent; †—Mann-Whitney U test, and §—indicates Chi-squared.

UNIVERSITY of the WESTERN CAPE

10.3389/fphys.2023.1210107

http://etd.uwc.ac.za/

TABLE 3 Physical activity levels of firefighters according to age, years of experience, body mass index, weekly MET minutes, musculoskeletal discomfort, and musculoskeletal injury in firefighters.

		Insufficiently active (*N* = 51)		Minimally active (*N* = 143)		Highly active (*N* = 115)		*p*-value
		X̃(p25th–p75th)		X̃(p25th–p75th)		X̃(p25th–p75th)		
Age		39.0 (32.0, 47.0)		40 (32.0 48.0)		35.0 (28.0, 45.0)		0.049*
Years of experience		15.0 (6.0, 22.0)		15.0 (6.0, 25.0)		10.0 (4.0, 19.0)		0.063
Body mass index		27.0 (23.2, 30.9)		27.3 (24.2, 30.9)		26.8 (24.4, 29.8)		0.819
Weekly MET minutes		99.0 (0.0, 419.0)		1812.0 (1257.0, 2280.0)		5088.0 (3798.0, 7560.0)		<0.001
		TWMETM		TLIPAM		TMIPAM		TVIPAM
	N	X̃(p25th–p75th)	N	X̃(p25th–p75th)	N	X̃(p25th–p75th)	N	X̃(p25th–p75th)
Injured	130	2080.0 (1202.5, 3699.0)	68	120.0 (60.0, 345.0)	116	360.0 (240.0, 660.0)	21	240.0 (180.0, 720.0)
Uninjured	178	2580.0 (1578.0, 5310.0)	80	145.0 (62.5, 360.0)	139	480.0 (215.0, 660.0)	54	360.0 (180.0, 720.0)
p-value		0.589		0.372		0.281		0.004**
Upper body injury	62	2090.0 (1173.8, 3575.3)	39	120 (60.0, 390.0)	55	420.0 (240.0, 660.0)	10	450.0 (180.0, 975)
Uninjured	247	2268.0 (1160.0, 4464.0)	109	150.0 (60.0, 360.0)	201	420.0 (207.5, 660.0)	66	310.0 (180.0, 720.0)
p-value		0.976		0.044*		0.466		0.105
Lower body injury	74	1986.5 (1199.5, 3880.0)	32	135.0 (60.0, 262.50	68	360.0 (205.0, 645.0)	15	240.0 (180.0, 720)
Uninjured	235	2280.0 (1149.0, 4200.0)	116	123.0 (60.0, 360.0)	188	480.0 (240.0, 660.0)	61	360.0 (180.0, 720.0)
p-value		0.796		0.377		0.492		0.283
Shoulder injury	17	1584.0 (1074.0, 2549.0)	9	60.0 (30.0, 280.0)	15	330.0 (240.0, 490.0)	2	570.0 (180.0)
Uninjured	292	2279.0 (1174.0, 4293.0)	139	130.0 (60.0, 360.0)	241	420.0 (230.0, 660.0)	74	340.0 (180.0, 720.0)
p-value		0.134		0.902		0.725		0.235
Lower back injury	24	1816.0 (1002.0, 3775.1)	16	120.0 (60.0, 390.0)	22	295.0 (112.5, 573.8)	5	360.0 (130.0, 870.0)
Uninjured	285	2268.0 (1183.0, 4100.0)	132	135.0 (60.0, 360.0)	234	450.0 (240.0, 660.0)	71	320.0 (180.0, 720.0)
p-value		0.591		0.061		0.740		0.691
Ankle and foot injury	39	2080.0 (1080.0, 3474.0)	20	95.0 (60.0, 330.0)	36	375.0 (120.0, 625.0)	7	200.0 (90.0, 300.0)
Uninjured	270	2272.5 (1167.5, 4239.0)	128	128.0 (60.0, 360.0)	220	335.0 (240.0, 660.0)	69	360.0 (180.0, 720.0)
p-value		0.609		0.749		0.678		0.230
Overall discomfort	130	2080.0 (2607)	65	130.0 (60.0, 360.0)	117	380.0 (210.0, 630.0)	25	360 (180.0, 720.0)
No discomfort	179	2655.0 (1440.0, 4986)	83	120.0 (60.0, 360.0)	139	480.0 (240.0, 700.0)	51	320.0 (180.0,720.0)
p-value		0.474		0.512		0.463		0.060
Neck discomfort	33	1812.0 (1094.3, 3932.3)	16	85.0 (48.8, 555.0)	29	420.0 (240.0, 720.0)	7	240.0 (80.0, 720.0)
No discomfort	276	2277.5 (1181.3, 3993.3)	132	140.0 (60.0, 360.0)	227	420.0 (220.0, 660.0)	69	360.0 (180.0, 720.0)
p-value		0.474		0.894		0.639		0.601
Shoulder discomfort	17	1584.0 (1074.3, 2549.0)	9	60.0 (30.0, 280.0)	37	300.0 (160.0, 660.0)	10	450.0 (180.0, 720.0)
No discomfort	292	2279.0 (1174.5, 4293.0)	139	130 (60.0, 360)	219	450.0 (240.0, 660.0)	66	340.0 (180.0, 720.0)
p-value		0.511		0.954		0.839		0.968
Upper back discomfort	7	1320.0 (1040.0, 3306.0)	10	300.0 (27.5, 978.8)	22	365.0 (135.0, 675.0)	4	720.0 (517.5, 720.0)
No discomfort	302	2263.5 (2276.8, 4050.0)	138	123.0 (60.0, 360.0)	234	430.0 (240.0, 660.0)	72	285.0 (180.0, 720.0)

(Continued on following page)

http://etd.uwc.ac.za/

TABLE 3 (*Continued*) Physical activity levels of firefighters according to age, years of experience, body mass index, weekly MET minutes, musculoskeletal discomfort, and musculoskeletal injury in firefighters.

		Insufficiently active (*N* = 51)		Minimally active (*N* = 143)		Highly active (*N* = 115)	*p*-value	
		X̃(p25th–p75th)		X̃(p25th–p75th)		X̃(p25th–p75th)		
p-value		0.885		0.669		0.714		0.494
Elbow discomfort	23	2946.0 (1062.0, 4800.0)	12	150.0 (42.5, 633.8)	21	600.0 (242.4, 735.0)	4	720.0 (247.5, 720.0)
No discomfort	286	2216.0 (1176.8, 3979.8)	136	123.0 (60.0, 360.0)	235	420.0 (215.0, 640.0)	72	310.0 (180.0, 720.0)
p-value		0.626		0.627		0.149		0.482
Wrist and hand discomfort	31	2640.0 (1205.0, 6288.0)	15	120.0 (60.0, 780.0)	26	445.0 (240.0, 727.5)	7	420.0 (200.0, 720.0)
No discomfort	278	2177.0 (1159.5, 3896.3)	133	126 (60.0, 360.0)	230	420.0 (218.8, 640.0)	69	300.0 (180.0, 720.0)
p-value		0.172		0.912		0.522		0.574
Lower back discomfort	71	2019.0 (1149.0, 3840.0)	45	140.0 (60.0, 420.0)	62	372.0 (118.8, 720.0)	14	240.0 (90.0, 450.0)
No discomfort	238	2280.0 (1176.8, 4050.0)	103	120.0 (60.0, 360.0)	194	470.0 (240.0, 645.0)	62	360.0 (180.0, 720.0)
p-value		0.745		0.002**		0.855		0.203
Hip discomfort	4	2980.5 (598.5, 3891.8)	9	200.0 (45.0, 1012.5)	17	260.0 (117.5, 675.0)	4	720.0 (247.5, 720.0)
No discomfort	305	2238.0 (1165.0, 4086.5)	139	120.0 (60.0, 360.0)	239	440.0 (240.0, 660.0)	72	310.0 (180.0, 720.0)
p-value		0.765		0.845		0.749		0.812
Thigh discomfort	18	2273.0 (815.0, 5280.0)	8	400.0 (52.5, 1136.3)	15	292.5 (140.0, 720.0)	5	420.0 (120.0, 720.0)
No discomfort	291	2240.0 (1188.0, 3960.0)	140	120.0 (60.0, 360.0)	241	440.0 (240.0, 660.0)	71	320.0 (180.0, 720.0)
p-value		0.898		0.877		0.625		0.753
Ankle and foot discomfort	29	2640.0 (2160.0, 6264.0)	12	120.0 (60.0, 603.75)	25	360.0 (240.0, 1080.0)	7	720.0 (180.0, 720.0)
No discomfort	280	2216.0 (1162.5, 3877.3)	136	128.0 (60.0, 360.0)	231	420.0 (215.0, 640.0)	69	320.0 (180.0, 720.0)
p-value		0.283		0.512		0.416		0.690

Note: * indicates statistical significance <0.05; ** indicates statistical significance <0.01.
X~—median; p25th–p75th—25th percentile to 75th percentile; %—percentage; TWMETM—total weekly metabolic equivalent minutes; TLIPAM—total low-intensity physical activity minutes; TMIPAM—total moderate-intensity physical activity minutes; TVIPAM—total vigorous-intensity physical activity minutes; †—indicates Mann–Whitney U test.

UNIVERSITY of the WESTERN CAPE

after adjustments for age, sex, BMI, and weekly MET minutes,a one-unit increase in push-up capacity increased the odds of neck discomfort, elbow discomfort, wrist and hand discomfort, and thigh discomfort by 5%, 5%, 6%, and 6%, respectively, and that in sit-up capacity increased the odds of MSD by 9%. In model 3, after adjustments for years of experience, sex, BMI, and weekly MET minutes, a one-unit increase in push-up capacity increased the odds of neck discomfort, elbow discomfort, ankle discomfort, and foot discomfort by 4%, 5%, 6%, and 7%, respectively. A one-unit increase in sit-up capacity increased the odds of reporting thigh discomfort by 8%.

4 Discussion

In this study, we found that firefighters with a higher level of physical fitness reported fewer musculoskeletal injuries. However, higher levels of physical fitness were also associated with increased odds of MSD. Several studies have found that a higher level of physical fitness may reduce the likelihood of MSIs, which is similar to the results of the present study, likely due to the increase in bone mineral density, connective tissue health, muscle mass, and improved balance and coordination (Hong et al., 2012; Poplin et al., 2013; Poplin et al., 2016). The improvements in bone and soft tissue health, as a result of physical activity and increased physical fitness, may increase the volume of physical workload needed to cause a progressive decrease in MSH, which would lead to sudden MSIs on duty. In the current study, fitter firefighters may have reported higher levels of MSD due to overload in workload and insufficient/inadequate recovery or rest following the workload. This hypothesis is supported by the results showing physical activity levels were higher in firefighters who reported MSD, particularly those who were vigorously active. It is also possible that some firefighters experienced MSD due to a high level of physical activity in their leisure time, especially when off- duty, and high levels of occupational activity when on-duty. This persistent overload may predispose firefighters to pain and

http://etd.uwc.ac.za/

TABLE 4 Physical fitness parameters based on musculoskeletal injuries in firefighters.

	abVO_2max (L•min)		relVO_2max (L•min)		Grip strength (kg)		Leg strength (kg)		Push-ups (rpm)		Sit-ups (rpm)		Sit-and-reach (cm)		Lean body mass (kg)	
	N	X ± SD	N	X ± SD	N	X ± SD	N	X̄ ± SD	N	X ± SD	N	X̄ ± SD	N	X ± SD	N	X ± SD
Injured	129	3.4 ± 0.3	129	41.1 ± 5.8	126	87.8 ± 17.7	126	113.9 ± 17.7	126	28.9 ± 14.7	126	26.4 ± 10.6	126	41.5 ± 9.7	128	60.6 ± 10.5
Uninjured	179	3.4 ± 0.3	179	43.1 ± 6.2	177	91.1 ± 17.3	177	117.8 ± 27.2	177	32.1 ± 13.3	177	29.8 ± 9.9	177	43.8 ± 8.7	180	60.2 ± 9.4
p-value		0.142		0.002**		0.108		0.367		0.008**		0.005**		0.015*		0.525
Upper body injury	62	3.4±.03	62	40.4 ± 5.1	62	91.5 ± 17.3	61	116.2 ± 28.5	60	28.0 ± 15.2	60	25.8 ± 11.4	61	42.2 ± 10.0	62	61.8 ± 10.2
Uninjured	247	3.4±0.3	247	42.8 ± 6.3	243	89.3 ± 17.3	242	116.2 ± 28.5	243	31.6 ± 13.3	243	29.1 ± 10.0	243	43.1 ± 8.9	246	59.9 ± 9.5
p-value		0.904		0.007**		0.373		0.938		0.075		0.031*		0.433		0.180
Lower body injury	74	3.4 ± 0.3	74	41.5 ± 5.9	73	86.2 ± 17.4	73	113.9 ± 32.9	73	29.7 ± 13.2	73	27.0 ± 10.1	73	40.9 ± 9.9	74	59.7 ± 9.7
Uninjured	235	3.4 ± 0.3	235	42.6 ± 6.2	231	90.8 ± 17.4	230	117.1 ± 27.4	230	31.3 ± 13.9	230	28.9 ± 10.4	231	43.4 ± 8.8	234	60.6 ± 9.7
p-value		0.161		0.173		0.046*		0.387		0.190		0.190		0.039*		0.494
Shoulder injury	17	3.4 ± 0.3	17	37.9 ± 4.6	16	96.9 ± 25.6	16	120.9 ± 24.9	16	22.2 ± 10.9	16	22.0 ± 10.2	16	40.3 ± 12.6	17	64.6 ± 11.5
Uninjured	292	3.5 ± 0.3	292	42.6 ± 6.1	288	89.3 ± 16.9	287	116.1 ± 29.0	287	31.4 ± 13.8	287	28.8 ± 10.3	288	42.9 ± 8.9	291	60.1 ± 9.5
p-value		0.259		0.002**		0.088		0.514		0.009**		0.011*		0.417		0.060
Lower back injury	24	3.4 ± 0.3	24	41.1 ± 5.8	24	90.3 ± 13.4	24	114.5 ± 29.6	24	25.2 ± 15.4	24	25.8 ± 11.5	24	40.7 ± 11.1	24	61.9 ± 11.5
Uninjured	285	3.4 ± 0.3	285	42.4 ± 6.2	280	89.7 ± 17.8	279	116.5 ± 28.8	279	31.4 ± 13.5	279	28.6 ± 10.2	280	43.0 ± 8.9	284	60.2 ± 9.5
p-value		0.641		0.317		0.871		0.750		0.036*		0.197		0.226		0.407
Ankle and foot injury	39	3.4 ± 0.3	39	40.7 ± 6.2	39	83.7 ± 14.9	39	111.9 ± 32.2	39	27.1 ± 14.4	39	24.9 ± 10.8	39	40.2 ± 10.7	39	59.3 ± 10.6
Uninjured	270	3.4 ± 0.3	270	42.6 ± 6.1	265	90.6 ± 17.7	264	116.9 ± 28.3	264	31.4 ± 13.6	264	28.9 ± 10.2	265	43.2 ± 8.9	269	60.5 ± 9.6
p-value		0.527		0.071		0.021*		0.310		0.066		0.022*		0.049*		0.451

Note: * indicates statistical significance <0.05; ** indicates statistical significance <0.01; X̄—mean; SD—standard deviation; L●min—liters per minute; mL●kg●min—milliliters per minute; kg—kilogram; rpm—repetitions per minute.

UNIVERSITY of the WESTERN CAPE

inflammation, possibly leading to MSD, and possibly, MSIs in firefighters (Vaulerin et al., 2016; Ras and Leach, 2022).

We found that an increase in relVO_2max, push-ups, sit-ups, and sit-and-reach decreased the odds of firefighters reporting MSIs. Nowak et al. (2018) reported that firefighters who previously experienced an MSI had a lower push-up and sit-up capacity and lower cardiorespiratory capacity than those without an MSI. In addition, measures of explosive power were also higher in firefighters without injuries than in those who had previous injuries (Nowak et al., 2018). Similarly, Poplin et al. (2013) reported that higher cardiorespiratory capacity was associated with lower incidence of injuries in firefighters. Another study by Poplin et al. (2016) reported that lower levels of physical fitness increased the odds of firefighters sustaining an injury over a 5-year period. Two systematic reviews conducted by de la Motte et al. (2017); Lisman et al. (2017) support the results of the current study, reporting that higher cardiorespiratory fitness and muscular endurance were associated with lower incidences of MSIs. Injury-related absenteeism and the medical expenses associated with it are costly to fire departments, with most of these injuries being related to sprains and strains (Poston et al., 2011; Frost et al., 2016). Physical activity is essential in the strengthening and thickening of connective tissues, an increase in bone mineral density, and improvements in muscle endurance and strength (de la Motte et al., 2017; Lisman et al., 2017), which is likely in firefighters with higher physical fitness levels, reducing the overall reported MSIs seen in the current study.

http://etd.uwc.ac.za/

TABLE 5 Physical fitness parameters based on the report of musculoskeletal discomfort at various sites.

Musculoskeletal discomfort	abVO2max (L•min)		relVO2max (L•min)		Grip strength (kg)		Leg strength (kg)		Push-ups (rpm)		Sit-ups (rpm)		Sit-and-reach (cm)		Lean body mass (kg)	
	N	X ± SD	N	X ± SD	N	X ± SD	N	X ± SD	N	X ± SD	N	± SD	N	X ± SD	N	X ± SD
Overall discomfort	130	3.4 ± 0.2	130	42.3 ± 6.1	127	88.4 ± 18.3	127	114.4 ± 29.5	127	31.7 ± 13.9	126	28.5 ± 11.0	127	42.4 ± 9.2	130	60.2 ± 9.7
No discomfort	179	3.3 ± 0.2	179	42.3 ± 6.2	177	90.7 ± 16.9	176	117.7 ± 28.4	177	30.3 ± 13.6	177	28.3 ± 9.9	177	43.1 ± 9.1	178	60.5 ± 9.7
p-value		0.038*		0.498		0.132		0.163		0.370		0.433		0.249		0.394
Neck discomfort	33	3.4 ± 0.3	33	42.2 ± 5.5	32	90.1 ± 14.0	32	116.9 ± 27.5	32	35.7 ± 12.8	32	29.2 ± 10.6	32	39.9 ± 8.2	33	60.7 ± 7.8
No discomfort	276	3.4 ± 0.3	276	42.3 ± 6.2	276	89.7 ± 17.9	276	116.2 ± 29.0	271	30.3 ± 13.8	271	28.3 ± 10.3	272	43.2 ± 9.2	275	60.3 ± 9.9
p-value		0.356		0.446		0.441		0.450		0.019*		0.334		0.029*		0.409
Shoulder discomfort	42	3.4 ± 0.3	42	42.7 ± 5.4	40	94.3 ± 18.0	40	120.3 ± 26.4	40	34.3 ± 12.8	40	31.0 ± 11.8	40	42.1 ± 9.4	42	62.6 ± 7.9
No discomfort	267	3.4 ± 0.3	267	42.4 ± 6.3	264	89.0 ± 17.3	263	115.7 ± 29.2	267	30.4 ± 13.9	263	28.0 ± 10.1	264	42.9 ± 9.1	266	60.0 ± 9.9
p-value		0.394		0.247		0.037*		0.176		0.047*		0.045*		0.286		0.054
Upper back discomfort	24	3.5 ± 0.3	24	44.5 ± 5.9	24	88.1 ± 15.1	24	109.9 ± 25.5	24	35.7 ± 12.2	24	32.5 ± 8.8	24	42.1 ± 9.4	24	59.1 ± 8.8
No discomfort	285	3.4 ± 0.3	285	42.1 ± 6.1	280	89.9 ± 17.7	279	115.9 ± 29.1	279	30.4 ± 13.8	279	28.1 ± 10.4	280	42.9 ± 9.1	284	60.5 ± 9.8
p-value		0.159		0.034*		0.314		0.127		0.036*		0.022*		0.333		0.253
Elbow discomfort	23	3.4 ± 0.3	23	42.2 ± 6.1	22	90.9 ± 14.1	22	117.1 ± 27.5	22	37.0 ± 11.9	22	31.8 ± 11.7	22	39.6 ± 7.7	23	61.5 ± 7.0
No discomfort	286	3.4 ± 0.3	286	42.3 ± 6.2	282	89.6 ± 17.7	281	116.3 ± 28.9	281	30.4 ± 13.8	281	28.2 ± 10.2	282	43.1 ± 9.2	285	60.3 ± 9.9
p-value		0.403		0.447		0.371		0.448		0.015*		0.055		0.044*		0.273
Wrist and hand discomfort	31	3.4 ± 0.3	31	41.9 ± 6.5	30	92.0 ± 13.1	30	120.9 ± 23.3	29	38.4 ± 14.5	30	31.9 ± 12.7	30	41.2 ± 9.8	31	60.4 ± 7.1
No discomfort	278	3.4 ± 0.3	278	42.4 ± 6.1	274	89.4 ± 17.9	273	115.8 ± 29.3	274	30.1 ± 13.5	273	28.0 ± 10.0	274	43.0 ± 9.1	277	60.3 ± 9.9
p-value		0.453		0.328		0.140		0.180		<0.001**		0.027*		0.146		0.478
Lower back discomfort	71	3.5 ± 0.3	71	41.6 ± 5.4	69	86.9 ± 14.8	69	111.6 ± 30.5	69	29.9 ± 14.4	68	27.4 ± 11.2	69	41.5 ± 9.3	71	60.3 ± 9.7
No discomfort	238	3.4 ± 0.3	238	42.5 ± 6.3	235	90.5 ± 18.2	235	117.7 ± 28.2	234	31.1 ± 13.6	235	28.7 ± 10.1	235	43.2 ± 9.1	237	60.4 ± 9.7
p-value		0.030*		0.134		0.067		0.061		0.262		0.187		0.084		0.462
Hip discomfort	19	3.4 ± 0.2	19	43.2 ± 6.3	19	90.8 ± 11.9	19	117.1 ± 25.4	19	36.1 ± 11.9	19	31.9 ± 9.4	19	40.8 ± 10.9	19	61.2 ± 9.5
No discomfort	290	3.4 ± 0.3	290	42.3 ± 6.1	285	89.6 ± 17.8	284	116.3 ± 29.1	284	30.5 ± 13.8	284	28.2 ± 10.4	285	42.99.0	289	60.3 ± 9.7
p-value		0.350		0.269		0.391		0.449		0.043*		0.062		0.163		0.347
Thigh discomfort	18	3.5 ± 0.2	18	42.2 ± 5.5	18	94.3 ± 10.6	18	125.1 ± 25.3	18	39.5 ± 12.4	18	34.3 ± 12.1	18	38.8 ± 9.3	18	63.4 ± 7.7

(Continued on following page)

UNIVERSITY of the WESTERN CAPE

TABLE 5 (*Continued*) Physical fitness parameters based on the report of musculoskeletal discomfort at various sites.

Musculoskeletal discomfort	abVO₂max (L•min)		relVO₂max (L•min)		Grip strength (kg)		Leg strength (kg)		Push-ups (rpm)		Sit-ups (rpm)		Sit-and-reach (cm)		Lean body mass (kg)	
	N	X±SD	N	X±SD	N	X̄ ± SD	N	X̄ ± SD	N	X̄ ± SD	N	± SD	N	X̄ ± SD	N	X̄ ± SD
No discomfort	291	3.4 ± 0.3	291	42.3 ± 6.2	286	89.4 ± 17.8	286	115.8 ± 28.9	285	30.3 ± 13.7	285	28.0 ± 10.1	286	43.1 ± 9.1	290	60.2 ± 9.8
p-value		[illegible]		[illegible]		[illegible]		0.092		[illegible]		[illegible]		[illegible]		[illegible]
Ankle and foot discomfort	29	3.5 ± 0.3	29	41.7 ± 6.2	29	89.7 ± 14.1	29	118.1 ± 28.1	29	35.2 ± 13.3	28	30.3 ± 11.0	29	40.9 ± 9.9	29	60.3 ± 9.2
No discomfort	280	3.4 ± 0.3	280	42.4 ± 6.1	275	89.7 ± 17.8	274	116.1 ± 28.9	274	30.4 ± 13.7	275	28.2 ± 10.3	275	43.0 ± 9.1	279	60.4 ± 9.7
p-value		[illegible]		[illegible]		0.496		0.360		[illegible]		0.158		0.115		[illegible]

Note: * indicates statistical significance <0.05; ** indicates statistical significance <0.01; X̄—mean; SD—standard deviation; L●min—liters per minute; mL●kg●min—milliliters per minute; kg—kilogram; rpm—repetitions per minute.

Moreover, studies have suggested that a substantial source of MSIs in firefighters is related to overexertion while engaged in fire suppression and other emergency situations (Frost et al., 2015a; Nowak et al., 2018; Le et al., 2020). Higher levels of physical fitness, particularly muscular strength and endurance, may increase the level of physical exertion needed to induce muscular and cardiorespiratory fatigue that leads to overexertion, thereby providing a protective effect on the musculoskeletal and cardiovascular systems (Henderson et al., 2007; Yu et al., 2015; Nowak et al., 2018; Le et al., 2020). Firefighters who have a higher level of physical fitness perform their duties with more efficiency and rigor. Thus, physical fitness and physicality are integral for firefighters' occupational performance (Williford et al., 1999; Rhea et al., 2004; Chizewski et al., 2021) and injury prevention (Poplin et al., 2012; Poplin et al., 2013; Vaulerin et al., 2016; Nowak et al., 2018). To ensure the highest occupational efficiency, firefighters should maintain all measures of physical fitness through regular physical activity (Durand et al., 2011; Yu et al., 2015; Nowak et al., 2018). In addition, it is well-documented that cardiorespiratory fitness, muscular strength, and endurance decline as firefighters age, due, in part, to a lack of leisure time physical activity and the natural decline in MSH as a product of the aging process (Baur et al., 2012; Punakallio et al., 2012; Walker et al., 2014; Perroni et al., 2015; Frontera, 2017). This predisposes the firefighters to MSIs, especially, if they lack the necessary levels of physical fitness needed for firefighting. Adequate levels of cardiorespiratory fitness, muscle strength, endurance, and muscular function are important for injury prevention and job performance in firefighters (Smith, 2011; Poplin et al., 2013; Nowak et al., 2018). Furthermore, physical activity has been shown to promote the release of myokines from muscle tissue (Hamrick, 2011; Lee and Jun, 2019). Myokines play an important role in stress response and coordinating both positive and negative musculoskeletal changes to exercise and/or work (Hamrick, 2011; Lee and Jun, 2019). This may, further, support that more physically active and, subsequently, more physically fit firefighters are less likely to sustain MSIs.

The present study showed that higher relVO$_{2max}$ and sit-up capacity were associated with lower odds of firefighters reporting upper limb injuries. In addition, an increase in relVO$_{2max}$, push-up and sit-up capacity was associated with lower odds of firefighters reporting shoulder injuries and an increase in push-up capacity reduced the odds of firefighting reporting lower back injuries. Previous studies noted that people involved in occupations that require repetitive upper body motions are particularly susceptible to an increase in upper limb injuries (Ranney et al., 1995; Latko et al., 1999). An increase in physical fitness, particularly upper body muscular endurance capacity, may increase the workload needed to lead to overexertion-related shoulder injuries (de la Motte et al., 2017), especially as many firefighting-related duties encompass repetitive upper body movements (Frost et al., 2015a; Nowak et al., 2018). Cady et al. (1979) reported that higher physical fitness, which encompassed a prediction model that included cardiorespiratory endurance, flexibility, muscular strength, and diastolic blood pressure, was associated with lower back injuries in firefighters. Previous studies noted that exercise increases muscular strength and endurance, which could, potentially, reduce the likelihood of lower back injuries in

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

TABLE 6 Association between physical fitness and musculoskeletal injuries in firefighters.

	Univariate models		Multivariate models			
	Model 1		Model 2[a]		Model 3[b]	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Dependent variable: musculoskeletal injuries						
abVO$_{2max}$ (L•min)	1.85 (0.81, 4.19)	0.143	—	—	—	—
relVO$_{2max}$ (mL•kg•min)	0.95 (0.91, 0.98)	0.005**	1.01 (0.93, 1.09)	0.909	1.02 (0.94, 1.11)	0.644
Grip strength (kg)	0.99 (0.98, 1.00)	0.109	—	—	—	—
Leg strength (kg)	0.99 (0.99, 1.00)	0.356	—	—	—	—
Push-ups (rpm)	0.98 (0.96, 0.99)	0.017*	0.99 (0.97, 1.01)	0.994	1.00 (0.98, 1.02)	0.869
Sit-ups (rpm)	0.97 (0.95, 0.99)	0.006**	0.99 (0.96, 1.01)	0.365	0.99 (0.96, 1.02)	0.505
Sit-and-reach (cm)	0.97 (0.95, 0.99)	0.034*	0.98 (0.95, 1.01)	0.153	0.98 (0.95, 1.01)	0.182
Lean body mass (kg)	1.01 (0.98, 1.03)	0.524	—	—	—	—
Dependent variable: upper body injuries						
abVO$_{2max}$ (L•min)	1.06 (0.393, 2.88)	0.903	—	—	—	—
relVO$_{2max}$ (mL•kg•min)	0.94 (0.89, 0.98)	0.007**	0.96 (0.87, 1.06)	0.407	0.95 (0.86, 1.05)	0.289
Grip strength (kg)	1.01 (0.99, 1.02)	0.372	—	—	—	—
Leg strength (kg)	1.00 (0.99, 1.01)	0.938	—	—	—	—
Push-ups (rpm)	0.98 (0.96, 1.00)	0.076	—	—	—	—
Sit-ups (rpm)	0.97 (0.94, 0.99)	0.032*	0.99 (0.96, 1.02)	0.442	0.99 (0.95, 1.02)	0.342
Sit-and-reach (cm)	0.99 (0.96, 1.02)	0.432	—	—	—	—
Lean body mass (kg)	1.02 (0.99, 1.05)	0.181	—	—	—	—
Dependent variable: lower body injuries			—	—	—	—
abVO$_{2max}$ (L•min)	1.97 (0.763, 5.09)	0.161	—	—	—	—
relVO$_{2}$max (mL•kg•min)	0.97 (0.93,1.01)	0.173	—	—	—	—
Grip strength (kg)	0.99 (0.97, 1.00)	0.048*	1.01 (0.99, 1.03)	0.203	0.99 (0.97, 1.01)	0.405
Leg strength (kg)	0.99 (0.99, 1.01)	0.415	—	—	—	—
Push-ups (rpm)	0.99 (0.97, 1.01)	0.386	—	—	—	—
Sit-ups (rpm)	0.98 (0.96, 1.01)	0.190	—	—	—	—
Sit-and-reach (cm)	0.97 (0.94, 0.99)	0.041*	0.97 (0.94, 1.00)	0.092	0.98 (0.95, 1.01)	0.124
Lean body mass (kg)	0.99 (0.96, 1.02)	0.493	—	—	—	—
Dependent variable: shoulder injuries						
abVO$_{2max}$ (L•min)	2.82 (0.48, 16.72)	0.253				
relVO$_{2max}$ (mL•kg•min)	0.87 (0.79, 0.95)	0.003**	0.86 (0.71, 1.03) §	0.105	0.83 (0.69, 1.01)	0.060
Grip strength (kg)	1.03 (0.99, 1.06)	0.090	—	—	—	—
Leg strength (kg)	1.01 (0.99, 1.02)	0.521	—	—	—	—
Push-ups (rpm)	0.95 (0.91, 0.99)	0.011*	0.97 (0.92, 1.01)	0.158	0.96 (0.92, 1.01)	0.105
Sit-ups (rpm)	0.94 (0.89, 0.99)	0.013*	0.97 (0.91, 1.03)	0.264	0.96 (0.91, 1.02)	0.167
Sit-and-reach (cm)	0.97 (0.92, 1.02)	0.251	—	—	—	—
Lean body mass (kg)	1.05 (0.99, 1.11)	0.063	—	—	—	—

(Continued on following page)

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

TABLE 6 (*Continued*) Association between physical fitness and musculoskeletal injuries in firefighters.

	Univariate models		Multivariate models			
	Model 1		Model 2[a]		Model 3[b]	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Dependent variable: lower back injuries						
abVO$_{2max}$ (L•min)	1.45 (0.32, 6.47)	0.629				
relVO$_{2max}$ (mL•kg•min)	0.97 (0.90, 1.04)	0.321				
Grip strength (kg)	1.00 (0.98, 1.03)	0.878				
Leg strength (kg)	0.99 (0.98, 1.01)	0.738				
Push-ups (rpm)	0.97 (0.94, 0.99)	0.039*	0.97 (0.94, 1.01)	0.157	0.98 (0.95, 1.02)	0.277
Sit-ups (rpm)	0.97 (0.94, 1.01)	0.199				
Sit-and-reach (cm)	0.97 (0.93, 1.02)	0.219				
Lean body mass (kg)	1.02 (0.98, 1.06)	0.405				
Dependent variable: ankle and foot injuries						
abVO$_{2max}$ (L•min)	1.49 (0.45, 5.02)	0.513				
relVO$_{2max}$ (mL•kg•min)	0.95 (0.89, 1.01)	0.074				
Grip strength (kg)	0.98 (0.96, 0.99)	0.022*	0.98 (0.96, 1.01)	0.135	0.99 (0.96, 1.01)	0.235
Leg strength (kg)	0.99 (0.98, 1.01)	0.300				
Push-ups (rpm)	0.98 (0.95, 1.00)	0.070				
Sit-ups (rpm)	0.96 (0.933, 0.99)	0.024*	0.99 (0.95, 1.03)	0.522	0.99 (0.96, 1.04)	0.942
Sit-and-reach (cm)	0.96 (0.93, 1.00)	0.048*	0.97 (0.93, 1.01)	0.134	0.97 (0.94, 1.01)	0.194
Lean body mass (kg)	0.99 (0.95, 1.02)	0.453				

Note: * indicates statistically significance <0.05; ** indicates statistical significance <0.01.
[a]—covariates adjusted for: age, sex, body mass index, and weekly MET minutes; b—covariates adjusted for: years of experience, sex, body mass index, and weekly MET minutes; L•min—liters per minute; mL•kg•min—milliliters per minute; kg—kilogram; rpm—repetitions per minute; §—significant when adjusted for age and sex only; §—significant when adjusted for years of experience and sex only.

firefighters (Taylor et al., 2014; Mayer et al., 2015; Moon et al., 2015). Similarly, Peate et al. (2007) reported that after an exercise intervention, improvements in abdominal strength and flexibility reduced the incidence of injuries in firefighters. Although not directly related, higher levels of muscular endurance may positively assist firefighters in reducing the incidence of injuries to their upper limbs and trunk, likely due to these areas having an increased stability and higher capacity to tolerate forceful repetitive movements (Cady et al., 1979; Beaton et al., 2002; Peate et al., 2007; de la Motte et al., 2017). The results of the current study indicated that for every 1 kg increase in grip strength and 1 cm increase in sit-and-reach score, there were lower odds of firefighters reporting lower limb injuries by 1% and 3%, respectively. A study reported that a higher sit-and-reach test score was associated with lower incidences of of MSIs (Lisman et al., 2017) and is likely related to a greater range of motion and a lower likelihood of stretching connective tissues to an uncomfortable degree. Similarly, Frost et al. (2015b) reported that push-up, deep squat, and sit-and-reach tasks in the functional movement screening significantly predicted injury status in firefighters. This was supported by Butler et al. (2013) who reported that the sit-and-reach score was a significant predictor of injury status in firefighters.

In the present study, with the introduction of age, sex, years of experience, BMI, and physical activity levels in the multivariate models, the significant associations were removed from all significant outcomes for MSIs. This suggests that although higher levels of physical fitness are necessary to protect firefighters from sustaining injuries, there are additional components that form part of a larger system of factors that also contribute to MSI prevention, which is supported by previous research (Nabeel et al., 2007; Vaulerin et al., 2016; Nowak et al., 2018; Ras and Leach, 2022). Firefighters remaining physically active to meet a minimum level of health-related physical fitness may be a prerequisite in reducing MSIs, but beyond this level may lead to chronic pain and injury (Poplin et al., 2016; Vaulerin et al., 2016; Lentz et al., 2019; Ras and Leach, 2022). This was seen in the present data, where firefighters who were more vigorously active reported less MSIs. However, similarly, firefighters who experienced MSD tended toward being

UNIVERSITY of the
WESTERN CAPE
http://etd.uwc.ac.za/

10.3389/fphys.2023.1210107

TABLE 7 Association between physical fitness and musculoskeletal discomfort in firefighters.

	Univariate models		Multivariate models			
	Model I		Model 2[a]		Model 3[b]	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Exploratory variable: $abVO_{2max}$ (L•min)						
Musculoskeletal discomfort	2.10 (0.92, 4.79)	0.077	—	—	—	—
Lower back discomfort	2.52 (0.96, 6.67)	0.062	—	—	—	—
Exploratory variable: grip strength (kg)						
Shoulder discomfort	1.02 (0.99, 1.04)	0.075	—	—	—	—
Thigh discomfort	1.02 (0.99, 1.04)	0.249	—	—	—	—
Exploratory variable: push-ups (rpm)						
Neck discomfort	1.03 (1.00, 1.06)	0.039*	1.04 (1.01, 1.07)	0.014*	1.04 (1.01, 1.08)	0.011*
Shoulder discomfort	1.02 (0.99, 1.05)	0.094	—	—	—	—
Upper back discomfort	1.03 (0.99, 1.06)	0.074	—	—	—	—
Elbow discomfort	1.04 (1.00, 1.07)	0.031*	1.05 (1.01, 1.08)	0.019**	1.05 (0.99, 1.09)	0.016*
Wrist and hand discomfort	1.05 (1.02, 1.08)	0.002**	1.06 (1.02, 1.09)	0.001**	1.06 (1.00, 1.09)	<0.001
Hip discomfort	1.03 (0.99, 1.07)	0.088	—	—	—	—
Thigh discomfort	1.05 (1.01, 1.09)	0.007**	1.06 (1.02, 1.11)	0.005**	1.07 (1.03, 1.12)	0.002**
Ankle and foot discomfort	1.03 (0.99, 1.06)	0.790	—	—	—	—
Exploratory variable: sit-ups (rpm)						
Shoulder discomfort	1.03 (0.99, 1.06)	0.091	—	—	—	—
Upper back discomfort	1.05 (1.00, 1.09)	0.045*	1.04 (0.99, 1.09)	0.143	1.04 (0.99, 1.09)	0.135
Wrist and hand discomfort	1.04 (0.99, 1.08)	0.055	—	—		
Thigh discomfort	1.07 (1.01, 1.12)	0.013*	1.09 (1.03, 1.51)	0.003**	1.08 (1.02, 1.14)	0.005**
Exploratory variable: sit-and-reach (cm)						
Neck discomfort	0.96 (0.924, 1.00)	0.060	—	—	—	—
Elbow discomfort	0.96 (0.92, 1.01)	0.090	—	—	—	—
Thigh discomfort	0.95 (0.903, 1.00)	0.058	—	—	—	—

Note: * indicates statistical significance <0.05; ** indicates statistical significance <0.01.
a—covariates adjusted for age, sex, body mass index, and weekly MET minutes; b—covariates adjusted for years of experience, sex, body mass index, and weekly MET minutes; L•min—liters per minute; mL•kg•min—milliliters per minute; kg—kilogram; rpm—repetitions per minute.

more physically active, particularly vigorously active, as well. Although there were instances where this tended toward significance, statistical significance was not seen, perhaps due to the relatively small numbers of firefighters experiencing MSD. Previous studies have reported that older firefighters, with more years of experience, and who were heavier and more physically inactive, were particularly susceptible to sustaining MSIs while on duty (Poston et al., 2011; Jahnke et al., 2013; Phelps et al., 2018; Nazari et al., 2020b; Hollerbach et al., 2020). Moreover, studies found women were especially susceptible to MSIs, due to multiple factors, such as poor fitting equipment, lower muscle mass, particularly in the upper limbs, and lower bone mineral density (Sinden et al., 2013; McQuerry et al., 2019; Song et al., 2019). After adjusting for age, sex, and BMI in the multivariate analysis, we noted that our results no longer achieved significance. This was also noted in correlations where age, sex, and BMI were positively correlated to MSIs in firefighters. In addition, it is likely that due to working as a firefighter for longer periods, regardless of their fitness levels, these firefighters were more likely to sustain an injury during their career (Poston et al., 2011; Hong et al., 2012; Frost et al., 2015a).

We found that push-up capacity was significantly associated with increased odds of firefighters reporting discomfort in the neck, elbow and forearm, wrist and hand, and thigh regions. In addition, an increase in sit-up capacity was associated with an increase in the odds of firefighters reporting upper back and thigh discomfort. Rintala et al. (2015) reported that fitter pilots flew their aircrafts at

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

speeds that induce higher acceleration speeds and physical workloads and, due to this higher workload, reported more symptoms of musculoskeletal pain, but fewer musculoskeletal disabilities. This may also relate to the firefighting profession, where fitter firefighters may perform their duties with greater rigor, power, and force (Williford et al., 1999; Chizewski et al., 2021), which may overload the firefighter's musculoskeletal system. These fitter firefighters might be engaged in more vigorous-intensity work at fire or emergency scenarios, compared to their less fit counterparts, which leads to MSD. In addition, if firefighters participate in regular vigorous-intensity leisure-time physical activity, this may exacerbate an already strained musculoskeletal system, or overload the musculoskeletal system, leading to burnout, that increases the risk of MSIs (Vaulerin et al., 2016; Ras and Leach, 2022). This might cause additional MSD in firefighters, but have a positive effect on reducing MSIs, as seen in the current results. However, managing the overall workload may be key to maintaining MSH and reducing injury incidence in firefighters. Previous research has noted that monitoring overall workload is important for firefighters (Poplin et al., 2013; Vaulerin et al., 2016; de la Motte et al., 2017; Ras and Leach, 2022). This could provide a possible explanation to why fitter firefighters were more likely to report MSD, especially if the MSD caused by high workloads could, eventually, lead to overuse injury (Vaulerin et al., 2016). Lusa et al. (2015) reported that firefighters who reported sleep disturbances had chronic low back pain symptoms (Halson, 2008). Abbasi et al. (2018) reported that firefighters who were heavily physically active had poorer sleep quality and were more likely to report MSDs. Due to sleep being integral to recovery, this may provide an explanation as to why fitter firefighters experienced more MSD in the current results. In contrast to the current results, Nabeel et al. (2007) reported that higher levels of physical fitness were associated with a significant decrease in the incidence of chronic pain in police officers. Similarly, Beaton et al. (2002) reported that neck, back, and shoulder pain was significantly lower in firefighters who participated in more frequent aerobic exercise. It may be that MSD is an indication of excessive workload or insufficient recovery, which has been supported in other populations, such as nurses, paramedics, surgeons, and welders (Menzel et al., 2004; Tam and Yeung, 2006; Szeto et al., 2009; Shahriyari et al., 2020). However, this area is understudied in firefighters, and the findings are not particularly intuitive. Investigating MSD may provide valuable insight into MSH of firefighters and how this may eventually lead, or predispose, firefighters to injury. It is recommended that more research be conducted in this area to better understand the causal mechanisms between physical fitness and MSD, and the implications of MSD for the likelihood of sustaining an injury.

4.1 Strengths and limitations

This was the first study examining the relationship between physical fitness and MSH in CoCTFRS firefighters, a demographic that has received little attention with respect to scientific research. The study used validated instruments and trained researchers who objectively assessed the markers of physical fitness, except cardiorespiratory fitness (Ras et al., 2022c). Validated questionnaires were used to assess MSH. This work contributes unique information to a field of study that has not yet received adequate attention, particularly in a South African setting. The present study, however, has some limitations. The study's cross-sectional design prevents the inference of causal associations. The study estimated relative and absolute cardiorespiratory fitness using a non-exercise calculation. The under-representation of female firefighters limits the generalizability of results to female firefighters. Although the study had a relatively large sample size, the low number of firefighters with MSD and MSIs limits the power of the statistical analysis.

5 Conclusion

The findings of the present study emphasize the need for firefighters maintaining high levels of physical fitness to lessen the risk of MSIs, particularly cardiorespiratory fitness, muscular endurance, and flexibility. In addition, our finding of a positive association between physical fitness and MSD indicates that care must be taken to implement well-structured fitness programs that take into account the need for adequate rest and recovery. This research highlights the importance of maintaining and/or improving physical fitness on MSH in firefighters, in the CoCTFRS, thus emphasizing the need for policy change. It is recommended that occupational health and safety professionals, as well as policymakers, ensure that firefighters participate in regular physical activity that is monitored for total weekly workload to reduce the likelihood of overexertion and ensure adequate recovery, and maintain an ideal level of health-related physical fitness to aid their occupational wellbeing. Furthermore, the development of workload guidelines is needed to further support the physical fitness requirements of firefighting and reduce the likelihood of MSIs and discomfort in firefighters. In future research, longitudinal studies are warranted to evaluate a potential causal relationship between physical fitness and improvements or decrements on the incidence of MSIs and, especially, MSD as this area is understudied with respect to firefighters. Although female firefighters represent a relatively small proportion of firefighters in the CoCTFRS, a larger and more representative sample of female firefighters should be included in future studies to allow for the generalizability of results to the female firefighter population.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the University of the Western Cape (UWC) Biomedical

http://etd.uwc.ac.za/

Research Ethics Committee (BMREC). The patients/participants provided their written informed consent to participate in this study.

Author contributions

JR, DS, ES, AK, and LL contributed to conception and design of the study. JR organized the database, performed the statistical analysis, collected the data, and wrote the first draft of the manuscript. JR, DS, ES, AK, and LL proofread and edited the drafts of the manuscript. All authors contributed to the article and approved the submitted version.

Funding

This research was funded by the National Research Foundation (NRF) (grant number 141282) and The Ryoichi Sasakawa Young Leaders Fellowship Fund (SLYFF). Neither funding bodies was involved in the study design, data collection, or interpretation of the data.

Acknowledgments

The authors thank all firefighters who consented to voluntarily participate in the study.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Abbasi, M., Rajabi, M., Yazdi, Z., and Shafikhani, A. A. (2018). Factors affecting sleep quality in firefighters. *Sleep Hypn.* 20 (4), 283–289. doi:10.5350/sleep.hypn.2018.20.0163

Andrews, K. L., Gallagher, S., and Herring, M. P. (2019). The effects of exercise interventions on health and fitness of firefighters: A meta-analysis. *Scand. J. Med. Sci. Sports* 29 (6), 780–790. doi:10.1111/sms.13411

Azmi, N. L. A. M., and Masuri, M. G. (2019). Work-related musculoskeletal disorder (WMSDs) and functional status of firefighters in Klang Valley. Healthscope: The Official Research Book of Faculty of Health Sciences, UiTM, 2. Retrieved from http://healthscopefsk.com/index.php/research/article/view/74

Baur, D. M., Christophi, C. A., Cook, E. F., and Kales, S. N. (2012). Age-related decline in cardiorespiratory fitness among career firefighters: Modification by physical activity and adiposity. *J. Obes.* 2012, 710903. doi:10.1155/2012/710903

Beaton, R., Murphy, S., Salazar, M., and Johnson, L. C. (2002). Neck, back, and shoulder pain complaints in urban firefighters: The benefits of aerobic exercise. *J. Musculoskelet. Pain* 10 (3), 57–67. doi:10.1300/J094v10n03_04

Bohlmann, I. M., Mackinnon, S., Kruger, H., Leach, L., van Heerden, J., Cook, I., et al. (2001). Is the international physical activity questionnaire (IPAQ) valid and reliable in the South African population? *Med. Sci. Sports Exerc* 33, S119. doi:10.1097/00005768-200105001-00672

Bustos, D., Guedes, J. C., Santos Baptista, J., Vaz, M., Torres Costa, J., and Fernandes, R. J. (2022). "Physiological monitoring systems for firefighters (A short review)," in *Occupational and environmental safety and health III [internet].* Editors P. M. Arezes, J. S. Baptista, P. Carneiro, J. Castelo Branco, N. Costa, and J. Duarte (Cham: Springer International Publishing), 293–305. doi:10.1007/978-3-030-89617-1_27

Butler, R. J., Contreras, M., Burton, L. C., Plisky, P. J., Goode, A., County, O., et al. (2013). Modifiable risk factors predict injuries in firefighters during training academies. *Work* 00, 11–17. doi:10.3233/WOR-121545

Cady, L. D., Bischoff, D. P., O'Connell, E. R., Thomas, P. C., and Allan, J. H. (1979). Strength and fitness and subsequent back injuries in firefighters. *J. Occup. Med.* 21 (4), 269–272. Avaliable At: http://www.jstor.org/stable/45005468.

Chairani, A. (2020). "Validity and reliability test of the nordic musculoskeletal questionnaire with formal and informal sector workers," in *Childhood stunting, wasting, and obesity, as the critical global health issues: Forging cross-sectoral solutions* (Solo, Indonesia: Universitas Sebelas Maret), 100. Available from: http://theicph.com/id_ID/2021/03/11/validity-and-reliability-test-of-the-nordic-musculoskeletal-questionnaire-with-formal-and-informal-sector-workers/u45_aulia-chairani_fp_medicine/.

Chizewski, A., Box, A., Kesler, R., and Petruzzello, S. J. (2021). Fitness fights fires: Exploring the relationship between physical fitness and firefighter ability. *Int. J. Environ. Res. Public Health* 18 (22), 11733. doi:10.3390/ijerph182211733

Crawford, J. O. (2007). The nordic musculoskeletal questionnaire. *Occup. Med. (Chic Ill)* 57 (4), 300–301. doi:10.1093/occmed/kqm036

de la Motte, S. J., Gribbin, T. C., Lisman, P., Murphy, K., and Deuster, P. A. (2017). Systematic review of the association between physical fitness and musculoskeletal injury risk: Part 2—muscular endurance and muscular strength. *J. Strength & Cond. Res.* 31 (11), 3218–3234. doi:10.1519/JSC.0000000000002174

de la Motte, S. J., Lisman, P., Gribbin, T. C., Murphy, K., and Deuster, P. A. (2019). Systematic review of the association between physical fitness and musculoskeletal injury risk: Part 3—flexibility, power, speed, balance, and agility. *J. Strength & Cond. Res.* 33 (6), 1723–1735. doi:10.1519/JSC.0000000000002382

Durand, G., Tsismenakis, A. J., Jahnke, S. A., Baur, D. M., Christophi, C. A., and Kales, S. N. (2011). Firefighters' physical activity: Relation to fitness and cardiovascular disease risk. *Med. Sci. Sports Exerc* 43 (9), 1752–1759. doi:10.1249/MSS.0b013e318215cf25

Frontera, W. R. (2017). Physiologic changes of the musculoskeletal system with aging: A brief review. *Phys. Med. Rehabil. Clin. N. Am. [Internet]* 28 (4), 705–711. doi:10.1016/j.pmr.2017.06.004

Frost, D. M., Beach, T. A. C., Crosby, I., and McGill, S. M. (2015a). Firefighter injuries are not just a fireground problem. *Work* 52 (4), 835–842. doi:10.3233/wor-152111

Frost, D. M., Beach, T. A. C., Crosby, I., and McGill, S. M. (2016). The cost and distribution of firefighter injuries in a large Canadian Fire Department. *Work* 55 (3), 497–504. doi:10.3233/WOR-162420

Frost, D. M., Beach, T. A. C., McGill, S. M., and Callaghan, J. P. (2015b). The predictive value of general movement tasks in assessing occupational task performance. *Work* 52 (1), 11–18. doi:10.3233/WOR-141902

Giuliani-Dewig, H. K., Gerstner, G. R., Mota, J. A., and Ryan, E. D. (2022). Examining the usability of workload monitoring in firefighter recruits. *J. Occup. Environ. Med.* 64 (10), 865–868. doi:10.1097/JOM.0000000000002592

Halson, S. L. (2008). Nutrition, sleep and recovery. *Eur. J. Sport Sci.* 8 (2), 119–126. doi:10.1080/17461390801954794

Hamrick, M. W. (2011). A role for myokines in muscle-bone interactions. *Exerc Sport Sci. Rev.* 39 (1), 43–47. doi:10.1097/JES.0b013e318201f601

Hedge, A., Morimoto, S., and Mccrobie, D. (1999). Effects of keyboard tray geometry on upper body posture and comfort. *Ergon. [Internet]* 42 (10), 1333–1349. doi:10.1080/001401399184983

Henderson, N. D., Berry, M. W., and Matic, T. (2007). Field measures of strength and fitness predict firefighter performance on physically demanding tasks. *Pers. Psychol.* 60, 431–473. doi:10.1111/j.1744-6570.2007.00079.x

Hollerbach, B. S., Kaipust, C. M., Poston, W. S. C., Haddock, C. K., Heinrich, K. M., and Jahnke, S. A. (2020). Injury correlates among a national sample of women in the US fire service. *J. Occup. Environ. Med.* 62 (8), 634–640. doi:10.1097/JOM.0000000000001918

Hong, O., Phelps, S., Feld, J., and Vogel, S. (2012). Occupational injuries, duty status, and factors associated with injuries among firefighters. *Workplace Health Saf.* 60 (12), 517–523. doi:10.1177/216507991206001203

http://etd.uwc.ac.za/

Jahnke, S. A., Poston, W. S. C., Haddock, C. K., and Jitnarin, N. (2013). Injury among a population based sample of career firefighters in the central USA. *Inj. Prev.* 19, 393–398. doi:10.1136/injuryprev-2012-040662

Kales, S. N., Soteriades, E. S., Christophi, C. A., and Christiani, D. C. (2007). Emergency duties and deaths from heart disease among firefighters in the United States. *N. Engl. J. Med. [Internet]* 356 (12), 1207–1215. doi:10.1056/NEJMoa060357

Kodom-Wiredu, J. K. (2019). The relationship between firefighters' work demand and work-related musculoskeletal disorders: The moderating role of task characteristics. *Saf. Health Work* 10 (1), 61–66. doi:10.1016/j.shaw.2018.05.004

Latko, W. A., Armstrong, T. J., Franzblau, A., Ulin, S. S., Werner, R. A., and Albers, J. W. (1999). Cross-sectional study of the relationship between repetitive work and the prevalence of upper limb musculoskeletal disorders. *Am. J. Ind. Med. [Internet* 36 (2), 248–259. doi:10.1002/(sici)1097-0274(199908)36:2<248::aid-ajim4>3.0.co;2-q

Le, A. B., Smith, T. D., McNulty, L. A., Dyal, M. A., and Dejoy, D. M. (2020). Firefighter overexertion: A continuing problem found in an analysis of non-fatal injury among career firefighters. *Int. J. Environ. Res. Public Health* 17 (21), 1–11. doi:10.3390/ijerph17217906

Lee, J. H., and Jun, H. S. (2019). Role of myokines in regulating skeletal muscle mass and function. *Front. Physiol.* 10, 42. doi:10.3389/fphys.2019.00042

Lentz, L., Randall, J. R., Gross, D. P., Senthilselvan, A., and Voaklander, D. (2019). The relationship between physical fitness and occupational injury in emergency responders: A systematic review. *Am. J. Industrial Med.* 62, 3–13. doi:10.1002/ajim. 22929

Liguori, G., Medicineof, A. C., and Fountaine, C. J. (2021). ACSM's Guidelines for Exercise Testing and Prescription; American College of Sports Medicine Series, *American College of Sports medicine series* (Philadelphia: Wolters Kluwer). Available from: https://books.google.co.za/books?id=6P-azQEACAAJ.

Lisman, P. J., de la Motte, S. J., Gribbin, T. C., Jaffin, D. P., Murphy, K., and Deuster, P. A. (2017). A systematic review of the association between physical fitness and musculoskeletal injury risk: Part 1—cardiorespiratory endurance. *J. Strength & Cond. Res.* 31 (6), 1744–1757. doi:10.1519/JSC.0000000000001855

Lusa, S., Miranda, H., Luukkonen, R., and Punakallio, A. (2015). Sleep disturbances predict long-term changes in low back pain among Finnish firefighters: 13-year follow-up study. *Int. Arch. Occup. Environ. Health* 88 (3), 369–379. doi:10.1007/s00420-014-0968-z

Mayer, J. M., Quillen, W. S., Verna, J. L., Chen, R., Lunseth, P., and Dagenais, S. (2015). Impact of a supervised worksite exercise program on back and core muscular endurance in firefighters. *Am. J. Health Promot.* 29 (3), 165–172. doi:10.4278/ajhp. 130228-QUAN-89

McQuerry, M., Kwon, C., and Johnson, H. (2019). A critical review of female firefighter protective clothing and equipment workplace challenges. *Res. J. Text. Appar.* 23, 94–110. doi:10.1108/rjta-01-2019-0002

Menzel, N. N., Brooks, S. M., Bernard, T. E., and Nelson, A. (2004). The physical workload of nursing personnel: Association with musculoskeletal discomfort. *Int. J. Nurs. Stud.* 41 (8), 859–867. doi:10.1016/j.ijnurstu.2004.03.012

Michaelides, M. A., Parpa, K. M., Thompson, J., and Brown, B. (2008). Predicting performance on a firefighter's ability test from fitness parameters. *Res. Q. Exerc Sport* 79 (4), 468–475. doi:10.1080/02701367.2008.10599513

Moon, T. Y., Kim, J. H., Gwon, H. J., Hwan, B. S., Kim, G. Y., Smith, N., et al. (2015). Effects of exercise therapy on muscular strength in firefighters with back pain. *J. Phys. Ther. Sci.* 27 (3), 581–583. doi:10.1589/jpts.27.581

Nabeel, I., Baker, B. A., McGrail, M. P., and Flottemesch, T. J. (2007). Correlation between physical activity, fitness, and musculoskeletal injuries in police officers. *Minn Med.* 90 (9), 40–43.

Nazari, G., Macdermid, J. C., Sinden, K., and D'Amico, R. (2020b). Prevalence of musculoskeletal symptoms among Canadian firefighters. *Work* 67 (1), 185–191. doi:10.3233/WOR-203264

Nazari, G., Osifeso, T. A., and MacDermid, J. C. (2020a). Distribution of number, location of pain and comorbidities, and determinants of work limitations among firefighters. *Rehabil. Res. Pract.* 2020, 1942513. doi:10.1155/2020/1942513

Nowak, A. M., Molik, B., Wójcik, A., Rutkowska, I., Nowacka-Dobosz, S., Kowalczyk, M., et al. (2018). Physical activity and injuries relating to physical fitness of professional firefighters. *Adv. Rehabilitation* 32 (2), 13–22. doi:10.5114/areh.2018.77933

Orr, R., Simas, V., Canetti, E., and Schram, B. (2019). A profile of injuries sustained by firefighters: A critical review. *Int. J. Environ. Res. Public Health* 16 (20), 3931. doi:10.3390/ijerph16203931

Peate, W. F., Bates, G., Lunda, K., Francis, S., and Bellamy, K. (2007). Core strength: A new model for injury prediction and prevention. *J. Occup. Med. Toxicol.* 2 (1), 3. doi:10.1186/1745-6673-2-3

Perroni, F., Guidetti, L., Cignitti, L., and Baldari, C. (2015). Age-related changes in upper body strength and lower limb power of professional Italian firefighters. *Sport Sci. Health* 11 (3), 279–285. doi:10.1007/s11332-015-0236-y

Phelps, S. M., Drew-Nord, D. C., Neitzel, R. L., Wallhagen, M. I., Bates, M. N., and Hong, O. S. (2018). Characteristics and predictors of occupational injury among career firefighters. *Workplace Health Saf.* 66 (6), 291–301. doi:10.1177/2165079917740595

Poplin, G. S., Harris, R. B., Pollack, K. M., Peate, W. F., and Burgess, J. L. (2012). Beyond the fireground: Injuries in the fire service. *Inj. Prev.* 18 (4), 228–233. doi:10.1136/injuryprev-2011-040149

Poplin, G. S., Roe, D. J., Burgess, J. L., Peate, W. F., and Harris, R. B. (2016). Fire fit: Assessing comprehensive fitness and injury risk in the fire service. *Int. Arch. Occup. Environ. Health* 89 (2), 251–259. doi:10.1007/s00420-015-1068-4

Poplin, G. S., Roe, D. J., Peate, W., Harris, R. B., and Burgess, J. L. (2013). Original contribution the association of aerobic fitness with injuries in the fire service. *Am. J. Epidemiol.* 10, 149. doi:10.1093/aje/kwt213

Poston, W. S. C., Jitnarin, N., Haddock, C. K., Jahnke, S. A., and Tuley, B. C. (2011). Obesity and injury-related absenteeism in a population-based firefighter cohort. *Obesity* 19 (10), 2076–2081. doi:10.1038/oby.2011.147

Punakallio, A., Lindholm, H., Luukkonen, R., and Lusa, S. (2012). Lifestyle factors predicting changes in aerobic capacity of aging firefighters at 3-and 13-year follow-ups. *J. Occup. Environ. Med.* 54 (9), 1133–1141. doi:10.1097/JOM.0b013e3182554b11

Ranney, D., Wells, R., and Moore, A. (1995). Upper limb musculoskeletal disorders in highly repetitive industries: Precise anatomical physical findings. *Ergon. [Internet]* 38 (7), 1408–1423. doi:10.1080/00140139508925198

Ras, J., Kengne, A. P., Smith, D., Soteriades, E. S., and Leach, L. (2022b). Effects of cardiovascular health, musculoskeletal health and physical fitness on occupational performance of firefighters: Protocol for a systematic review and meta-analysis. *BMJ Open* 12 (7), 061435. doi:10.1136/bmjopen-2022-061435

Ras, J., and Leach, L. (2022). Relationship between physical activity, coronary artery disease risk factors and musculoskeletal injuries in the city of Cape Town fire and rescue service. *Inq. J. Health Care Organ. Provis. Financing* 59, 84485. doi:10.1177/00469580221084485

Ras, J., Smith, D. L., Kengne, A. P., Soteriades, E. E., and Leach, L. (2022a). Cardiovascular disease risk factors, musculoskeletal health, physical fitness, and occupational performance in firefighters: A narrative review. *J. Environ. Public Health* 2022, 7346408. doi:10.1155/2022/7346408

Ras, J., Smith, D. L., Soteriades, E. S., Kengne, A. P., and Leach, L. (2022c). A pilot study on the relationship between cardiovascular health, musculoskeletal health, physical fitness and occupational performance in firefighters. *Eur. J. Investig. Health Psychol. Educ. [Internet]* 12 (11), 1703–1718. doi:10.3390/ejihpe12110120

Rexhepi, A. M., and Brestovci, B. (2014). Prediction of VO2max based on age, body mass, and resting heart rate. *Hum. Mov. [Internet]* 15 (1), 56–59. doi:10.2478/humo-2014-0003

Rhea, M. R., Alvar, B. A., and Gray, R. (2004). Physical fitness and job performance of firefighters. *J. Strength Cond. Res. [Internet]* 18 (2), 348–352. doi:10.1519/R-12812.1

Rintala, H., Häkkinen, A., Siitonen, S., and Kyröläinen, H. (2015). Relationships between physical fitness, demands of flight duty, and musculoskeletal symptoms among military pilots. *Mil. Med.* 180 (12), 1233–1238. doi:10.7205/MILMED-D-14-00467

Shahriyari, M., Afshari, D., and Latifi, S. M. (2020). Physical workload and musculoskeletal disorders in back, shoulders and neck among welders. *Int. J. Occup. Saf. Ergonomics* 26 (4), 639–645. doi:10.1080/10803548.2018.1442401

Sinden, K., MacDermid, J., Buckman, S., Davis, B., Matthews, T., and Viola, C. (2013). A qualitative study on the experiences of female firefighters. *Work* 45, 97–105. doi:10.3233/WOR-121549

Smith, D. L., Barr, D. A., and Kales, S. N. (2013). Extreme sacrifice: Sudden cardiac death in the US fire service. *Extrem Physiol. Med.* 2 (1), 6–9. doi:10.1186/2046-7648-2-6

Smith, D. L., DeBlois, J. P., Kales, S. N., and Horn, G. P. (2016). Cardiovascular strain of firefighting and the risk of sudden cardiac events. *Exerc Sport Sci. Rev.* 44 (3), 90–97. doi:10.1249/JES.0000000000000081

Smith, D. L. (2011). Firefighter fitness: Improving performance and preventing injuries and fatalities. *Curr. Sports Med. Rep.* 10 (3), 167–172. doi:10.1249/JSR.0b013e31821a9fec

Smith, D. L., Haller, J. M., Korre, M., Sampani, K., Porto, L. G. G., Fehling, P. C., et al. (2019). The relation of emergency duties to cardiac death among US firefighters. *Am. J. Cardiol.* 123 (5), 736–741. doi:10.1016/j.amjcard.2018.11.049

Song, J. Y., Kim, M. G., and Ahn, Y. S. (2019). Injury-related hospital admission of female firefighters in South Korea. *Int. J. Occup. Saf. Ergonomics* 25 (4), 575–582. doi:10.1080/10803548.2017.1411666

Sun, Q., Chen, S., Wang, Y., Zhang, J., Lavie, C., and Sui, X. (2022). Cross-validation of non-exercise estimated cardiorespiratory fitness: The NHANES study. *J. Surg. Res. Pract.* 2022, 1–19. doi:10.46889/jcmr.2022.31009

Szeto, G. P. Y., Ho, P., Ting, A. C. W., Poon, J. T. C., Cheng, S. W. K., and Tsang, R. C. C. (2009). Work-related musculoskeletal symptoms in surgeons. *J. Occup. Rehabil.* 19 (2), 175–184. doi:10.1007/s10926-009-9176-1

http://etd.uwc.ac.za/

Tam, G. Y. T., and Yeung, S. S. (2006). Perceived effort and low back pain in non-emergency ambulance workers: Implications for rehabilitation. *J. Occup. Rehabil.* 16 (2), 231–240. doi:10.1007/s10926-006-9019-2

Taylor, P., Beach, T. A. C., Frost, D. M., Mcgill, S. M., and Callaghan, J. P. (2014). Physical fitness improvements and occupational low-back loading – An exercise intervention study with firefighters. *Ergonomics* 57, 744–763. doi:10.1080/00140139.2014.897374

Vaulerin, J., d'Arripe-Longueville, F., Emile, M., and Colson, S. S. (2016). Physical exercise and burnout facets predict injuries in a population-based sample of French career firefighters. *Appl. Ergon.* 54, 131–135. doi:10.1016/j.apergo.2015.12.007

Walker, A., Driller, M., Argus, C., Cooke, J., and Rattray, B. (2014). The ageing Australian firefighter: An argument for age-based recruitment and fitness standards for urban fire services. *Ergonomics* 57, 612–621. doi:10.1080/00140139.2014.887790

Williford, H. N., Duey, W. J., Olson, M. S., Howard, R., and Wang, N. (1999). Relationship between fire fighting suppression tasks and physical fitness. *Ergonomics* 42 (9), 1179–1186. doi:10.1080/001401399185063

Yoon, J. H., Kim, Y. K., Kim, K. S., and Ahn, Y. S. (2016). Characteristics of workplace injuries among nineteen thousand Korean firefighters. *J. Korean Med. Sci.* 31 (10), 1546–1552. doi:10.3346/jkms.2016.31.10.1546

Yu, C. C. W., Au, C. T., Lee, F. Y. F., So, R. C. H., Wong, J. P. S., Mak, G. Y. K., et al. (2015). Association between leisure time physical activity, cardiopulmonary fitness, cardiovascular risk factors, and cardiovascular workload at work in firefighters. *Saf. Health Work* 6 (3), 192–199. doi:10. 1016/j.shaw.2015.02.004

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

CHAPTER ELEVEN: PUBLICATION TEN − ORIGINAL RESEARCH ARTICLE SIX

Physical fitness, Cardiovascular and Musculoskeletal health, and Occupational performance in Firefighters

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 25 August 2023
DOI 10.3389/fpubh.2023.1241250

Check for updates

OPEN ACCESS

EDITED BY
Gianpiero Greco,
University of Bari Aldo Moro, Italy

REVIEWED BY
Katie M. Heinrich,
The Phoenix, United States
Ja Gu,
Centers for Disease Control and Prevention (CDC), United States

*CORRESPONDENCE
Jaron Ras
3405618@myuwc.ac.za

RECEIVED 16 June 2023
ACCEPTED 14 August 2023
PUBLISHED 25 August 2023

CITATION
Ras J, Smith DL, Kengne AP, Soteriades ES and Leach L (2023) Physical fitness, cardiovascular and musculoskeletal health, and occupational performance in firefighters.
Front. Public Health 11:1241250.
doi: 10.3389/fpubh.2023.1241250

COPYRIGHT
© 2023 Ras, Smith, Kengne, Soteriades and Leach. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Physical fitness, cardiovascular and musculoskeletal health, and occupational performance in firefighters

Jaron Ras[1]*, Denise L. Smith[2], Andre P. Kengne[3], Elpidoforos S. Soteriades[4,5] and Lloyd Leach[1]

[1]Department of Sport, Recreation and Exercise Science, Faculty of Community and Health Sciences, University of the Western Cape, Cape Town, South Africa, [2]Health and Human Physiological Sciences, Skidmore College, Saratoga Springs, NY, United States, [3]Non-communicable Diseases Research Unit, South African Medical Research Council, Cape Town, South Africa, [4]Healthcare Management Program, School of Economics and Management, Open University of Cyprus, Nicosia, Cyprus, [5]Environmental and Occupational Medicine and Epidemiology (EOME), Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston, MA, United States

Introduction: To perform their work efficiently and safely, firefighters should maintain all aspects of physical fitness. Cardiac-related incidents are the leading cause of duty-related deaths in firefighters, and many firefighters have poor musculoskeletal health (MSH) that hinder their occupational performance (OP). Establishing the relationship between physical fitness, cardiovascular health (CVH), MSH and OP may add new insight on the most significant factors influencing OP in firefighters, specifically in the City of Cape Town Fire and Rescue Service (CoCTFS), which had not been studied before. Therefore, the purpose of this study was to investigate whether physical fitness, CVH and MSH were associated with OP in firefighters, in the COCTFRS.

Methods: This cross-sectional study included 283 full-time firefighters aged 20–65 years from Cape Town, South Africa. A researcher-generated questionnaire was used to collect data on sociodemographic characteristics, lifestyle factors and MSH. Physical measures were used to collect information on physical fitness, CVH, and OP [using a physical ability test (PAT)]. Linear and binary logistic regressions, adjusted for age, sex, height and weekly metabolic equivalent minutes (WMETM), multivariate analysis of covariance (MANCOVA), adjusted for age, sex, height and body mass index (BMI) and backward stepwise regressions were used to investigate the associations between the various constructs.

Results: From multivariable analyses, age, lean body mass, body fat percentage (BF%), estimated absolute oxygen consumption (abVO_{2max}), grip strength, leg strength, push-ups, sit-ups, WMETM and heart rate variability were associated with PAT completion times (all $p < 0.01$). The MANCOVA showed a significant difference between performance categories of the PAT based on physical fitness and CVH (both $p < 0.001$). WMETM, BF%, abVO_{2max}, grip strength, leg strength and sit-ups explained the highest proportion (50.5%) of the variation in PAT completion times.

Conclusion: Younger, non-obese, fitter and stronger firefighters, with a better CVH status, performed significantly better and were most likely to pass the PAT in firefighters, in Cape Town, South Africa. Firefighters should maintain high levels of physical fitness and a good level of CVH to ensure a satisfactory level of OP.

http://etd.uwc.ac.za/

KEYWORDS

firefighters, occupational performance, ability test, cardiovascular, musculoskeletal, physical fitness, cardiorespiratory, strength and endurance

1. Introduction

Firefighting is a strenuous occupation that involves routine exposure of firefighters to high temperatures, hazardous chemicals and fumes, which, along with the high physical demands, present a substantial burden on the cardiovascular system (1, 2). These exposures require firefighters to wear heavy, insulated personal protective equipment (PPE), all of which, place significant strain on their cardiovascular and musculoskeletal systems (3, 4). In addition, in order to perform their work efficiently and safely, firefighters are required to maintain all aspects of their physical fitness (5–7).

Previous studies have reported that several firefighting tasks have an average oxygen consumption ($\dot{V}O_2$) of 23.0 to 42.5 mL·kg^{-1}·min^{-1} (8–10), with the most strenuous tasks requiring an average of 44.0 mL·kg^{-1}·min^{-1} (11). In order to effectively handle these job demands, firefighters should maintain a cardiorespiratory fitness level of about 42 mL·kg^{-1}·min^{-1} (3), while also being encouraged to maintain good levels of muscular strength and muscular stamina to perform their duties adequately (12). Firefighters who are unable to perform their intense duties with sufficient competency and efficiency are at risk of underperforming while on active duty (12–14). An inability to complete required job tasks in a timely manner not only places their lives at risk, but also the lives of the civilians, while also increasing the risk of potential damage to property and infrastructure (1, 12).

Due to the strenuous nature of firefighting, firefighters who are relatively unfit may have to overexert themselves to carry out their duties to an acceptable standard (1, 2). Furthermore, firefighters that have subclinical cardiovascular disease or an unfavourable cardiovascular disease (CVD) risk profile are particularly susceptible to cardiac incidents related to overexertion, which occur at an unacceptable rate (15, 16). In fact, cardiac-related incidents are the leading cause of duty-related deaths among firefighters, accounting for 40–50% of all line-of-duty firefighter fatalities in the United States. Many of these firefighters have underlying CVD risk factors, such as smoking, hypertension, dyslipidaemia, diabetes and obesity (1, 15–17). This is consistent with previous findings from a study conducted on firefighters in the City of Cape Town Fire and Rescue Service (CoCTFRS), where it has been reported that firefighters had multiple CVD risk factors, most notably being dyslipidaemia (40.3%), cigarette smoking (39.5%), obesity (37.1%), and hypertension (33.1%) (18). Firefighters in Cape Town have been reported to have a good knowledge of CVD risk factors, however, had poor attitudes toward health habits related to improve CVD risk, such as physical activity and diet, which become progressively worse as they age (19, 20). This has also been shown in previous studies, indicating that attitudes progressively become worse in firefighters throughout their careers, perhaps attributable to the stressful nature of the occupation (21–23). Moreover, the stressors of firefighting also contribute to work-related musculoskeletal injuries and musculoskeletal discomfort (24, 25). In one research study, firefighters reported that musculoskeletal pain negatively affected their work output and was associated with work limitations (26). Previous research has also shown that many firefighters report being physically inactive, despite being aware of the physical nature of their occupation (27–30). In spite of the well-known intense physical requirements of firefighting, many firefighters do not maintain the appropriate levels of physical conditioning that are required for peak performance at work (29, 31, 32). However, studies have shown that firefighters, particularly in the CoCTFRS, that are overworked are predisposed to musculoskeletal injuries and musculoskeletal discomfort (30, 33).

Ageing and obesity predispose firefighters to musculoskeletal injuries (34, 35) and are related to reduced work performance (6, 7, 36). In addition, though firefighters may be relatively healthy, maintaining adequate muscular strength and endurance is essential, as several studies have reported significant relationships between muscular strength and endurance and occupational tasks (6, 7, 36). This may be explained by forceful repetitive movements required by firefighters, such as the forcible entry, hose drag, victim rescue, and heavy equipment carries, that, require high levels of muscular strength and endurance (5–7, 36). Furthermore, it has been consistently reported, in studies performed in different fire departments, globally, that measures of physical fitness, particularly cardiorespiratory fitness and muscular endurance, explained the most variance in occupational performance times in firefighters (3, 5–7, 37, 38). It is apparent that performing firefighting-related tasks with sufficient intensity and efficiency is based on multiple factors mainly associated with a healthy cardiovascular and musculoskeletal system (5, 7, 14, 36, 38). In the CoCTFRS there are no policies or legislations that encourage firefighters to maintain an appropriate level of physical fitness and cardiovascular health to ensure optimal occupational performance, which becomes particularly worrisome given the scarcity of research on the health, wellness, physical fitness, and occupational performance of this population (18, 20).

Previous studies have suggested relationships between physical fitness, cardiovascular health and musculoskeletal health that, collectively, may significantly impact the occupational performance of firefighters (30, 39–42). However, these relationships have not been fully explored, with most studies opting to investigate the relationship between physical fitness and occupational performance, only. This has left a gap in the literature on what the cumulative effect of physical fitness, cardiovascular and musculoskeletal health may have on occupational performance in firefighters, which is particularly relevant for research conducted on firefighters in South Africa. In addition, no study has investigated the determinants of occupational performance, using physical fitness, cardiovascular health and musculoskeletal health in firefighters, in the CoCTFRS. This research will highlight the importance of physical fitness, cardiovascular health, and musculoskeletal health on occupational performance in firefighters, in Africa, where firefighters are understudied. In addition, a better understanding of the parameters that contribute to occupational performance will enable firefighters, instructors and policymakers,

http://etd.uwc.ac.za/

particularly in South Africa, to prepare adequately for the physically demanding requirements of the profession. We hypothesise that there will be an inverse relationship between physical fitness and PAT completion times and a positive association between cardiovascular health and musculoskeletal health PAT completion times. A better understanding of the determinants of occupational performance may help support the development of policies standardizing occupational requirements for an acceptable level of physical fitness and cardiovascular health. Therefore, the purpose of this study was to investigate whether physical fitness, cardiovascular health and musculoskeletal health were factors significantly associated with occupational performance in firefighters, in the City of Cape Town Fire and Rescue Service (CoCTFRS).

2. Methods

2.1. Study design and population

A cross-sectional study design was employed to determine the association between physical fitness parameters (cardiorespiratory fitness, muscular strength and endurance, flexibility and body composition), cardiovascular health (CVD risk factors, CVD risk score, HRV, cardiovascular health index), musculoskeletal health (Musculoskeletal injuries and musculoskeletal discomfort), and occupational performance in a cohort of firefighters. The PAT was administered by the CoCTFRS and was used as the measure of occupational performance in the present study. The study took place between June and August 2022. Written informed consent was obtained from all participants. In total, 1,000 firefighters are currently employed in the CoCTFRS, and using Slovin's formula, a minimal sample size of 278 firefighters was calculated for this study. Overall, 309 full-time male and female firefighters between the ages of 20 to 65 years from the CoCTFRS were systematically sampled and agreed to participate in the study. Due to the time constraints as a result of the testing, 309 firefighters of the total firefighter population was randomly sampled to participate in the study. However, after the initial health screening, 26 firefighters were excluded due to medical concerns. From the original 309 firefighters, 283 attempted the PAT (92% response rate), and 15 firefighters failed to complete the PAT due to exhaustion. Ethical clearance was granted by the Biomedical Research Ethics Committee (ethical clearance number: BM21/10/9) of the University of the Western Cape. Approval was granted by the Chief Fire Officer, as well as the departments of Research and Policy and Strategy research branch of the City of Cape Town (CCT).

2.2. Sampling and participant recruitment

Data collection took place during the annual physical fitness assessment conducted by the CoCTFRS. To ensure consistency of the testing results, a single fire station was used, located in the CCT metropolitan area, to assure the same layout of the PAT, environmental conditions and testing surface. Although the PAT was administered by the fire department, for the present study, all PAT measures were collected and recorded by trained researchers that were familiarised with all the testing instruments and research procedures. Due to time constraints and agreement with the CoCTFRS on the number of firefighters that would be allowed to participate in the study, firefighters were selected using random systematic sampling, where every third firefighter was selected to participate from the 96 platoons (32 fire stations) that participated in this study. Each of the 96 platoons consisted of 8 to 12 firefighters. All full-time firefighters between the age range of 20–65 years were considered. Firefighters excluded were those on administration duty, those on sick leave, those employed as part-time or on a seasonal basis, or those that did not participate in the PAT on the day of testing due to medical concerns or injuries impacting their ability to complete the PAT.

2.3. Physical fitness measures

Physical fitness was measured by trained researchers (43) in accordance with the American College of Sports Medicine (ACSM) guidelines (44). Cardiorespiratory capacity was from a validated non-exercise calculation (43) to estimate oxygen consumption ($\dot{V}O_2$). For muscular endurance, push-ups and sit-ups tests were used, upper and lower body strength were assessed using the handgrip and leg strength tests and to assess flexibility, the sit-and-reach test was used. Body mass and Lean body mass (LBM) were used as measures of body composition and were assessed using a Tanita© (Tanita©, Tokyo, Japan) BC-1000 Plus bioelectrical impedance (BIA) analyser. Cardiorespiratory fitness was estimated using the non-exercise method, applying the following formula: oxygen consumption ($\dot{V}O_{2max}$) = 3.542 + (−0.014 × Age) + (0.015 × Body Mass [kg]) + (−0.011 × Resting Heart Rate) (45). Relative $\dot{V}O_{2max}$ (rel$\dot{V}O_{2max}$) was then calculated from absolute $\dot{V}O_{2max}$ (ab$\dot{V}O_{2max}$) value generated. For the push-ups and sit-ups tests, firefighters were requested to perform as many repetitions, in a minute, as possible and the test was terminated when firefighters reached volitional fatigue or were unable to maintain a good technique (44). Grip strength was measured using a Takei® 5,401-C handgrip dynamometer and leg strength using a Takei® back and leg strength dynamometer, following standardized protocols and given three attempts with the highest being recorded (44). To ensure accurate results, firefighters were allowed a full recovery between each test. The sit-and-reach required firefighters to reach as forward as far as possible on the ruler of a standardized sit-and-reach box. For a full description of the methods used to assess physical fitness consult the study published by Ras et al. (43).

For relative cardiorespiratory fitness, 42 $mL \cdot kg^{-1} \cdot min^{-1}$ (3) was used to indicate the minimum cardiorespiratory fitness needed for firefighting. For measures of absolute cardiorespiratory fitness, grip and leg strength, push-ups and sit-ups and flexibility, the 50th percentile was used to classify firefighters with the minimum required strength, endurance and flexibility measures and categorized as "good." This percentile was chosen due to the scarcity of objective measures of minimum measures of strength, endurance and flexibility needed for acceptable PAT performance. In total, to calculate the 50th percentile for the fitness measures, 304 firefighters' data were used. Based on the 50th percentile, firefighters that had an absolute cardiorespiratory fitness of 3.40 L min or above was considered "good." For muscular strength, a grip strength of 89.9 kg or above and leg strength of 116.5 kg or above were considered "good." For muscular endurance, a push-ups and sit-ups capacity of 30 repetitions per minute or above were considered to be "good." For flexibility, a

http://etd.uwc.ac.za/

sit-and-reach score of 43 cm or above was considered "good." Firefighters that fell below the 50th percentile were considered to have a "low" level of muscular strength, muscular endurance and flexibility.

2.4. Cardiovascular health measures

In the current study, cardiovascular health was used as an umbrella term and was investigated using several approaches. These approaches included three main subcomponents: CVD risk factors, cardiovascular health metrics and heart rate variability (HRV). Height and waist and hip circumference were assessed using a stadiometer and tape measure, using standardized techniques (44), and using a bioelectrical impedance analysis (BIA) scale body fat percentage (BF%) and weight were measured. CVD risk factors included age, smoking, hypertension, dyslipidaemia, diabetes, obesity and physical inactivity. Cardiovascular health metrics were used to classify firefighters' cardiovascular health index. The cardiovascular health metrics included an ideal/good body mass index (BMI), blood pressure, non-fasting blood glucose, total cholesterol, level of physical activity, diet and cigarette smoking status. In addition, cardiovascular health index was classified as "good" if firefighters had five to seven metrics rated as ideal, "intermediate" if firefighters had three to four metrics classified as ideal and "poor" if firefighters had zero to two metrics classified as ideal. The 2008 Framingham risk model, developed by D'Agostino et al. (46), was used to assess cardiovascular disease risk of firefighters. Furthermore, the American College of Cardiology (ACC) 10 year atherosclerotic cardiovascular disease (ASCVD) and ASCVD lifetime risk were calculated to assess the cardiovascular disease risk of firefighters (47, 48). For HRV, a Polar™ (Polar Electro Oy, Kempele, Finland) H10 heart rate monitor was used, at rest, while firefighters were in a seated position, and analyzed using the Kubio© Software version 3.4.3. Prior to testing, firefighters were asked to remain in a seated position for at least 5 min, thereafter, HRV measures were taken for 5 min. For more information on the methods used to assess cardiovascular health, as well as the classifications of CVD risk factors and cardiovascular health metrics, please refer to the study published by Ras et al. (43).

2.5. Classification of musculoskeletal health

Musculoskeletal health was subcategorized as musculoskeletal injuries and musculoskeletal discomfort status, which was further separated into those that sustained an injury while on duty and those that did not, as well as those who were experiencing musculoskeletal discomfort and those who did not. Thereafter, subcategories for those that reported musculoskeletal injuries and musculoskeletal discomfort were categorized based on the location of the musculoskeletal injury or the musculoskeletal discomfort experienced, specifically upper body musculoskeletal injury, lower body musculoskeletal injury, lower back musculoskeletal injury, upper body musculoskeletal discomfort, lower body musculoskeletal discomfort and lower back musculoskeletal discomfort. Musculoskeletal injury and discomfort were measured subjectively via two validated questionnaires, namely the Cornell Musculoskeletal Discomfort Questionnaire (49) and the Nordic Musculoskeletal Questionnaire (50), under the supervision of a trained researcher to ensure the questionnaires were being completed accurately. The Nordic Musculoskeletal Disorders questionnaire comprised 11 questions, divided into three sections and nine categories. This was answered by indicating a "yes" or "no" response to the nine anatomical sites to indicate if a participant did or did not experience injury/trouble to one or more regions during their time as a firefighter. For the Cornell Musculoskeletal Discomfort Questionnaire, the sections were divided into the following twelve body regions: neck, shoulder, upper back, upper arm, low back, forearm and elbow, wrist and hand, hip, thigh, knee, lower leg and foot and ankle. The questionnaire also included data on the frequency of discomfort, the severity and the effect of the discomfort on the ability to do their work.

2.6. Occupational performance

2.6.1. Physical ability test

The PAT was used to assess operational performance and was conducted according to the testing protocol of the CoCTFRS. The PAT was developed by the CoCTFRS as part of the fitness and wellness programme in consultation with industry experts. The PAT consists of tasks that are designed to simulate the various duties that firefighters perform, while also attempting the simulate the physical stressors that firefighters are routinely exposed to. To simulate an emergency fire callout, the PAT was conducted while firefighters wore their full PPE equipment and breathing apparatus set. However, firefighters were not required to use the mouthpiece of the breathing apparatus set while performing the PAT to ensure a "full" tank was used for the duration of testing. The PAT consisted of six tasks, which included the step-up, charged hose drag and pull, forcible entry, equipment carry, ladder raise and extension and the rescue drag. Firefighters were required to complete the simulation protocol in under 9 min (540 s) in order to pass. Firefighters passed the PAT if the total completion time was under 540 s. If they failed to complete an individual task, they were, nevertheless, graded competent overall. However, firefighters that failed to pass a specific task were graded "not yet competent" in that task. Firefighters were required to pass the task on the next physical fitness assessment. Firefighters were allowed 20 s of recovery between tasks. The timer was restarted once the recovery period had elapsed, regardless of whether the firefighter was in the starting position. The tasks included:

2.6.2. Step-ups

Firefighters were required to perform 30 step-ups on a 200 mm platform while carrying a high-rise pack weighing 40 kg in total, which consisted of 20 kg weights, strapped together in a twin donut method. The step-up task had a time limit of 90 s to be deemed competent.

2.6.3. Charged hose drag and pull

Firefighters' were required to place a 45 mm hose line over their shoulder or across the chest and advance the hose tied to a tyre to the 27 meter mark. Thereafter, the firefighters dropped to at least one-knee or in a seated position and pull the hose-line to the 15 meter mark. The firefighters had a time limit of 180 s to complete the test to be deemed competent

http://etd.uwc.ac.za/

2.6.4. Forcible entry

The forcible entry event required firefighters to pick up a 6 kg sledgehammer and strike a tyre to drive it for a distance of 600 mm. Firefighters were required to complete the task in 60 s to be deemed competent.

2.6.5. Equipment carry

Firefighters were required to remove two foam drums, each weighing 25 kg, from a 1.2 meter-high platform, one at a time, and place them on the ground. The firefighters proceeded to walk both drums, carried in each hand, 25 meters toward and around the first marked position and walk another 25 meters (50 meters in total) back to the starting position. Upon returning, the firefighters placed the foam drums back onto the platform, one at a time. In this task, firefighters were required to complete the task in 60 s to be deemed competent.

2.6.6. Ladder raise and extension

Firefighters were required to walk a seven-to-eight-meter aluminum ladder 6 meters toward the building, raise the ladder using every rung, using the hand-over-hand technique, until stationary against the wall. Immediately thereafter, the firefighters walked to the second pre-position and, using the hauling line, hoisted a 35 kg drum, pulling down the line hand-over-hand, until the fly section reached the pulley and then lower the ladder once again. The firefighters then walked back to the ladder and lowered the ladder using the hand-over-hand technique, returning the ladder it's the original position. The firefighters were given 90 s to complete this test and deemed competent.

2.6.7. Rescue drag

This event required firefighters to grasp an 80 kg tyre on the shoulders of the harness and drag the tyre 11 meters to a prepositioned mark, perform a 180-degree turn, around the mark, and continue an additional 11 meters toward the finish line. Firefighters were required to complete this task in 60 s to be deemed competent.

2.7. Statistical analysis

The data were analysed using SPSS® software, version 28 (Chicago, Illinois, United States). The data were collected, coded and cleaned for errors using the double entry method on Microsoft Excel. Descriptive statistical analyses, such as the median and 25th and 75th percentiles were computed. Mann–Whitney U analysis was performed to determine the difference between PAT completion times based on physical fitness, cardiovascular health and musculoskeletal health groups. Univariable and multivariable linear regressions were performed to determine the independent variables associated with PAT performance as an outcome. Due to the differences in units of measurements for the exploratory and outcome variables, standardized beta coefficients were preferred to interpret the strength of the association. Univariable and multivariable logistic regressions were performed to determine the independent variables associated with PAT pass rates. In the regression analysis, independent (exploratory) variables of physical fitness variables included abVO_{2max}, relVO_{2max}, grip strength, leg strength, push-ups, sit-ups, and LBM. Exploratory cardiovascular health variables included age, BMI, BF%, waist circumference, systolic blood pressure, diastolic blood pressure, total cholesterol, non-fasting blood glucose, weekly MET minutes and Framingham risk score. Exploratory variables for musculoskeletal health included musculoskeletal injury, upper body musculoskeletal injury, lower body musculoskeletal injury, lower back musculoskeletal injury, upper body musculoskeletal discomfort, lower body musculoskeletal discomfort and lower body musculoskeletal discomfort. In the multivariable analysis on physical fitness and cardiovascular health parameters, model 2 was adjusted for age and sex and model 3 was adjusted for age, sex, height and weekly METs. Multivariate analysis of covariance (MANCOVA) was conducted to determine the difference/degree of variance between performance categories on the PAT in terms of physical fitness and cardiovascular health. Categories included top performers (75th to 99th percentile), above average performers (50th to 75th percentile), below average performers (25th to 50th percentile), and poor performers (1st to 25th percentile), which was considered as the grouping/independent (fixed factors) variable and physical fitness and cardiovascular health parameters were considered the dependent variables list in the analysis. Covariates adjusted for included age, sex, height and BMI for physical fitness and sex, height and weekly MET minutes for cardiovascular health. Analysis of covariance (ANCOVA) was conducted to determine the difference between performance categories and each dependent variable. Bonferroni correction ($0.05/4 = 0.0125$) was applied to significant ANCOVA results, and stepwise comparisons were reported. Backward stepwise linear regression models were performed to determine the factors contributing most to PAT completion times. To control for collinearity the VIF and Durbin–Watson statistics were used. A VIF <5 was used to indicate that no substantial collinearity was present and a Durbin–Watson statistic between 1.5 and 2.5 indicated that no autocorrelation was present. For data that were not normally distributed, data were fractionally ranked, and then normalized using the inverse DF, IDF. NORMAL transformation (51). A value of p of <0.05 was used to indicate statistical significance.

3. Results

In Table 1 we delineate the PAT times according to sex, age-group, cardiovascular health, musculoskeletal health, and physical fitness. The median PAT completion time was 369.5 (293.3, 488.8) seconds. It was higher in women than in men and increased with age (both $p < 0.001$). Firefighters with good relative cardiorespiratory fitness levels, good grip and leg strength, and good push-ups and sit-ups stamina had significantly faster completion times than firefighters with low cardiorespiratory fitness, grip and leg strength and push-ups and sit-ups stamina (all $p < 0.001$). Obese, physically inactive and firefighters with a poor cardiovascular health index had a significantly slower PAT completion time than non-obese physically active and those with an intermediate or good cardiovascular health index (all $p < 0.001$). Firefighters that reported upper body musculoskeletal injury had a slower PAT completion time than those without an injury ($p = 0.048$) and those that reported lower back musculoskeletal injury had a significantly slower completion time ($p = 0.028$).

In Table 2 we describe the linear association between physical fitness and cardiovascular health in relation to PAT completion times. Based on physical fitness, the univariable linear regression analysis

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

TABLE 1 Descriptive statistics of firefighters according to age-category, sex, physical fitness, cardiovascular and musculoskeletal health.

Variable	N	$\tilde{X}$ ($p25^{th}$–$p75^{th}$)
Demographic characteristics		
Age (years)	268	36.0 (29.0, 46.0)
Years of experience (years)	268	12.0 (4.0, 19.0)
Height (cm)	268	173.5 (169.1, 178.3)
Weight (kg)	268	81.0 (72.5, 89.9)
Physical fitness		
abVO$_{2max}$ (L·min^{-1})	268	3.4 (3.3, 3.6)
relVO$_{2max}$ (mL·kg^{-1}·min^{-1})	268	42.3 (38.4, 46.7)
Grip strength (kg)	268	90.9 (80.0, 101.9)
Leg strength (kg)	268	118.0 (101.6, 135.8)
Push-ups (rpm)	268	30.0 (21.3, 41.0)
Sit-ups (rpm)	268	30.0 (22.0, 36.0)
Flexibility (cm)	268	44.0 (37.0, 50.0)
Lean body mass (kg)	268	61.9 (54.9, 67.7)
Cardiovascular health		
Body mass index (kg·m^{-2})	268	26.8 (23.9, 30.0)
Body fat percentage (%)	268	19.5 (14.3, 26.1)
Systolic blood pressure (mmHg)	268	137.2 (124.8, 144.9)
Diastolic blood pressure (mmHg)	268	80.8 (73.7, 90.0)
Total cholesterol (mmol·L^{-1})	268	4.5 (3.9, 5.3)
Low-density lipoprotein cholesterol (mmol·L^{-1})	268	2.6 (2.0, 3.3)
High-density lipoprotein cholesterol (mmol·L^{-1})	268	1.2 (1.1, 2.1)
Triglycerides (mmol·L^{-1})	268	1.4 (0.9, 2.1)
Non-fasting blood glucose (mmol·L^{-1})	268	5.4 (4.9, 6.1)
Framingham risk score (%)	268	0.9 (0.2, 5.5)
Lifetime ASCVD risk score▲	266	50.0 (39.0, 50.0)
10-year ASCVD risk score ¶	108	5.4 (2.3, 8.9)
Heart rate variability		
Heart rate variability (ms)	263	722.0 (633.0, 822.0)
SDNN (ms)	263	33.4 (22.8, 47.5)
RMSSD (ms)	263	24.5 (14.7, 38.9)
LF (Hz)	263	0.09 (0.07, 0.11)
HF (Hz)	263	0.17 (0.16, 0.21)
LF/HF ratio (Hz)	263	2.79 (1.61, 5.20)
Categories of physical ability test performance (time)		
Top performers	67	250.0 (226.0, 273.0)
Above average performers	67	330.0 (309.0, 347.0)
Below average performers	67	420.0 (384.0, 441.0)
Poorest performers	67	601.0 (517.0, 728.0)

	N	$\tilde{X}$ ($p25^{th}$–$p75^{th}$)	$p^{§}$	Pass rate % (N)
Physical ability test (seconds)				
Total firefighters#	268	369.5 (293.3, 488.8)		81.3 (230)

(Continued)

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

 10.3389/fpubh.2023.1241250

TABLE 1 (Continued)

	N	$\tilde{X}$ ($p25^{th}$–$p75^{th}$)	$p^{§}$	Pass rate % (*N*)
Sex				
Male	239	351.0 (286.0, 441.0)	<0.001**	87.7 (221)
Female	29	654.9 (491.5, 852.5)		29.0 (9)
Age-group				
20–29 years	71	337.0 (274.0, 425.0)	<0.001**	92.9 (65)
30–39 years	86	338.0 (272.3, 443.8)		88.0 (81)
40–49 years	67	430.0 (327.0, 550.0)		73.2 (52)
50+ years	43	413.0 (321.0, 594.0)		64.0 (32)
Physical fitness				
Good absolute cardiorespiratory fitness	139	322.0 (268.0, 390.0)	<0.001**	93.0 (132)
Low absolute cardiorespiratory fitness	129	441.0 (347.5, 552.0)		69.5 (132)
Good relative cardiorespiratory fitness	139	372.0 (298.0, 488.0)	0.740	83.2 (119)
Low relative cardiorespiratory fitness	129	367.0 (287.5, 492.5)		79.3 (111)
Good grip strength	142	320.5 (261.5, 428.5)	<0.001**	92.4 (134)
Low grip strength	126	423.5 (337.0, 551.0)		68.9 (93)
Good leg strength	143	327.0 (268.0, 409.0)	<0.001**	95.9 (141)
Low leg strength	125	438.0 (337.0, 539.5)		64.7 (86)
Good push-ups stamina	151	327.0 (262.0, 420.0)	<0.001**	90.8 (139)
Low push-ups stamina	117	433.0 (352.5, 559.5)		69.3 (88)
Good sit-ups stamina	151	334.0 (262.0, 438.0)	<0.001**	88.3 (136)
Low sit-ups stamina	117	429.0 (330.0, 535.5)		72.2 (91)
Good flexibility	146	351.5 (286.8, 483.8)	0.321	82.7 (124)
Low flexibility	122	379.5 (304.5, 490.0)		79.2 (103)
Cardiovascular health				
Aged	70	428.5 (340.0, 536.3)	<0.001**	69.6 (55)
Young	198	346.5 (277.0, 461.0)		85.8 (175)
Obesity	68	392.0 (324.8, 606.0)	<0.001**	66.7 (50)
Non-obese	200	351.5 (281.0, 460.0)		86.5 (180)
Central obesity	129	390.0 (30.8.0, 535.5)	<0.001**	74.1 (103)
No central obesity	139	337.0 (281.0, 441.0)		88.2 (127)
Hypertension	122	357.0 (292.0, 495.8)	0.930	77.5 (100)
Normotensive	146	380.0 (293.8, 485.0)		84.4 (130)
Dyslipidaemia	86	390.5 (295.5, 532.3)	0.076	77.1 (74)
Normal	182	352.5 (290.5, 455.5)		83.4 (156)
Hypertriglyceridemia	101	377.0 (302.4, 460.5)	0.921	87.2 (95)
Normal	167	354.0 (291.0, 499.0)		77.6 (135)
Diabetes	12	434.0 (325.8, 29.5)	0.237	78.6 (11)
Normal	256	366.0 (293.0, 487.0)		81.4 (219)
Physical inactivity	190	394.5 (312.8, 507.3)	<0.001**	76.8 (146)
Physically active	93	319.5 (255.0, 379.5)		90.3 (84)
Cigarette smoker	97	377.0 (306.5, 460.5)	0.461	85.7 (84)
Non-smoker	171	357.0 (285.2, 495.0)		78.9 (146)
Poor diet	1	725.0 (725.0, 725.0)	0.029*	0.0 (1)
Intermediate diet	44	403.0 (330.0, 529.8)		73.9 (34)
Good diet	223	357.0 (286.0, 477.0)		83.1 (196)

(Continued)

UNIVERSITY of the WESTERN CAPE
Page | 227
http://etd.uwc.ac.za/

TABLE 1 (Continued)

	N	$\tilde{X}$ ($p25^{th}$–$p75^{th}$)	$p^{§}$	Pass rate % (N)
Poor CVHI	83	429.0 (320.0, 533.0)	<0.001**	76.9 (70)
Intermediate CVHI	151	337.0 (270.0, 441.0)		84.4 (135)
Good CVHI	32	393.5 (326.3, 506.0)		78.1 (25)
Musculoskeletal health				
Musculoskeletal injury	110	377.5 (297.0, 499.0)	0.150	79.8 (95)
No injury	157	354.0 (290.0, 478.0)		82.2 (134)
Upper body musculoskeletal injury	54	402.0 (317.5, 527.3)	0.048*	76.3 (45)
No injury	214	360.5 (286.0, 465.0)		82.6 (185)
Lower body musculoskeletal injury	63	374.0 (294.0, 490.0)	0.873	81.8 (54)
No injury	205	369.0 (293.0, 488.5)		81.1 (176)
Lower back injury	20	480.5 (328.3, 561.8)	0.028*	68.2 (15)
No injury	248	364.0 (289.5, 477.8)		82.4 (215)
Musculoskeletal discomfort	111	374.0 (281.0, 499.0)	0.722	80.3 (94)
Without musculoskeletal discomfort	157	364.0 (294.0, 483.0)		81.9 (136)
Upper body discomfort	96	373.0 (293.8, 504.3)	0.655	81.9 (81)
Without musculoskeletal discomfort	172	367.5 (293.3, 478.8)		80.2 (149)
Lower body discomfort	64	345.0 (274.0, 482.8)	0.266	80.9 (55)
Without musculoskeletal discomfort	204	370.0 (298.5, 493.8)		81.4 (175)
Lower back discomfort	57	377.0 (298.9, 552.5)	0.161	83.3 (46)
Without musculoskeletal discomfort	211	364.0 (291.0, 478.0)		74.2 (184)

$\tilde{X}$, median; $p25^{th}$–$p75^{th}$, 25^{th} percentile to 75^{th} percentile; CVHI, cardiovascular health index; ASCVD, atherosclerotic cardiovascular disease; VO_{2max}, oxygen consumption; $L·min^{-1}$, litres per min; $mL·kg^{-1}·min^{-1}$, millilitres per kilogram per minute; $mmol·L^{-1}$, millimole per litre; mmHg, millimetres mercury; kg, kilogram; $kg·m^{-2}$, kilogram per meter squared; cm, centimetres; Hz, hertz; ms, milliseconds; %, percentage; cm, centimetres; rpm, repetitions per minute; SDNN, standard deviation of all normal-to-normal; RMSSD, root-mean-square of successive differences; LF, low-frequency; HF, high frequency; LF/HF, low and high frequency ratio; p, significance level; §, Mann–Whitney U analysis; ¹, indicates that only firefighters over the age of 40 years were included; *, indicates that only firefighters under the age of 60 were included.

indicated that there was a significant negative linear association between abVO_{2max}, grip strength, leg strength, push-ups, sit-ups, lean body mass LBM and PAT completion times in firefighters. In the multivariable analysis, after adjustment for age and sex, firefighters with a higher abVO_{2max}, grip and leg strength, push-ups and sit-ups capacity and LBM performed the PAT significantly faster (all $p < 0.001$). After height and weekly MET minutes were included in the model, firefighters with a higher grip and leg strength, push-ups and sit-ups capacity and LBM performed the PAT significantly faster (all $p < 0.001$). These results support the research hypothesis that occupational performance is inversely associated with physical fitness in firefighters.

When evaluating cardiovascular health, univariable analysis indicated significant positive associations were found between age, BMI, BF%, diastolic blood pressure, Framingham risk score and PAT completion times, and negative relationship was found between weekly MET minutes and PAT completion times. In the multivariate analysis, after adjustment for sex, an increase in age ($p < 0.001$) was associated with slower PAT completion times. When height and Weekly MET minutes were included, an increase in age ($p < 0.001$) remained associated with slower PAT completion times. For weekly MET minutes, after adjustment for age and sex, an increase in weekly MET minutes ($p = 0.004$) was associated with faster associated PAT completion times. After height was included in the model, firefighters with a higher total weekly MET minutes ($p < 0.001$) remained associated with faster PAT completion times. The results support the hypothesis of the study, however, after robust analysis only age and weekly MET minutes remained significantly associated with PAT completion times.

When evaluating HRV, the univariable analysis indicated that firefighters that had a higher HRV, SDNN, RMSSD and LF performed the PAT significantly faster. After adjustment for age, sex, height and weekly MET minutes, an increase in HRV and SDNN remained associated with faster PAT completion times. These results support the hypothesis that cardiovascular health is positively associated with occupational performance in firefighters.

In Table 3, using logistic regression, we present the association between physical fitness, cardiovascular health and musculoskeletal health variables and PAT performance times in firefighters. Firefighters with good absolute cardiorespiratory fitness, grip strength, leg strength, push-up capacity, and sit-up capacity had increased odds of passing the PAT (all $p<0.001$). After adjustment for age and sex, a good absolute cardiorespiratory fitness ($p<0.001$), grip ($p<0.012$), and leg strength ($p<0.001$) remained significantly associated to an increased odds of passing the PAT. In model 3, after adjustment for age, sex, height and weekly MET minutes, good absolute cardiorespiratory fitness, grip and leg strength increased the odds of firefighter passing the PAT, which support the hypothesis of the study. Univariable analysis found that age, obesity ($p=0.002$), high BF% ($p<0.001$), central obesity ($p<0.001$), hypertriglyceridemia ($p = 0.047$), and physical inactivity ($p = 0.018$) decreased the odds of firefighters passing the PAT. After adjustment for age, height and

Page | 228
http://etd.uwc.ac.za/

TABLE 2 Linear regression assessing the association between physical fitness, cardiovascular health and musculoskeletal health variables, and PAT completion times.

	Univariable linear models					Multivariable linear models									
	Model 1					Model 2[a]					Model 3[b]				
	B	SE	*β*	R^2	Value of *p*	*B*	SE	*β*	R^2	Value of *p*	*B*	SE	*β*	R^2	Value of *p*
Model: Physical ability test (s)															
abV̇O$_{2max}$ (L·min^{-1})	−284.41	36.78	−0.182	0.186	<0.001**	−204.04	34.87	−0.308	0.358	<0.001**	−111.43	35.22	−0.159	0.451	0.002**
relV̇O$_{2max}$ (mL·kg^{-1}·min^{-1})	−0.206	1.78	−0.007	0.000	0.908	3.368	1.874	0.116	0.282	0.074	−0.47	1.77	−0.016	0.419	0.790
Grip strength (kg)	−5.11	0.53	−0.531	0.265	<0.001**	−3.70	0.564	−0.369	0.377	<0.001**	−2.64	0.55	−0.263	0.476	<0.001**
Leg strength (kg)	−3.12	0.33	−0.509	0.277	<0.001**	−2.09	0.34	−0.341	0.367	<0.001**	−1.57	0.32	−0.257	0.479	<0.001**
Push-ups (rpm)	−5.36	0.71	−0.421	0.175	<0.001**	−4.05	0.72	−0.319	0.356	<0.001**	−4.29	0.63	−0.339	0.520	<0.001**
Sit-ups (rpm)	−6.98	0.96	−0.409	0.165	<0.001**	−5.35	0.93	−0.313	0.355	<0.001**	−5.36	0.82	−0.315	0.511	<0.001**
Sit-and-reach (cm)	−1.48	1.19	−0.076	0.006	0.249	−2.080	1.05	−0.107	0.285	0.049*	−1.76	0.94	0.94	0.427	0.063
Lean body Mass (kg)	−8.28	1.00	−0.453	0.207	<0.001**	−7.55	1.08	−0.413	0.391	<0.001**	−4.25	1.24	−0.233	0.456	<0.001**
Model: Physical ability test (s)															
Age (years)[§]	5.02	1.03	0.286	0.084	<0.001**	5.22	0.92	0.297	0.275	<0.001**	4.81	0.83	0.274	0.430	<0.001**
Body mass index (kg·m^{-2})	5.37	2.45	0.134	0.022	0.029*	−0.32	2.26	−0.008	0.275	0.888	−1.44	2.02	−0.036	0.431	0.477
Bodyfat percentage (%)	6.26	1.09	0.333	0.112	<0.001**	1.69	1.14	0.090	0.281	0.140	0.96	1.03	0.051	0.432	0.352
Waist circumference (cm)	1.13	0.87	0.079	0.007	0.198	0.09	0.89	0.006	0.275	0.920	0.71	0.79	0.050	0.432	0.369
Systolic blood pressure (mmHg)	−1.19	0.71	−0.103	0.008	0.094	−1.10	0.64	−0.09	0.283	0.086	−0.58	0.58	−0.49	0.432	0.319
Diastolic blood pressure (mmHg)	2.02	0.94	0.131	0.024	0.032*	0.69	0.85	0.045	0.277	0.416	0.53	0.76	0.035	0.431	0.483
Total cholesterol (mmol·L^{-1})	8.56	8.41	0.007	0.003	0.310	−6.39	7.64	−0.047	0.277	0.404	−5.70	6.83	−0.42	0.432	0.405
LDL-C (mmol·L^{-1})	9.41	9.98	0.058	0.03	0.347	−6.19	8.91	−0.038	0.276	0.488	−6.26	7.96	−0.038	0.432	0.433
HDL-C (mmol·L^{-1})	−5.97	29.05	−0.013	0.00	0.837	−68.53	25.68	−0.145	0.296	0.008**	−61.74	22.94	−0.130	0.451	0.008**
Triglycerides (mmol·L^{-1})	15.45	9.93	0.095	0.009	0.121	13.32	8.99	0.082	0.281	0.140	7.79	8.06	0048	0.432	0.334
Non-fasting blood glucose (mmol·L^{-1})	0.98	8.18	0.062	0.000	0.905	−4.86	7.13	−0.037	0.278	0.496	−9.08	6.38	−0.068	0.436	0.156
Diet (score)	8.58	5.12	0.102	0.010	0.095	1.82	4.46	0.022	0.275	0.684	5.34	3.99	0.064	0.434	0.183
Weekly MET minutes (MET·min^{-1})[¶]	−0.02	0.00	−0.247	0.061	<0.001**	−0.01	0.00	−0.203	0.313	0.004**	−0.011	0.003	−0.179	0.430	<0.001**
Framingham risk score (%)	5.69	1.99	0.173	0.030	0.005**	5.09	3.00	0.155	0.283	0.099	3.94	2.69	0.120	0.435	0.146
Model: Physical ability test (s)															
Heart rate variability (ms)	−0.24	−0.20	−0.202	0.041	0.001**	−0.23	0.06	−0.190	0.313	<0.001**	−0.135	0.058	−0.112	0.443	0.021*
SDNN (ms)	−2.14	0.49	−0.261	0.065	<0.001**	−1.53	0.45	−0.187	0.300	<0.001**	−0.962	0.413	−0.118	0.438	0.021*
RMSSD (ms)	1.41	0.42	−0.203	0.039	<0.001**	−1.03	0.38	−0.148	0.289	0.006**	−0.600	0.345	−0.087	0.433	0.083
LF (Hz)	−1126.63	412.19	−0.167	0.023	0.007**	−303.40	371.38	−0.045	0.280	0.415	−204.42	332.74	−0.030	0.433	0.540
HF (Hz)	212.42	176.63	0.074	0.005	0.230	83.34	152.09	0.029	0.279	0.584	95.11	136.29	0.033	0.433	0.486
LF/HF (Hz)	−1.00	2.54	−0.024	0.001	0.694	−0.03	2.19	−0.001	0.278	0.989	−0.09	1.97	−0.002	0.432	0.965

*indicates statistically significance <0.05 and **indicates statistical significance <0.01; VO$_{2max}$, oxygen consumption; L·min^{-1}, litres per min; mL·kg^{-1}·min^{-1}, millilitres per kilogram per minute; mmol·L^{-1}, millimole per litre; mmHg, millimetres mercury; kg, kilogram; kg·m^{-2}, kilogram per meter squared; cm, centimetres; Hz, hertz; ms, milliseconds; %, percentage; MET·min^{-1}, metabolic equivalent minutes; rpm, repetitions per minute; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; SDNN, standard deviation of all normal-to-normal; RMSSD, root-mean-square of successive differences; LF, low-frequency; HF, high frequency; LF/HF, low and high frequency ratio; *B*, unstandardized beta coefficient; SE, standard error; ***β***, standardized beta coefficient; R^2, *R* squared; §, age was removed as a covariate in the adjustment; ¶, weekly MET minutes removed as a covariate in the adjustment.

[a]Multivariable logistic regression adjusted for age and sex.

[b]Multivariable logistic regression adjusted for age, sex, height, and weekly MET minutes.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

10.3389/fpubh.2023.1241250

TABLE 3 Logistic regression assessing the association between physical fitness, cardiovascular health, and musculoskeletal health variables and PAT performance (passing the PAT).

	Univariable logistic models		Multivariable logistic models			
	Model 1		Model 2[a]		Model 3[b]	
	OR (95% CI)	Value of *p*	OR (95% CI)	Value of *p*	OR (95% CI)	Value of *p*
Model: PAT performance						
Good absolute cardiorespiratory fitness	5.75 (2.75, 12.00)	<0.001	4.07 (1.72,9.64)	0.001**	3.20 (1.32, 7.75)	0.010*
Good relative cardiorespiratory fitness	1.29 (0.711, 2.36)	0.397	1.42 (0.57, 3.52)	0.453	1.04 (0.40, 2.68)	0.413
Good grip strength	5.78 (2.606, 12.80)	<0.001**	3.16 (1.28, 7.76)	0.012*	2.67 (1.01, 7.06)	0.049*
Good leg strength	12.99 (5.33, 31.68)	<0.001**	5.56 (2.12, 14.57)	<0.001**	4.97 (1.87,13.24)	0.001**
Good push-ups stamina	4.40 (2.26, 8.57)	<0.001**	1.62 (0.73, 3.57)	0.083	2.34 (0.96, 5.71)	0.063
Good sit-ups stamina	2.91 (1.55, 5.44)	<0.001**	0.62 (0.28, 1.37)	0.235	1.69 (0.75, 3.79)	0.206
Good flexibility	1.25 (0.69, 2.28)	0.465	1.54 (0.72, 3.29)	0.264	1.59 (0.73, 3.48)	0.248
Model: PAT performance						
Sex¶	0.06 (0.02, 0.14)	<0.001**	0.03 (0.01, 0.08)	<0.001**	0.08 (0.02, 0.26)	<0.001**
Aged§	0.38 (0.20, 0.71)	0.002**	0.89 (0.86, 0.93)	<0.001**	0.89 (0.85, 0.93)	<0.001**
Obesity	0.31 (0.17, 0.58)	<0.001**	0.54 (0.86, 0.94)	0.117	0.61 (0.27, 1.38)	0.238
High BF%	0.32 (0.17, 0.60)	<0.001**	0.75 (0.34, 1.67)	0.479	0.91 (0.39, 2.11)	0.832
Central obesity	0.32 (0.17, 0.59)	<0.001**	0.81 (0.36, 1.83)	0.613	0.99 (0.43, 2.29)	0.990
Hypertension	0.64 (0.35, 1.16)	0.140	0.95 (0.43, 2.09)	0.888	0.94 (0.41, 2.26)	0.886
Dyslipidaemia	0.67 (0.36, 1.23)	0.197	1.34 (0.62, 2.90)	0.462	1.25 (0.56, 2.77)	0.588
Hypertriglyceridemia	0.51 (0.26, 0.99)	0.047*	0.47 (0.21, 1.05)	0.065	2.01 (0.89, 4.55)	0.093
Diabetes	0.84 (0.23, 3.11)	0.791	1.47 (0.29, 7.23)	0.636	1.56 (0.30, 8.13)	0.595
Cigarette smoking	1.60 (0.82, 3.12)	0.166	0.91 (0.41, 2.02)	0.813	0.78 (0.33, 1.85)	0.579
Physical inactivity	0.43 (0.22, 0.86)	0.018*	0.34 (0.1.44, 0.82)	0.016*	0.35 (0.13, 0.96)	0.041*
Poor diet	1.54 (0.75, 3.17)	0.244	0.99 (0.41, 2.41)	0.987	1.26 (0.50, 3.17)	0.624
CVHI (Good)						
Intermediate CVHI	1.62 (0.85, 3.09)	0.145	1.56 (0.71, 3.44)	0.268	1.33 (0.58, 3.06)	0.496
Poor CVHI	1.07 (0.41, 1.83)	0.889	1.13 (0.28, 4.63)	0.867	0.88 (0.21, 3.68)	0.861
Model: PAT performance▲						
Heart rate variability	1.003 (1.001, 1.005)	0.009**	1.003 (1.001, 1.006)	0.011*	1.003 (1.000, 1.006)	0.039*
SDNN	1.025 (1.010, 1.041)	<0.001**	1.018 (0.999, 1.037)	0.066	1.016 (0.996, 1.037)	0.117
RMSSD	1.018 (1.006, 1.031)	0.005**	1.015 (0.999, 1.032)	0.060	1.014 (0.997, 1.032)	0.104
LF	34.7222 (4.100, 294.071)	0.001**	3.225 (0.227, 45.790)	0.387	4.850 (0.298, 79.049)	0.267
HF	0.222 (0.002, 29.422)	0.546	0.216 (0.002, 28.821)	0.540	1.281 (0.003, 537.546)	0.936
LF/HF	1.013 (0.945, 1.087)	0.709	0.898 (0.902, 1.085)	0.989	0.977 (0.887, 1.076)	0.642
Model: PAT performance						
Musculoskeletal injury	0.86 (0.47, 1.59)	0.634	1.66 (0.77, 3.56)	0.193	1.63 (0.74, 3.58)	0.228
Upper limb injuries	0.68 (0.34, 1.35)	0.270	0.0.83 (0.35, 1.95)	0.665	0.86 (0.35, 2.12)	0.748
Lower limb injuries	0.95 (0.47, 1.94)	0.897	0.46 (0.18, 1.15)	0.095	0.47 (0.18, 1.19)	0.110
Lower back injury	0.46 (0.18, 1.19)	0.111	0.39 (0.13, 1.22)	0.106	0.39 (0.12, 1.27)	0.118
Musculoskeletal discomfort	0.90 (0.49, 1.65)	0.736	1.16 (0.55, 2.45)	0.699	1.09 (0.50, 2.6)	0.833
UBMSD	0.89 (0.48, 1.66)	0.730	0.95 (0.44, 2.05)	0.904	0.90 (0.49, 1.68)	0.746
LBMSD	0.97 (0.48, 1.94)	0.925	1.32 (0.56, 3.10)	0.519	0.97 (0.49, 1.95)	0.938
Lower back discomfort	0.58 (0.29, 1.14)	0.112	0.59 (0.26, 1.39)	0.232	0.65 (0.27, 1.57)	0.339

*indicates statistically significance <0.05 and **indicates statistical significance <0.01. OR, odds ratio; SE, standard error; CI, confidence intervals; ¶, sex removed as a covariate in the adjustment; §, age was removed as a covariate in the adjustment; ▲, continuous independent variable; SDNN, standard deviation of all normal-to-normal; RMSSD, root-mean-square of successive differences; LF, low-frequency; HF, high frequency; LF/HF, low and high frequency ratio.

[a]Multivariable logistic regression adjusted for age and sex.

[b]Multivariable logistic regression adjusted for age, sex, height, and weekly MET minutes.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

weekly MET minutes female ($p < 0.001$) firefighters were less likely to pass PAT. When adjusting for sex, height and weekly MET minutes, aged firefighters were less likely to pass the PAT ($p < 0.001$). After adjustment for age, sex, height and weekly MET minutes physically inactive ($p = 0.018$) firefighters were less likely to pass the PAT. Moreover, we found that an increase in HRV, SDNN, RMSSD and LF were significantly associated with an increase in PAT pass rates (all $p <$ 0.01). After adjustment, only an increase in HRV was associated with an increased odds of firefighters passing the PAT ($p = 0.039$).

A backward stepwise multiple regression reported that the variation of ab$\dot{V}O_{2max}$, grip strength, leg strength, push-ups, sit-ups and LBM used in the model explained a significant proportion (49.0%) of the variation observed in PAT completion times [$F(7, 256) = 40.1$, $p < 0.001$] (Supplementary Table S1). The variation in age, BMI, systolic blood pressure, diastolic blood pressure and weekly MET minutes used in the model explained a significant proportion (30.1%) of the variation of PAT completion times [$F(6, 256) = 18.4$, $p < 0.001$]. The model that included both physical fitness and cardiovascular health parameters showed that the variation in weekly MET minutes, BF%, ab$\dot{V}O_{2max}$, grip strength, leg strength and sit-ups explained the highest proportion (50.5%) on the variation of PAT completion times [$F(6, 256) = 45.6$, $p < 0.001$]. These results are consistent with the hypothesis, indicating that physical fitness and cardiovascular health contribute significantly to the occupational performance in firefighters. In Table 4 we explore the differences between the physical fitness and cardiovascular health of firefighters based on performance on the PAT. The results of the MANCOVA indicated that there was a significant difference between the performance categories on the PAT and physical fitness, where firefighters with higher levels of physical fitness were more likely to be better performers on the PAT, controlling for age, sex, height and BMI [$F(9, 750) = 3.5$, $p < 0.001$, Pillai's Trace $V = 0.305$]. ANCOVA indicated that ab$\dot{V}O_{2max}$ ($p < 0.001$), rel$\dot{V}O_{2max}$ ($p = 0.032$), grip strength ($p = 0.001$), leg strength ($p < 0.001$), push-ups ($p < 0.001$), sit-ups ($p < 0.001$), and LBM ($p < 0.001$) was significantly different and more likely to be higher between highest and lowest performance groups on the PAT. After Bonferroni correction, ab$\dot{V}O_{2max}$, grip strength, leg strength, push-ups and sit-ups remained robust to the adjustment. Notably, rel$\dot{V}O_{2max}$ and LBM were no longer significant after the correction.

Based on cardiovascular health, MANCOVA indicated that there was a significant difference between the performance categories on the PAT and cardiovascular health parameters, where firefighters with worse a cardiovascular health were more likely to be poorer performers on the PAT, controlling for sex, height and weekly MET minutes [$F(14, 741) = 2.7$, $p < 0.001$, Pillai's Trace $V = 0.393$]. ANCOVA indicated that age ($p < 0.001$), non-fasting blood glucose ($p = 0.031$), triglycerides ($p = 0.033$), weekly MET minutes ($p < 0.001$), and Framingham risk score ($p < 0.001$) was significantly different and more likely to be lower between the highest and lowest performance groups. After Bonferroni correction age, weekly MET minutes and Framingham risk score remained robust to the correction. Non-fasting blood glucose and triglycerides did not remain significant after Bonferroni correction.

4. Discussion

Our results indicated that younger, non-obese firefighters, with a higher physical fitness and lower cardiovascular disease risk score, had significantly faster PAT completion times (better occupational performance) and higher pass rates. In addition, the top performing (highest quartile) firefighters had significantly higher ab$\dot{V}O_{2max}$, grip and leg strength and push-ups and sit-ups capacity compared to the poorest performers and, unsurprisingly, firefighters with a higher physical fitness level performed best on the PAT, while having the highest pass rates. The results were consistent with what has been reported in the literature, which consistently shows that firefighters that have a higher cardiorespiratory fitness level, muscular strength and endurance, and a more favourable body composition perform best on the occupational performance simulation protocols (5, 13, 14, 52). Physically fit firefighters are likely able to sustain a high work-rate for the duration of the occupational testing, completing the sequence of tasks faster. We found that firefighters aged 45 years or older, with a BMI of 30 $kg \cdot m^{-2}$ or higher had the slowest times on the PAT, especially those with other comorbidities. These results are consistent with previous studies, which indicated that age and obesity are significant predictors of occupational performance in firefighters (5, 13, 53–55). This is likely due to the age-related decline in cardiorespiratory fitness, muscular strength and lean body mass, that is often accompanied by the accumulation of fat mass (32, 56–58). The association between a better overall cardiovascular health status and better occupational performance may be indirectly related to these participants, generally, being more physically active and having a better physical fitness level, particularly cardiorespiratory fitness, which has been shown to be significantly associated in the literature (29, 59, 60). The results may inform policy makers and fire department heads in Cape town on the importance of firefighters maintaining an acceptable level of physical fitness, cardiovascular health and musculoskeletal health in order to perform their duties with sufficient rigor and efficiency, which will also contribute toward their overall health and wellbeing while in the fire service. These results also highlight the importance of annual health screenings and physical fitness testing for firefighters.

The current results indicated that higher absolute cardiorespiratory fitness was significantly related to faster occupational completion times in firefighters. Firefighters who had the highest estimated cardiorespiratory fitness levels, were the top performers. This is supported by previous literature which reported that measured cardiorespiratory fitness is essential for occupational performance in firefighters (13, 61, 62). After adjustment for covariates, the differences in absolute and relative cardiorespiratory fitness were small, perhaps due to cardiorespiratory fitness being estimated in the present study, rather being measured using physical testing. Previous studies (3, 7, 63) have recommended that firefighters should maintain a cardiorespiratory standard of 42 $mL \cdot kg^{-1} \cdot min^{-1}$. However, in the present study, meeting the minimum cardiorespiratory fitness standard of 42 $mL \cdot kg^{-1} \cdot min^{-1}$ was not a significant factor in passing the PAT, rather absolute cardiorespiratory fitness played a more central role in PAT performance. Siddall et al. (52, 63) noted that in firefighters in the United Kingdom, the required oxygen consumption (and thus the percent of $\dot{V}O_{2max}$ needed) fluctuates significantly based on the task performed, which may explain why this standard was not related to passing the current PAT. Although meeting the standard of 42 $mL \cdot kg^{-1} \cdot min^{-1}$ was not needed to pass the PAT in the current study, firefighters with a higher absolute and relative $\dot{V}O_{2max}$ completed the PAT significantly quicker. In the current results, after adjustment, the top performers and poorest performers showed a mean absolute cardiorespiratory fitness level of

http://etd.uwc.ac.za/

TABLE 4 Multivariable comparisons evaluating the difference between physical fitness and cardiovascular health parameters based on physical ability test performance.

Variable	V	G1	G2	G3	G4	F	Value of p						
								Stepwise comparisons†					
		Top performers ($n = 65$)	Above average ($n = 67$)	Below average ($n = 67$)	Poorest performers ($n = 65$)		Overall	G1 vs. G2	G1 vs. G3	G1 vs. G4	G2 vs. G3	G2 vs. G4	G3 vs. G4
		x̄ (SE)	x̄ (SE)	x̄ (SE)	x̄ (SE)								
Pillai's Trace	0.305					3.5	<0.001**						
ab$\dot{V}O_{2max}$ ($L \cdot min^{-1}$)		3.59 (0.02)	3.46 (0.02)	3.39 (0.02)	3.36 (0.02)	6.8	<0.001**	0.789	0.002**	<0.001**	0.121	0.015*	1.000
rel$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)		43.20 (0.31)	43.24 (0.28)	42.40 (0.28)	42.09 (0.32)	2.9	0.032*	1.000	0.383	0.149	0.223	0.065	1.000
Grip strength (kg)		97.11 (1.87)	90.44 (1.68)	88.23 (1.69)	86.11 (1.94)	5.6	0.001**	0.038*	0.004**	0.001**	1.000	0.638	1.000
Leg strength (kg)		128.2 (3.18)	120.84 (2.87)	113.79 (1.89)	107.67 (3.31)	6.3	<0.001**	0.455	0.007**	<0.001**	0.512	0.025*	0.971
Push-ups (rpm)		39.43 (1.54)	34.29 (1.38)	28.93 (1.39)	24.61 (1.59)	14.2	<0.001**	0.064	<0.001**	<0.001**	0.042*	<0.001**	0.247
Sit-ups (rpm)		34.72 (1.17)	29.58 (1.05)	28.68 (1.06)	23.55 (1.21)	12.4	<0.001**	0.005**	0.001**	<0.001**	1.000	0.002**	0.009**
Sit-and-reach (cm)		45.92 (1.17)	43.02 (1.06)	42.14 (1.06)	41.82 (1.22)	2.3	0.082	–	–	–	–	–	–
Lean body Mass (kg)		61.75 (0.68)	61.24 (0.61)	61.00 (0.62)	58.76 (0.71)	3.1	0.027*	1.000	1.000	0.033*	1.000	0.067	0.098
Pillai's Trace	0.393					2.7	<0.001**						
Age (years)		33.45 (1.27)	36.31 (1.18)	38.62 (1.19)	44.39 (1.31)	11.3	<0.001**	0.562	0.024*	<0.001**	1.000	<0.001**	0.008**
BMI ($kg \cdot m^{-2}$)		27.33 (0.58)	27.27 (0.54)	27.14 (0.55)	27.33 (0.60)	0.0	0.994	–	–	–	–	–	–
WC (cm)		90.29 (1.59)	92.02 (1.49)	93.33 (1.51)	96.47 (1.65)	2.2	0.084	–	–	–	–	–	–
BF% (%)		20.94 (1.12)	20.13 (1.04)	20.33 (1.06)	23.29 (1.15)	1.6	0.197	–	–	–	–	–	–
SBP (mmHg)		136.52 (1.97)	137.40 (1.83)	132.82 (1.86)	136.83 (2.03)	1.3	0.291	–	–	–	–	–	–
DBP (mmHg)		79.47 (1.52)	83.44 (1.41)	81.27 (1.44)	82.98 (1.57)	1.5	0.222	–	–	–	–	–	–
NFBG ($mmol \cdot L^{-1}$)		5.89 (0.18)	5.29 (0.16)	5.67 (0.18)	5.89 (0.18)	2.9	0.031*	0.064	1.000	1.000	0.657	0.098	1.000
TC ($mmol \cdot L^{-1}$)		4.64 (0.17)	4.70 (0.16)	4.69 (0.16)	4.92 (0.18)	0.4	0.718	–	–	–	–	–	–
LDL-C ($mmol \cdot L^{-1}$)		2.70 (0.14)	2.67 (0.14)	2.64 (0.13)	2.91 (0.15)	0.7	0.565	–	–	–	–	–	–
HDL-C ($mmol \cdot L^{-1}$)		1.39 (0.05)	1.29 (0.04)	1.23 (0.04)	1.26 (0.05)	2.1	0.091	–	–	–	–	–	–
Triglycerides ($mmol \cdot L^{-1}$)		1.36 (1.14)	1.55 (0.13)	1.91 (1.33)	1.81 (1.15)	2.9	0.033*	0.188	0.198	0.216	0.187	0.201	0.197
Diet (score)		9.46 (0.28)	9.92 (0.26)	9.93 (0.26)	10.48 (0.29)	1.9	0.127	–	–	–	–	–	–
Weekly METs ($MET \cdot min^{-1}$)		3983.5 (369.4)	4139.4 (343.8)	2716.5 (349.8)	1800.7 (381.7)	7.9	<0.001**	1.000	0.091	<0.001**	0.024*	<0.001**	0.464
Framingham risk score (%)		1.03 (0.66)	2.56 (0.62)	4.04 (0.63)	6.09 (0.68)	8.9	<0.001**	0.506	0.008**	<0.001**	0.564	0.001**	0.162

Univariable comparisons of each parameter of physical fitness and cardiovascular health. Stepwise comparisons of each performance category after Bonferroni correction. *indicates statistical significance <0.05 and **indicates statistical significance <0.01. Physical fitness MANCOVA: adjusted for age, sex, height, and body mass index. Cardiovascular health MANCOVA: adjusted for sex, height and weekly MET minutes. $\bar{x}$, adjusted mean; SE, standard error; †, indicates Bonferroni correction; V, Pillai's trace; F, test statistic ANOVA; G1, top performers; G2, above average performers; G3, below average performers; G4, below average performers; VO_{2max}, oxygen consumption; $L \cdot min^{-1}$, litres per min; $mL \cdot kg^{-1} \cdot min^{-1}$, millilitres per kilogram per minute; $mmol \cdot L^{-1}$, millimole per litre; mmHg, millimetres mercury; kg, kilogram; $kg \cdot m^{-2}$, kilogram per meter squared; cm, centimetres; %, percentage; $MET \cdot min^{-1}$, metabolic equivalent minutes; rpm, repetitions per minute.

10.3389/fpubh.2023.1241250

http://etd.uwc.ac.za/

3.59 vs. 3.36 L·min^{-1} and 43.2 vs. 42.1 mL·kg^{-1}·min^{-1}, and a median completion time of 250.0 s vs. 601.0 s. Fitter firefighters may be able to sustain a high physical work rate for an extended period of time (52, 64), allowing firefighters to complete the tasks swiftly. Firefighters were allowed a 20 s full recovery period between tasks, which may account for the absence of significance between firefighters that met the requirement of 42 mL·kg^{-1}·min^{-1} and those that did not. A similar observation was made by Rhea et al. (13) which noted that providing firefighters a full recovery period between tasks lessened the cardiovascular fitness level required for each task. However, the study used a 10 min recovery, which is significantly higher than the present study.

We found that an increase in grip and leg strength were significantly associated to faster PAT completion times. Similarly, Rhea et al. (13) reported that in a cohort of 20 full-time firefighters from the Unites States, bench press (r = −0.66), squat (r = −0.30), and grip strength (r = −0.71) were inversely related to occupational performance. Moreover, higher strength levels in either the upper or lower body enhanced the performance on specific tasks that taxed either the upper body or lower body more. In addition, firefighters who performed best on tasks, such as the hose drag and pull, which equally taxed the upper and lower body, were those that had the highest upper and lower body strength levels (13). This was supported by studies conducted by Michaelides et al. (5, 6) that reported that in a cohort of 72 firefighters from Arkansas, United States, abdominal (r = −0.53), bench press (r = −0.31), and squat (r = −0.22) strength were inversely related to ability test performance, performing the ability test quicker than weaker firefighters. Chizewski et al. (7) corroborates these findings where the study noted that in 89 full-time from Illinois, United States, firefighters an increase in bench press strength significantly reduced the total occupational performance completion time and for each task in the battery. A study noted that between the fastest and slowest performers there was a 13% difference in strength levels (3). von Heimburg et al. (38) reported that in firefighters from Trondheim, Norway, a minimum muscular strength level is required to perform tasks efficiently and beyond this point little benefit is gained for an increase in muscular strength capacity. The PAT test used in the present study required firefighters to have the ability to produce substantial force, particularly in the step-up and hose drag and pull tasks, which is designed to exhaust the lower extremities. This is not exclusive to the current study, as previous studies have noted that leg strength and grip strength have been related to the stair climb and hose drag tasks, respectively (13, 65–67). Notably, in the current study, an increase in leg strength was associated with an increase in the likelihood (OR = 4.97) of passing the PAT, more so than the other physical fitness variables. In contrast, though studies have found leg strength was significantly associated with occupational performance, these studies did not report similar strengths in the association between leg strength and occupational performance, as in the present study (5, 6, 13, 14). It is likely that different occupational performance testing protocols tax different aspects of physical fitness and put emphasis on different muscle groups, making them very particular to the fire departments testing protocols (7, 36, 38).

We noted that sit-ups and push-ups were inversely associated to PAT completion times. Michaelides et al. (6) reported that sit-ups (r =−0.27) and push-ups (r =−0.31) were inversely related to occupational performance in firefighters. Another study by Michaelides et al. (5) reported that muscular endurance was significant in the prediction model for occupational performance in firefighters. Similarly, Chizewski et al. (7) reported that sit-ups (r =−0.407) and push-ups (r =−0.380) were inversely related to occupational performance and, together, explained 45% of the variance in occupational performance times when entered into the regression model. Rhea et al. (13) further supports this where the study reported that higher endurance capacity in the row (r =−0.61), bench press (r =−0.71), shoulder press (r =−0.73), biceps curl (r =−0.69), squat (r =−0.47), abdominal curl (r =−0.24), and handgrip (r =−0.25) tests were inversely related to occupational performance times. This was also supported by Williford et al. (36) who found that in a cohort of firefighters from Alabama, United States, push-ups (r =−0.38) and sit-ups (r =−0.32) were negatively correlated with occupational performance in firefighters. However, did not contribute significantly to the prediction model. The PAT, and other occupational performance tests, require firefighters to sustain a minimum amount of muscular force for a number of repetitions (12). Inherently, firefighters with high levels of muscular stamina would perform better without experiencing substantial levels of fatigue. The results of the present study indicated that flexibility was not significantly associated with occupational performance, which is consistent to previous literature (6, 7, 14). In contrast, Michaelides et al. (5) noted that higher flexibility, using the sit-and-reach test, was not significantly associated with occupational performance, however, flexibility added significantly to their prediction model. Williford et al. (36) reported that higher flexibility did not improve overall occupational performance but improved the performance on the stair climb (r =−0.25). Although flexibility may not consistently be significantly related to occupational performance, good flexibility may be important for reducing the incidence of injuries in firefighters (68), and, possibly, in the performance of certain tasks, such as the stair climb (12, 36).

We found that age, obesity, Framingham risk score and physical activity levels of firefighters were significantly associated with PAT completion times and PAT pass rates. Michaelides et al. (6) noted that age was negatively related (r =−0.42) to ability test completion times. Similarly, Myhre et al. (61) reported that, in 222 full-time firefighters from the United States consisting of one army and seven air force base fire departments, age (r = 0.38) was positively related to occupational performance. Studies by Chizewski et al. (7), skinner et al. (14), and Williford et al. (36) reported that, although age was not related to total completion times, aging was positively related to the self-contained breathing apparatus (SCBA) crawl (r = 0.359), the dummy drag (r = 0.389), and the stair climb (r = 0.48) in each study, respectively. Michaelides et al. (6) reported that BMI (r = 0.34) and BF% (r = 0.57) was positively related to completion times in firefighters. Another study by Michaelides et al. (5) reported that BF% (r = 0.41) was positively correlated with occupational performance completion times. Similarly, Schonfeld et al. (62) reported that in a cohort of 20 full-time firefighters from the Kennedy Space centre Florida, United States, BF% (0.467) was moderately related to occupational performance times in firefighters. This was supported by Williford et al. (36) who reported that BF% (r = 0.30) was positively related to total occupational performance completion times and related to the completion of all tasks, except the hose advance. Skinner et al. (14) noted that in a cohort of 42 Australian full-time firefighters, BMI was not related to occupational performance, however, BF% was positively related to completion times (r = 0.481). Chizewski et al. (7) reported that BMI was not related to total occupational performance completion times, however, BMI was negatively related to the performance of specific tasks, such as the

Page | 233
http://etd.uwc.ac.za/

SCBA crawl (r =−0.276), and negatively related to the hose advance (r =−0.272), and ladder raise (r =−0.274). The combination of the general attrition in physical fitness and accumulation of fat mass that is associated with aging (32, 56–58), increases the non-functional weight firefighters are required to overcome (12), providing a possible explanation for the reduction in their occupational performance. Higher levels of cardiorespiratory fitness and weekly physical activity has been linked to a favourable cardiovascular health profile and cardiovascular functioning (69, 70), which may directly relate to better occupational performance in firefighters (12, 64, 71).

The current study found that HRV, SDNN, RMSSD and LF were significantly and inversely associated with occupational completion times in firefighters. This was supported in a study by Lesniak et al. (72) who reported that HRV was correlated with occupational performance in firefighters. Porto et al. (73) noted that SDNN and RMSSD were higher and LF was dominant in fitter firefighters. Similarly, a systematic review conducted by Tomes et al. (74) noted that HRV was a reliable indicator of key physical fitness and occupational performance parameters (74). The results of the current study and previous research suggests that firefighters with higher parasympathetic dominance, who are in a more relaxed state, may perform better on occupational performance tasks (74, 75). This measure may be an important indicator for firefighters' overall cardiovascular health and fitness levels, particularly in relation to firefighters' work performance (72, 74, 76).

We found that weekly MET minutes, BF%, abVO_{2max}, grip strength, leg strength and sit-ups explained 50.5% of the variance in PAT completion times in firefighters. Similarly, Michaelides et al. (5) noted that the fitness parameters, which included flexibility, sit-ups, push-ups, BF%, 1-RM bench press and squat explained 59% of the variance in occupational performance completion times in firefighters. Davis et al. (37) supported this and noted that push-ups, sit-ups, and grip strength explained 54% of the variability in occupational performance completion times in firefighters. In addition, Davis et al. noted that BF%, LBM and cardiorespiratory fitness were significantly associated with fatigue resistance in firefighters. Furthermore, the study found that aging, LBM and grip strength explained 60.6% of the variance in PAT pass rates. Williford et al. (36) reported that run time, pull-ups and fat free weight explained 53% of the variance in occupational performance completion times. In contrast, Siddal et al. (52) noted that age and LBM did not contribute to the strength of the regression models and that abVO_{2max}, fat mass/BF% accounted for the most variance in occupational performance with 56.7 and 57.2%, respectively. Williams-Bell et al. (77) reported that abVO_{2max} or relVO_{2max}, body mass and handgrip strength were significantly associated with occupational performance in firefighters and accounted for 65–71% of the variance in occupational performance completion times. Furthermore, the final model removed push-ups from the equation, which also seen in the final model in the current study (77). Moreover, in the current study, grip and leg strength remained significant in the regression model. In contrast, Williams-Bell et al. (77) reported that measures of strength and power were no longer significant predictors after absolute cardiorespiratory fitness was included. However, the study indicated that when relative cardiorespiratory fitness was used as the only measure of cardiorespiratory fitness, grip strength was significantly related to occupational performance. The result of the backward stepwise multivariable regression suggests that fitter and stronger firefighters, with a higher muscular endurance and favourable body composition perform best on the PAT and are more likely to pass the occupational performance test.

The current results found that musculoskeletal health was not a significant contributing factor in the model to predict firefighters' performance on the PAT. This was supported by MacDermid et al. (78), where the study noted no relationship between task performance and self-reported work limitations in firefighters from Ontario, Canada. The study noted that those who reported lower limb discomfort took 10 s longer to complete the stair climb task. It is intuitive to anticipate that that there would be an association between occupational performance and musculoskeletal health in firefighters. The failure to find a significance may indicate that firefighters were completely recovered from any injury, or the discomfort may not have been significant enough to cause a decrease in absolute performance. Perhaps, having discomfort in specific regions may limit performance of tasks that tax that specific region that firefighters are experiencing discomfort in. However, firefighters may make up for this by performing well in the other tasks, which may have been the case in the present study.

This is the first study of its nature to be conducted in this population. Therefore, the results of the present study may contribute meaningfully toward informing policy makers on the need for the development of new policies and legislation aimed at encouraging firefighters to either maintain or improve their levels of physical fitness, cardiovascular health and musculoskeletal health in the CoCTFRS. The absence of research on firefighters in Africa, and particularly in South Africa, presumably contributed to the stagnated development of new policies focused on the occupational health and wellbeing of firefighters (18). This arguably has led to the progressive deterioration in firefighter health and wellness that has become problematic in firefighters in South Africa (18, 30). This research highlights the need for annual health screening and physical fitness testing of firefighters and emphasizes the value that routine testing may provide for the fire and rescue service in Cape Town. Firefighters have reported that two primary barriers to physical activity were a lack of resources, such as facilities and equipment to exercise regularly, and the lack of energy to exercise while on- or off-duty (79). While many firefighters reported that they opted for unhealthy snacks, because of the unpredictable nature of emergency callouts and the need for quick meals (21, 22). Policy makers and fire department heads in Cape Town should take this into consideration when implementing policies to ensure that firefighters remain sufficiently active in order to either maintain or improve their physical fitness. While also ensuring that they are educated on the benefits of opting for healthier diets while on- or off-duty. In addition, implementing minimum requirements for cardiorespiratory fitness, and muscular strength and endurance are necessary to ensure that firefighters are physically capable of performing their duties (33, 80). This will also help maintain good CVH in firefighters to ensure that they are not at risk for CVD-related events while on duty (4, 81).

4.1. Strengths and limitations

This was the first study investigating the association between physical fitness, cardiovascular health, musculoskeletal health and occupational performance in Africa. The measures for physical fitness, cardiovascular health and occupational performance were objectively measured using standardized and validated instruments (43). Furthermore, this paper adds novel information into an area

http://etd.uwc.ac.za/

which has been understudied in firefighters, particularly in a South African context. There are, however, several limitations of the present study. Firstly, this study used a cross-sectional study design, which precludes the inference of causal relationships. Secondly, musculoskeletal injuries and musculoskeletal discomforts were self-reported, which may have introduced reporting bias. Thirdly, cardiorespiratory fitness was estimated using a non-exercise calculation (and we found little variability in relative $\dot{V}O_{2max}$ among groups), which may have reduced the expected associations between relative cardiorespiratory fitness and other variables. Lastly, female firefighters were under-represented, limiting the generalizability of our findings to the female firefighter population.

5. Conclusion

The present study provides evidence that multiple parameters of physical fitness and cardiovascular health are related to overall occupational performance in firefighters. The findings show that younger, leaner, fitter and stronger firefighters with a favourable cardiovascular health profile performed significantly better and were most likely able to pass each individual task. The results emphasize the need for firefighters to maintain high levels of physical fitness and a good cardiovascular health profile to ensure they maintain an acceptable level of occupational performance. This study adds novel research into the field, highlighting the factors that contribute significantly to occupational performance in firefighters, particularly in a South African context, where firefighters are understudied. The results of this study may be used by municipal fire departments to highlight the need for developing physical fitness standards to ensure the cardiovascular and musculoskeletal health of firefighters, to improve the career longevity and occupational performance of firefighters. By implementing regular physical activity programmes and promoting minimum fitness standards, fire departments could improve the services provided by firefighters, protect firefighters' health, reduce the likelihood of civilian casualties and secure essential infrastructure.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the Biomedical Research Ethics Committee (ethical clearance number: BM21/10/9) of the University of the Western Cape (UWC). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

JR, DS, ES, AK, and LL contributed to the conception and design of the study, proofread, and edited the drafts of the manuscript. JR organized the database, performed the statistical analysis, collected the data, and wrote the first draft of the manuscript. All authors contributed to the article and approved the submitted version.

Funding

This research was funded by the National Research Foundation (NRF) (grant number 141282) and The Ryoichi Sasakawa Young Leaders Fellowship Fund (SLYFF). Neither funding bodies were involved in the study design, data collection or interpretation of the data.

Acknowledgments

The authors thank all firefighters that consented to voluntarily participate in the study.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1241250/full#supplementary-material

References

1. Smith DL, Haller JM, Korre M, Sampani K, Porto LGG, Fehling PC, et al. The relation of emergency duties to cardiac death among US firefighters. *Am Chem J*. (2019) 123:736–41. doi: 10.1016/j.amjcard.2018.11.049

2. Le AB, Smith TD, McNulty LA, Dyal MA, Dejoy DM. Firefighter overexertion: a continuing problem found in an analysis of non-fatal injury among career firefighters. *Int J Environ Res Public Health*. (2020) 17:7906. doi: 10.3390/ijerph17217906

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

3. von Heimburg ED, Rasmussen AKR, Medbø JI. Physiological responses of firefighters and performance predictors during a simulated rescue of hospital patients. *Ergonomics*. (2006) 49:111–26. doi: 10.1080/00140130500435793

4. Smith DL, DeBlois JP, Kales SN, Horn GP. Cardiovascular strain of firefighting and the risk of sudden cardiac events. *Exerc Sport Sci Rev*. (2016) 44:90–7. doi: 10.1249/JES.0000000000000081

5. Michaelides MA, Parpa KM, Thompson J, Brown B. Predicting performance on a firefghter's ability test from fitness parameters. *Res Q Exerc Sport*. (2008) 79:468–75. doi: 10.1080/02701367.2008.10599513

6. Michaelides MA, Parpa KM, Henry LJ, Thompson GB, Brown BS. Assessment of physical fitness aspects and their relationship to firefighters' job abilities. The. *J Strength Cond Res*. (2011) 25:956. doi: 10.1519/JSC.0b013e3181cc23ea

7. Chizewski A, Box A, Kesler R, Petruzzello SJ. Fitness fights fires: exploring the relationship between physical fitness and firefighter ability. *Int J Environ Res Public Health*. (2021) 18:11733. doi: 10.3390/ijerph182211733

8. Sothmann MS, Gebhardt DL, Baker TA, Kastello GM, Sheppard VA. Performance requirements of physically strenuous occupations: validating minimum standards for muscular strength and endurance. *Ergonomics*. (2004) 47:864–75. doi: 10.1080/00140130410001670372

9. Sothmann MS, Saupe KW, Jasenof D, Blaney J, Fuhrman SD, Woulfe T, et al. Advancing age and the cardiorespiratory stress of fire suppression: determining a minimum standard for aerobic fitness. *Hum Perform*. (1990) 3:217–36. doi: 10.1207/s15327043hup0304_1

10. Swank AM, Adams KJ, Barnard KL, Berning JM, Stamford BA. Age-related aerobic power in volunteer firefighters, a comparative analysis. *J Strength Cond Res*. (2000) 14:170–174. Available from: https://journals.lww.com/nsca-jscr/Fulltext/2000/05000/Age_Related_Aerobic_Power_in_Volunteer.9.aspx

11. Elsner KL, Kolkhorst FW. Metabolic demands of simulated firefighting tasks. *Ergonomics*. (2008) 51:1418–25. doi: 10.1080/00140130802120259

12. Ras J, Kengne AP, Smith DL, Soteriades ES, November RV, Leach L. Effects of cardiovascular disease risk factors, musculoskeletal health, and physical fitness on occupational performance in firefighters: a systematic review and meta-analysis. *Int J Environ Res Public Health*. (2022) 19:11946. doi: 10.3390/ijerph191911946

13. Rhea MR, Alvar BA, Gray R. Physical fitness and job performance of firefighters. *J Strength Cond Res*. (2004) 18:348–52. doi: 10.1519/R-12812.1

14. Skinner TL, Kelly VG, Boytar AN, Peeters G, Rynne SB. Aviation rescue firefighters physical fitness and predictors of task performance. *J Sci Med Sport*. (2020) 23:1228–33. doi: 10.1016/j.jsams.2020.05.013

15. Smith DL, Barr DA, Kales SN. Extreme sacrifice: sudden cardiac death in the US fire service. *Extrem Physiol Med*. (2013) 2:1–9. doi: 10.1186/2046-7648-2-6

16. Yang J, Teehan D, Farioli A, Baur DM, Smith D, Kales SN. Sudden cardiac death among firefighters ≤45 years of age in the United States. *Am J Cardiol*. (2013) 112:1962–7. doi: 10.1016/j.amjcard.2013.08.029

17. Sen S, Palmieri T, Greenhalgh D. Cardiac fatalities in firefighters: an analysis of the U.S. fire administration database. *J Burn Care Res*. (2016) 37:191–5. doi: 10.1097/BCR.0000000000000225

18. Ras J, Leach L. Prevalence of coronary artery disease risk factors in firefighters in the city of Cape Town fire and rescue service – a descriptive study. *J Public Health Res*. (2021) 10:2000. doi: 10.4081/jphr.2021.2000

19. Ras J, Leach L. Firefighters' health knowledge, cardiovascular disease risk factors and sociodemographic characteristics as predictors of firefighters attitudes toward health. *J Occup Environ Med*. (2022) 64:e705–13. doi: 10.1097/JOM.0000000000002679

20. Ras J, Mosie D, Strauss M, Leach L. Knowledge of and attitudes toward health and cardiovascular disease risk factors among firefighters in Cape Town, South Africa. *J Public Health Res*. (2021) 11:2307. doi: 10.4081/jphr.2021.2307

21. Bucala M, Sweet E. Obesity in the fire service: an inside look at the perceptions of firefighters towards obesity and other health issues. *Res Sq*. (2019). doi: 10.21203/rs.2.15518/v1

22. Dobson M, Choi B, Schnall PL, Wigger E, Garcia-Rivas J, Israel L, et al. Exploring occupational and health behavioral causes of firefighter obesity: a qualitative study. *Am J Ind Med*. (2013) 56:776–90. doi: 10.1002/ajim.22151

23. Kay BF, Lund MM, Taylor PN, Herbold NH. Assessment of firefighters' cardiovascular disease-related knowledge and behaviors. *J Am Diet Assoc*. (2001) 101:807–9. doi: 10.1016/S0002-8223(01)00200-0

24. Hong O, Phelps S, Feld J, Vogel S. Occupational injuries, duty status, and factors associated with injuries among firefighters. *Workplace Health Saf*. (2012) 60:517–23. doi: 10.1177/216507991206001203

25. Yoon JH, Kim YK, Kim KS, Ahn YS. Characteristics of workplace injuries among nineteen thousand Korean firefighters. *J Korean Med Sci*. (2016) 31:1546. doi: 10.3346/jkms.2016.31.10.1546

26. Nazari G, Osifeso TA, MacDermid JC. Distribution of number, location of pain and comorbidities, and determinants of work limitations among firefighters. *Rehabil Res Practice*. (2020), 2020:1942513

27. Durand G, Tsismenakis AJ, Jahnke SA, Baur DM, Christophi CA, Kales SN. Firefighters' physical activity: relation to fitness and cardiovascular disease risk. *Med Sci Sports Exerc*. (2011) 43:1752–9. doi: 10.1249/MSS.0b013e318215cf25

28. Barry AM, Lyman KJ, Dicks ND, Landin KD, McGeorge CR, Hackney KJ, et al. Firefighters' physical activity and waist circumference as predictors of VO2max. *J Occup Environ Med*. (2019) 61:849–53. doi: 10.1097/JOM.0000000000001690

29. Yu CCW, Au CT, Lee FYF, So RCH, Wong JPS, Mak GYK, et al. Association between leisure time physical activity, cardiopulmonary fitness, cardiovascular risk factors, and cardiovascular workload at work in firefighters. *Saf Health Work*. (2015) 6:192–9. doi: 10.1016/j.shaw.2015.02.004

30. Ras J, Leach L. Relationship between physical activity, coronary artery disease risk factors and musculoskeletal injuries in the City of Cape Town fire and rescue service. *INQUIRY: J Health Care Organ Provis Financ*. (2022) 59:00469580221084485. doi: 10.1177/00469580221084485

31. Vicente MM, Herrero DC, Prieto JP. Cardiorespiratory fitness in Spanish firefighters. *J Occup Environ Med*. (2021) 63:e318–22. doi: 10.1097/JOM.0000000000002199

32. Baur DM, Christophi CA, Cook EF, Kales SN. Age-related decline in cardiorespiratory fitness among career firefighters: modification by physical activity and adiposity. *J Obes*. (2012) 2012:10903. doi: 10.1155/2012/710903

33. Ras J, Soteriades ES, Smith DL, Kengne AP, Leach L. Association between physical fitness and musculoskeletal health in firefighters. *Front Physiol*. (2023):14. doi: 10.3389/fphys.2023.1210107

34. Poston WSC, Jitnarin N, Haddock CK, Jahnke SA, Tuley BC. Obesity and injury-related absenteeism in a population-based firefighter cohort. *Obesity*. (2011) 19:2076–81. doi: 10.1038/oby.2011.147

35. Phelps SM, Drew-Nord DC, Neitzel RL, Wallhagen MI, Bates MN, Hong OS. Characteristics and predictors of occupational injury among career firefighters. *Workplace Health Saf*. (2018) 66:291–301. doi: 10.1177/2165079917740595

36. Williford HN, Duey WJ, Olson MS, Howard R, Wang N. Relationship between fire fighting suppression tasks and physical fitness. *Ergonomics*. (1999) 42:1179–86. doi: 10.1080/001401399185063

37. Davis PO, Dotson CO, Santa Maria DL. Relationship between simulated fire fighting tasks and physical performance measures. *Med Sci Sports Exerc*. (1982) 14:13. doi: 10.1249/00005768-198201000-00013

38. von Heimburg E, Ingulf Medbø J, Sandsund M, Reinertsen RE. Performance on a work-simulating firefighter test versus approved laboratory tests for firefighters and applicants. *Int J Occup Saf Ergon*. (2013) 19:227–43. doi: 10.1080/10803548.2013.11076981

39. Davis SC, Jankovitz KZ, Rein S. Physical fitness and cardiac risk factors of professional firefighters across the career span. *Res Q Exerc Sport*. (2002) 73:363–70. doi: 10.1080/02701367.2002.10609033

40. Seyedmehdi SM, Attarchi M, Cherati AS, Hajsadeghi S, Tofighi R, Jamaati H. Relationship of aerobic fitness with cardiovascular risk factors in firefighters. *Work*. (2016) 55:155–61. doi: 10.3233/WOR-162375

41. Strauss M, Foshag P, Jehn U, Brzęk A, Littwitz H, Leischik R. Higher cardiorespiratory fitness is strongly associated with lower cardiovascular risk factors in firefighters: a cross-sectional study in a German fire brigade. *Sci Rep*. (2021) 11:2445. doi: 10.1038/s41598-021-81921-1

42. Poplin GS, Roe DJ, Peate W, Harris RB, Burgess JL. The Association of Aerobic Fitness with Injuries in the fire service. *Am J Epidemiol*. (2014) 179:149–55. doi: 10.1093/aje/kwt213

43. Ras J, Smith DL, Soteriades ES, Kengne AP, Leach L. A pilot study on the relationship between cardiovascular health, musculoskeletal health, physical fitness and occupational performance in firefighters. *Eur J Investig Health Psychol Educ*. (2022) 12:1703–18. doi: 10.3390/ejihpe12110120

44. Liguori GMedicine AC of S, Fountaine CJ. ACSM's guidelines for exercise testing and prescription. Wolters Kluwer; (2021). (American College of Sports Medicine Series). Available from: https://books.google.co.za/books?id=6P-azQEACAAJ

45. Rexhepi AM, Brestovci B. Prediction of VO2max based on age, body mass, and resting heart rate. *Human Movement*. (2014) 15:56–9. doi: 10.2478/humo-2014-0003

46. D'Agostino RB, Vasan RS, Pencina MJ, Wolf PA, Cobain M, Massaro JM, et al. General cardiovascular risk profile for use in primary care. *Circulation*. (2008) 117:743–53. doi: 10.1161/CIRCULATIONAHA.107.699579

47. Lloyd-Jones DM, Leip EP, Larson MG, D'Agostino RB, Beiser A, Wilson PWF, et al. Prediction of lifetime risk for cardiovascular disease by risk factor burden at 50 years of age. *Circulation*. (2006) 113:791–8. doi: 10.1161/CIRCULATIONAHA.105.548206

48. Lloyd-Jones DM, Braun LT, Ndumele CE, Smith SC, Sperling LS, Virani SS, et al. Use of risk assessment tools to guide decision-making in the primary prevention of atherosclerotic cardiovascular disease: a special report from the American Heart Association and American College of Cardiology. *Circulation*. (2019) 139:e1162–77. doi: 10.1161/CIR.0000000000000638

49. Hedge A, Morimoto S, Mccrobie D. Effects of keyboard tray geometry on upper body posture and comfort. *Ergonomics*. (1999) 42:1333–49. doi: 10.1080/001401399184983

50. Crawford JO. The Nordic musculoskeletal questionnaire. *Occup Med (Chic Ill)*. (2007) 57:300–1. doi: 10.1093/occmed/kqm036

51. Templeton GF. A two-step approach for transforming continuous variables to normal: implications and recommendations for IS research. *Commun Assoc Inf Syst*. (2011) 28:41–58. doi: 10.17705/1CAIS.02804

http://etd.uwc.ac.za/

52. Siddall AG, Stevenson RDM, Turner PJF, Bilzon JLJ. Physical and physiological performance determinants of a firefighting simulation test. *J Occup Environ Med*. (2018) 60:637–43. doi: 10.1097/JOM.0000000000001313

53. Saari AI, Renz G, Davis P, Abel MG. The influence of age on firefighter combat challenge performance and exercise training habits. *J. Strength Cond. Res*. (2020). Available at: www.nsca.com

54. Siddall AG, Stevenson RDM, Turner PFJ, Stokes KA, Bilzon JLJ, Stevenson RDM, et al. Development of role-related minimum cardiorespiratory fitness standards for firefighters and commanders (2016) 59:1335. doi: 10.1080/00140139.2015.1135997,

55. Phillips DB, Scarlett MP, Petersen SR. The influence of body mass on physical fitness test performance in male firefighter applicants. *J Occup Environ Med*. (2017) 59:1101–8. doi: 10.1097/JOM.0000000000001145

56. Perroni F, Guidetti L, Cignitti L, Baldari C. Age-related changes in upper body strength and lower limb power of professional Italian firefighters. Sport Sci. *Health*. (2015) 11:279–85. doi: 10.1007/s11332-015-0236-y

57. Perroni F, Cignitti L, Cortis C, Capranica L. Physical fitness profile of professional Italian firefighters: differences among age groups. *Appl Ergon*. (2014) 45:456–61. doi: 10.1016/j.apergo.2013.06.005

58. Walker A, Driller M, Argus C, Cooke J, Rattray B. *The ageing Australian firefighter: An argument for age-based recruitment and fitness standards for urban fire services*. *57*, Ergonomics. Taylor & Francis; (2014), 612–621

59. Chu DJ, al Rifai M, Virani SS, Brawner CA, Nasir K, Al-Mallah MH. The relationship between cardiorespiratory fitness, cardiovascular risk factors and atherosclerosis. *Atherosclerosis*. (2020) 304:44–52. doi: 10.1016/j.atherosclerosis.2020.04.019

60. Donovan R, Nelson T, Peel J, Lipsey T, Voyles W, Israel RG. Cardiorespiratory fitness and the metabolic syndrome in firefighters. *Occup Med (Chic Ill)*. (2009) 59:487–92. doi: 10.1093/occmed/kqp095

61. Myhre LG, Tucker DM, Bauer DH, Fisher JR Jr, Grimm WH. Relationship between selected measures of physical fitness and performance of a simulated fire fighting emergency task. ARMSTRONG LAB BROOKS AFB TX; (1997). Available at: https://apps.dtic.mil/sti/citations/ADA319915

62. Schonfeld BR, Doerr DF, Convertino VA. An occupational performance test validation program for fire fighters at the Kennedy Space Center. *J Occup Environ Med*. (1990) 32. doi: 10.1097/00043764-199007000-00016

63. Siddall A, Standage M, Stokes K, Bilzon J. Development of occupational fitness standards for the UK fire and rescue services. (FRS: University of Bath) (2014) (October). 59:1–59.

64. Nazari G, Lu S, MacDermid JC. Quantifying physiological responses during simulated tasks among Canadian firefighters: a systematic review and meta-analysis. *J Mil Veteran Fam Health*. (2021) 7:55–75. doi: 10.3138/jmvfh-2019-0063

65. Nazari G, MacDermid JC, Sinden KE, Overend TJ. The relationship between physical fitness and simulated firefighting task performance. *Rehabil Res Pract*. (2018) 2018:1–7. doi: 10.1155/2018/3234176

66. Misner JE, Boileau RA, Plowman SA, Elmore BG, Gates MA, Gilbert JA, et al. Leg power characteristics of female firefighter applicants. *J Occup Environ Med*. (1988) 30:433–7. doi: 10.1097/00043764-198805000-00011

67. Kleinberg CR, Ryan ED, Tweedell AJ, Barnette TJ, Wagoner CW. Influence of lower extremity muscle size and quality on stair-climb performance in career firefighters. *J Strength Cond Res*. (2016) 30:1613–8. doi: 10.1519/JSC.0000000000001268

68. Hilyer JC, Brown KC, Sirles AT, Peoples L. A flexibility intervention to reduce the incidence and severity of joint injuries among municipal firefighters. *J Occup Med*. (1990) 32:631–7. doi: 10.1097/00043764-199007000-00015

69. DeFina LF, Haskell WL, Willis BL, Barlow CE, Finley CE, Levine BD, et al. Physical activity versus cardiorespiratory fitness: two (partly) distinct components of cardiovascular health? *Prog Cardiovasc Dis*. (2015) 57:324–9. doi: 10.1016/j.pcad.2014.09.008

70. Alves AJ, Viana JL, Cavalcante SL, Oliveira NL, Duarte JA, Mota J, et al. Physical activity in primary and secondary prevention of cardiovascular disease: overview updated. *World J Cardiol*. (2016) 8:575–83. doi: 10.4330/wjc.v8.i10.575

71. Hauschild VD, DeGroot DW, Hall SM, Grier TL, Deaver KD, Hauret KG, et al, *Occup environ med*. *74*, Occupational and Environmental Medicine. BMJ Publishing Group; (2017). 144–153.

72. Lesniak AY, Sell KM, Morris C, Abel MG. Relationship between heart rate variability vs. occupational performance, physical activity and fitness measures in structural firefighters. *J Sport Human Perf*. (2022) 10:56–72. doi: 10.12922/jshp.v10i1.169

73. Porto LGG, Schmidt ACB, de Souza JM, Nogueira RM, Fontana KE, Molina GE, et al. Firefighters' basal cardiac autonomic function and its associations with cardiorespiratory fitness. *Work*. (2019) 62:485–95. doi: 10.3233/WOR-192883

74. Tomes C, Schram B, Orr R. Relationships between heart rate variability, occupational performance, and fitness for tactical personnel: a systematic review. *Front Public Health*. (2020) 8:583336. doi: 10.3389/fpubh.2020.583336

75. Rodrigues S, Paiva JS, Dias D, Cunha JPS. Stress among on-duty firefighters: an ambulatory assessment study. *PeerJ*. (2018) 6:e5967. doi: 10.7717/peerj.5967

76. Ras J, Leach L. Use of Mobile Technology in Assessing Occupational Performance and Stress in firefighters. D Mentor, (Ed.) *Handbook of research on new media, training, and skill development for the modern workforce*. Hershey, PA, USA: IGI Global; (2022), 150–186

77. Williams-Bell FM, Villar R, Sharratt MT, Hughson RL. Physiological demands of the firefighter candidate physical ability test. *Med Sci Sports Exerc*. (2009) 41:653–62. doi: 10.1249/MSS.0b013e31818ad117

78. MacDermid JC, Tang K, Sinden KE, D'Amico R. Work functioning among firefighters: a comparison between self-reported limitations and functional task performance. *J Occup Rehabil*. (2019) 29:194–204. doi: 10.1007/s10926-018-9778-6

79. Muegge CM, Zollinger TW, Song Y, Wessel J, Monahan PO, Moffatt SM. Barriers to weight management among overweight and obese firefighters. *J Occup Environ Med*. (2020) 62:37–45. doi: 10.1097/JOM.0000000000001751

80. Ras J, Smith DL, Soteriades ES, Kengne AP, Leach L. Association between physical fitness and cardiovascular health in firefighters. *Int J Environ Res Public Health*. (2023) 20. doi: 10.3390/ijerph20115930

81. Smith DL, Haller JM, Korre M, Fehling PC, Sampani K, Grossi Porto LG, et al. Pathoanatomic findings associated with duty-related cardiac death in US firefighters: a case-control study. *J Am Heart Assoc*. (2018) 7:e009446. doi: 10.1161/JAHA.118.009446

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

CHAPTER TWELVE: PUBLICATION ELEVEN − ORIGINAL RESEARCH ARTICLE SEVEN

Evaluation of the Relationship between Occupational-Specific Task Performance and Measures of Physical Fitness, Cardiovascular and Musculoskeletal Health in Firefighters

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Abstract

Introduction: Firefighters are required to perform physically strenuous tasks such as hose drags, victim rescues, forcible entries and stair climbs to complete their public safety mission. Occupational-specific tasks (OSTs) are often used to evaluate the ability of firefighters to adequately/safely perform their duties. Depending on the regions, OSTs include six to eight individual tasks, which emphasize distinct aspects of their physical fitness, while also requiring different levels of cardiovascular and musculoskeletal health. Therefore, the aim of this study was to evaluate the relationship between specific occupational task performance and measures of physical fitness, cardiovascular and musculoskeletal health (MSH).

Methods: Using a cross-sectional design, 282 full-time male and female firefighters were recruited. A researcher-generated questionnaire and physical measures were used to collect data on sociodemographic characteristics, cardiovascular health (CVH), MSH and weekly physical activity habits. Physical measures were used to collect data on physical fitness and occupational-specific task performance (OSTP).

Results: Absolute cardiorespiratory fitness (ab$\dot{V}O_2max$), grip strength, leg strength, push-ups, sit-ups and lean body mass (all $p<0.001$) had an inverse association with completion times on all OSTP. Age was positively related to the performance of all tasks (all $p<0.05$). Higher heart rate variability (HRV) was associated with better performance on all tasks (all $p<0.05$). Bodyfat percentage (BF%) and diastolic blood pressure were positively associated with the step-up task ($p<0.05$). Lower back musculoskeletal injury (LoBMSI), musculoskeletal discomfort (MSD), and lower limb MSD were associated with a decreased odds of passing the step-up. Upper body MSIs (UBMSI), LoBMSIs and Lower back MSD were associated with decreased odds of passing the rescue drag.

Conclusion: Firefighters that were taller, leaner, stronger and fitter with a more favourable CVH profile, higher HRV and less musculoskeletal discomfort performed best on all OSTs.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

12.1. Introduction

Firefighting is a strenuous and challenging occupation where firefighters are required to be prepared, at all times, to respond to fire and rescue emergencies. Some of these emergencies, especially those on the fire ground, require high levels of physical exertion, which often entail coping with environmental stressors, such as high temperatures, physical hazards and dangerous chemicals and fumes, [1–3]. The harsh environments often require firefighters to be encapsulated in personal protective equipment (PPE), placing an additional burden on an already strained cardiovascular and musculoskeletal system [3–5]. The strenuous work conditions of firefighting necessitate that firefighters maintain peak physical conditioning to manage these various and, often, unpredictable high-demand environments and situations [5–7].

Although firefighting elicits near maximum physiological responses, placing significant strain on the cardiovascular system, studies have found that firefighters often have multiple cardiovascular disease (CVD) risk factors and poor overall cardiovascular health (CVH) [8–10]. The cardiovascular risk profile of firefighters progressively worsens as they age [11,12]. In addition, despite many firefighters possessing the ability to perform the necessary work-related tasks required in firefighting, many firefighters are reported to not meet the minimum physical fitness levels required for the profession [3,13–16], placing an additional burden on an already strained cardiovascular and musculoskeletal system [1–3,5,6]. Low levels of CVH and physical fitness are prominent precursors contributing to the high incidence of cardiac events and over-exertion related incidents, which account for 40 to 50% of all on-duty fatalities among firefighters [1,2,4]. To cope with the physiological and psychological stressors of the job firefighters need good cardiovascular and musculoskeletal health and acceptable level of physical fitness [3,5,6].

Previous research has indicated that age and obesity were associated with significantly reduced

http://etd.uwc.ac.za/

occupational performance of firefighters, particularly for duties requiring heavy lifting and dragging [3,5,17,18]. Activities that include a large static component may provide an exaggerated blood pressure response, especially if the tasks require overhead movements, which may be especially prominent in firefighters suffering from blood pressure irregularities [19–21]. Firefighters are encouraged by fire departments to remain physically active to ensure they maintain an adequate level of physical fitness. Previous studies have indicated that cardiorespiratory fitness may be the most important factor contributing to adequate occupational performance [22,23]. In addition, a higher level of muscle strength and endurance has been shown to improve occupational performance, particularly for tasks involving heavy lifting, dragging, pulling and breaching [3,5,6,18]. An added benefit of firefighters remaining physically active is the preservation of MSH, which constitutes a major concern in the profession [24,25]. Deterioration of MSH, which is common in firefighters, may reduce occupational performance due to guarding of the painful area [26,27] or reduced force production as a protective mechanism. Firefighting requires firefighters to perform awkward movement patterns to perform their duties, while carrying asymmetrical loads [27–29]. It has been suggested that previous musculoskeletal injuries (MSIs) or current MSD may impact firefighters' effectiveness in performing specific body movements [26]. Thus, firefighters are required to maintain high levels of work functioning in all occupational-specific tasks [27,30,31].

To assess firefighters' occupational performance, fire departments use simulation protocols designed to replicate the duties that firefighters are required to perform [5,6,32,33]. Each occupational-specific task reflects a core or critical task that firefighters are required to perform, such as the forcible entry, hose drag, ladder raise and victim rescue [3,5,6]. The performance of each task is timed to ensure firefighters are able to complete their duties with sufficient rigour and intensity. In addition, to pass the occupational-specific tasks, firefighters

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

are required to complete each task within a given time limit. Several studies have assessed the relationship between physical fitness [3,5,6,18], specific CVH [3,18,34] and MSH [27] parameters and occupational performance in firefighters. However, there remains a need to evaluate the relationship between performance on each of the individual occupational-specific tasks and measures of physical fitness, CVH and MSH, warranting further investigation. Determining the factors influencing specific firefighter task performance in this population may highlight the tasks firefighters are most likely to fail and assist in the establishment of intervention strategies to assist firefighters in improving their performance. Therefore, the aim of this study was to evaluate the performance of occupational-specific tasks in association with firefighters' physical fitness, cardiovascular health (CVH) and musculoskeletal health (MSH).

12.2. Methods

12.2.1. Study Design and Population

A cross-sectional study design was employed to collect information on occupational performance, using occupational-specific tasks (based on the physical ability test), physical fitness (cardiorespiratory fitness, muscular strength and endurance, flexibility, and body composition), CVH (CVD risk factors, CVH metrics, heart rate variability) and MSH (MSIs and MSD) in firefighters. In total, 309 full-time male and female firefighters from the City of Cape Town Fire and Rescue Service (CoCTFRS), ranging in age from 20 to 65 years, took part in the study. From the original 309 firefighters, 283 agreed to participate in the physical ability test (PAT) on the day of testing. Amongst the 282 that performed the PAT, 268 completed all occupational-specific tasks that were part of the PAT. All volunteers for this study provided written informed consent before proceeding. Data collection took place from June to August of 2022. The University of the Western Cape's Biomedical Research Ethics Committee gave

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

its approval (ethical clearance number: BM21/10/9). The Chief Fire Officer, the Department of Policy and Strategy, and the research all gave their approval.

12.2.2. Sampling and Participant Recruitment

Data collection took place during annual physical fitness assessments at a standardized fire station located in the City of Cape Town (CCT) metropolitan area to assure consistency in the terrain, environmental conditions and testing surface. To ensure the consistency and reliability of the testing results, all physical measures and the occupational-specific tasks were collected and recorded by trained researchers that were familiarised with all the testing instruments and research procedures [35]. Every third firefighter from the 96 platoons (32 fire stations) was selected using random systematic sampling. The 96 firefighter platoons each had 8 to 12 members. All firefighters that were between the ages of 20-65 years were eligible to participate in the study. Firefighters who were on administrative duty, sick leave, worked part-time or seasonally, or did not participate in the PAT, on the day of testing, were all disqualified from partaking in this study.

UNIVERSITY of the
WESTERN CAPE

12.2.3. Occupational-Specific Tasks

The occupational-specific tasks, that constituted the PAT, were used to assess operational performance and were conducted according to the testing protocol of the CoCTFRS wellness manual. The CoCTFRS worked with professionals in the field to establish the occupational-specific tasks as part of the fitness and wellness programme. The OSTs consist of tasks that are intended to replicate the numerous tasks that firefighters are required to carry out, while also attempting to replicate the physical strains to which firefighters are frequently exposed to. Firefighters were required to complete the entire simulation protocol in under 9 minutes (540

http://etd.uwc.ac.za/

seconds), while firefighters wore their full PPE equipment and breathing apparatus set, in order to pass. Firefighters were allowed 20 seconds of recovery between tasks. The simulation included six tasks, which were used to simulate various stressors firefighters are placed under. These tasks encompassed the step-up, charged hose drag and pull, forcible entry, equipment carry, ladder raise and extension and the rescue drag. Individual OSTs each had their own completion times that needed to be met in order to pass the PAT. Failure to complete a task resulted in firefighters being graded as “not yet competent”. The step-up required firefighters to perform 30 step-ups on a standardized platform of 200 mm and were given a time limit of 90 seconds. The charged hose drag and pull required firefighters to drag a tyre 27 meters, drop to one knee or in a seated position, pull a tyre another 15 meters and had a time limit of 180 seconds. The firefighters moved to the forcible entry task where they were required to strike the tyre, using a sledge hammer, moving the tyre 600 mm in under 60 seconds. For the equipment carry, firefighters were tasked to remove two 25 kg foam drums from a 1.2-meter platform, carry the foam drums 25 meters and walk back another 25 meters, placing the drums back on the platform which needed to be completed in under 90 seconds. For the ladder raise and extension firefighters were tasked to walk a seven-to-eight-meter ladder toward a building, place the ladder against the building and immediately walk toward a hauling line and hoist a 35 kg drum until it reaches the pulley and then lower the drum, in under the time limit of 90 seconds. Then, firefighters lower the ladder and walk the ladder back to the starting position. The rescue drag required firefighters to grasp an 80 kg tyre and drag the tyre 11 meters, perform a 180-degree turn and continue for another 11 meters toward the finish line in under 60 seconds. A full description of the PAT can be found in Ras et al. [35].

12.2.3. Physical Fitness Measures

Physical fitness was measured using the American College of Sports Medicine (ACSM)

http://etd.uwc.ac.za/

guidelines [36]. Cardiorespiratory capacity was calculated using a validated non-exercise calculation [35] to determine oxygen consumption ($\dot{V}O_2$). The push-ups and sit-ups tests were used to assess muscular endurance, handgrip and leg strength tests were used to assess upper and lower body muscle strength and the sit-and-reach test was used to assess flexibility. Body mass and Lean body mass (LBM) was used as a measure for body composition and assessed using a bioelectrical impedance (BIA) analyser. For a full description of the methods used to assess physical fitness consult the study published by: Ras et al. [37].

12.2.4. Classification of Physical Fitness Measures

For relative cardiorespiratory fitness, 42 mL•kg•min [38] was used to indicate the minimum cardiorespiratory fitness needed for firefighting. Cardiorespiratory fitness was expressed as both absolute and relative cardiorespiratory fitness, which was noralized to body mass, and odds ratios were calculated on both separately. Due to the absence of standardized minimum requirements of abosulte cardiorespiratory fitness, muscular strength, endurance and flexibility, the 50th percentile was used to indicate good levels of physical fitness. An absolute cardiorespiratory fitness level of 3.40 L•min was considered "good". For grip and leg strength, firefighters that had a grip strength above 89.9 kg and leg strength above 116.5 kg were considered "good". For push-ups and sit-ups, firefighters that performed 30 or more push-ups and sit-ups were considered "good". For flexibility, a sit-and-reach above 43 cm was considered "good". Firefighters falling below the 50th percentile were classified as having a "low" level of muscular strength and endurance and flexibility.

12.2.5. Cardiovascular Health Measures

Cardiovascular health (CVH) was investigated using several approaches. These approaches

http://etd.uwc.ac.za/

included three main subcomponents, specifically traditional CVD risk factors, CVH metrics and heart rate variability (HRV). Using standardized techniques [36], height was measured with a stadiometer and waist and hip circumference were assessed using a tape measure, and body fat percentage (BF%) was calculated using a BIA scale. The traditional CVD risk factors included age, obesity, physical inactivity, dyslipidaemia, diabetes, hypertension and cigarette smoking. Cardiovascular health metrics were used to classify firefighters' cardiovascular health index (CVHI). The CVH metrics included smoking status, blood pressure, non-fasting blood glucose (NFBG), total cholesterol (TC), an ideal/good body mass index (BMI), level of physical activity, and diet. In addition, CVHI was classified as "poor" if firefighters had zero to two metrics classified as ideal, "intermediate" if firefighters had three to four metrics classified as ideal and "good" if firefighters had five to seven metrics rated as ideal. The 2008 Framingham risk model, developed by D'Agostino et al. [39], was used to assess cardiovascular risk of firefighters. The 2008 Framingham risk model, developed by D'Agostino et al. [39], was used to assess cardiovascular disease risk of firefighters. In addition, to determine the cardiovascular disease risk among firefighters, the American College of Cardiology (ACC) 10-year atherosclerotic cardiovascular disease (ASCVD) and ASCVD lifetime risks were calculated. [40,41]. For HRV, a Polar™ (Polar Electro Oy, Kempele, Finland) H10 heart rate monitor was used, at rest, while firefighters were in a seated position, and analyzed using the Kubio© Software version 3.4.3. For more information on the methods used to assess CVH, as well as the classifications of CVD risk factors and CVH metrics, please refer to Ras et al. [42].

12.2.6. Classification of Musculoskeletal Health

Musculoskeletal health was subdivided as musculoskeletal injury (MSI) and musculoskeletal discomfort (MSD) status, which was further separated into those that sustained an injury while on duty and those that did not, and those that are experiencing MSD and those without.

http://etd.uwc.ac.za/

Musculoskeletal injury and discomfort were measured subjectively via two validated questionnaires, namely the Cornell Musculoskeletal Discomfort Questionnaire [43] and the Nordic Musculoskeletal Questionnaire [44]. Subcategories for those that reported MSIs and MSD were categorized based on the location of the MSI or the MSD experienced, specifically upper body MSI (UBMSI), lower body MSI (LBMSI), lower back MSI (LoBMSI) upper body MSD (UBMSD), lower body musculoskeletal discomfort (LBMSD) and lower back MSD (LoMSD).

12.2.7. Statistical Analysis

The data were analysed using SPSS® software, version 28 (Chicago, Illinois, USA). Descriptive statistical analyses, such as the median and 25th and 75th percentiles were performed. Thereafter, group comparisons used the Mann-Whitney U and Kruskal-Wallis H test. Univariable and multivariable linear regressions were performed to determine the independent variables associated with occupational-specific tasks, i.e., step-up, charged hose drag and pull, forcible entry, equipment carry, ladder raise and extension and rescue drag, which was considered the outcome (dependent variable) in firefighters. Completion time for each tasks was recorded to nearest second. Univariable and multivariable logistic regressions were performed to determine the independent variables associated with the occupational-specific tasks pass rates. Pass rates were calculated from predetermined cut-off values. Exploratory physical fitness variables included abV̇O2max, relV̇O2max, grip strength, leg strength, push-ups, sit-ups, and LBM. Exploratory CVH variables included age, BMI, BF%, WC, SBP, DBP, TC, NFBG, weekly MET minutes and Framingham risk score. Exploratory variables for MSH included MSI, upper body musculoskeletal injury (UBMSI), lower body musculoskeletal injury (LBMSI), lower back musculoskeletal injury (LoBMSI), MSD, lower back musculoskeletal discomfort (LoBMSD), upper body musculoskeletal discomfort

http://etd.uwc.ac.za/

(UBMSD) and lower body musculoskeletal discomfort (LBMSD). Multivariable models were adjusted for age, sex, height and weekly metabolic equivalent minutes. To control for collinearity the VIF and Durbin-Watson statistics were used. A VIF <5 was used to indicate that no substantial collinearity was present and a Durbin-Watson statistic between 1.5 and 2.5 indicated no autocorrelation was present. Linear least absolute shrinkage and selection operator (LASSO) regression was also used to build a prediction model for each CVH parameter to reduce the number of predictors (n = 19). To ensure cross-validation of the model and evaluate the predictive ability of the model a five-fold cross-validation method was used. For reporting, the more parsimonious model within 1 standard error of the optimal model was preferred. Indicators (physical fitness) with non-zero coefficients were reported, only. For data that were not normally distributed, data were fractionally ranked, and then normalized using the inverse DF, IDF.NORMAL transformation [45]. A p-value of <0.05 was used to indicate statistical significance.

12.3. Results

In Table 12.1 we present data on all six occupational-specific tasks based on participant characteristics. Time to complete all occupational-specific tasks were significantly different between male and female firefighters (p <0.001), with males performing better than females. Based on age-group, performance time of the individual occupational-specific tasks was significantly different between age categories (p <0.001). Firefighters with good grip strength (p <0.01), leg strength (p <0.001), push-ups (p <0.001) and sit-ups (p <0.001) had significantly shorter completion time on all individual occupational-specific tasks. Aged firefighters had significantly longer completion times on all occupational-specific tasks (p <0.01), except the forcible entry. Firefighters that were obese, had central obesity, and were physical inactive had

http://etd.uwc.ac.za/

significantly longer completion times for all the occupational-specific tasks ($p < 0.01$). Firefighters that reported UBMSIs had longer completion times on the step-up and ladder raise and extension tasks ($p < 0.05$). Firefighters that reported LoBMSIs had longer completion times on the step-up, charged hose drag and pull and the ladder raise and extension ($p < 0.05$), and firefighters with LoBMSD had longer completion times on the ladder raise and extension ($p < 0.05$).

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Table 12.1: Differences among individual occupational tasks according to sex, age-group, physical fitness, cardiovascular and musculoskeletal health.

	Step-Up		Charged hose drag and pull		Forcible entry		Equipment carry		Ladder raise and extension		Rescue drag	
Variable	N	$\tilde{X}$ (p25th - p75th)	N	$\tilde{X}$ (p25th - p75th)	N	$\tilde{X}$ (p25th - p75th)	N	$\tilde{X}$ (p25th - p75th)	N	$\tilde{X}$ (p25th - p75th)	N	$\tilde{X}$ (p25th - p75th)
Demographic characteristics												
Total firefighters	279	65.0 (58.0, 75.0)	277	86.0 (66.0, 115.0)	273	32.0 (21.0, 48.5)	271	50.0 (40.0, 67.0)	268	72.5 (55.0, 96.8)	267	51.0 (38.0, 77.0)
Sex												
Male	248	65.0 (58.0, 74.0)	247	82.0 (65.0, 105.0)	244	29.6 (20.0, 46.0)	242	48.1 (38.0, 60.9)	239	70.0 (54.0, 89.0)	239	50.0 (37.0, 66.0)
Female	31	79 (72.0, 103.0)	30	172.5(120.3, 218.5)	29	54 (38.2, 100.0)	29	75 (57.5, 112.5)	29	75.0 (57.5, 112.5)	28	111.0 (78.8, 164.5)
p-value		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †
Age group												
20-29 years	72	63.5 (56.0, 71.0)	72	80.4 (59.5, 99.8)	71	27.0 (20.0, 36.0)	71	46.0 (35.8, 55.0)	71	67.4 (55.0, 88.0)	71	48.0 (36.0, 62.0)
30-39 years	88	63 (57.0, 73.9)	88	79.0 (63.0, 106.8)	87	27.0 (19.0, 49.0)	87	47.0 (37.0, 58.0)	86	66.5 (54.0, 80.5)	87	48.0 (36.4, 69.3)
40-49 years	70	67.5 (61.0, 76.5)	70	107.0 (79.0, 148.5)	70	38.0 (26.0, 60.0)	68	57.5 (45.0, 73.8)	67	87.0 (59.0, 120.0)	66	56.5 (42.4, 89.3)
50+ years	48	73.9 (62.2, 84.8)	46	98.0 (79.5, 141.3)	44	37.5 (22.8, 53.8)	44	58.0 (44.0, 86.3)	43	82.0 (60.0, 102.0)	43	57.0 (46.9, 85.4)
p-value		<0.001 †		<0.001 †		0.004 **		<0.001 †		0.001 **		0.002 **
Physical fitness												
Good rel$\dot{V}O_2$max	144	65.0 (57.4, 72.9)	144	89.5 (68.0, 110.8)	142	31.5 (22.8, 48.0)	141	(50.0 (39.0, 66.5)	139	74.0 (55.0, 96.0)	138	51.0 (38.9, 78.0)
Low rel$\dot{V}O_2$max	135	68.0 (60.0, 80.0)	133	82.6 (66.0, 121.4)	131	33.0 (19.0, 52.0)	130	51.9 (40.0, 71.0)	129	72 (54.6, 98.0)	129	50.0 (37.7, 77.0)
p-value		0.022 *		0.746		0.819		0.587		0.710		0.652
Good ab$\dot{V}O_2$max	140	62.5 (56.0, 73.5)	139	70.0 (60.0, 91.2)	139	25.0 (18.0, 38.0)	139	44.0 (34.3, 54.0)	139	62.0 (51.2, 82.0)	139	44.0 (34.0, 58.0)
Low ab$\dot{V}O_2$max	139	69.0 (62.0, 78.0)	138	104.0 (82.0, 141.3)	134	38.2 (27.0, 60.02)	132	58.5 (47.0, 82.8)	129	82.0 (64.0, 110.9)	128	61.0 (47.3, 89.8)
p-value		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †
Good grip strength	121	62.7 (56.0, 73.9)	121	71.0 (59.0, 91.0)	121	25.6 (17.0, 39.5)	121	44.0 (33.0, 56.0)	121	60.0 (48.0, 83.5)	121	42.0 (33.4, 60.5)
Low leg strength	158	67.5 (61.0, 76.3)	156	100.0 (79.3, 139.0)	152	36.0 (25.0, 59.8)	150	56.0 (45.0, 75.2)	147	78.0 (64.0, 103.0)	146	55.3 (48.0, 85.5)
p-value		0.003**		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †
Good leg strength	107	61.0 (54.0, 72.0)	107	68.6 (58.0, 90.0)	107	25.0 (17.0, 35.0)	107	42.0 (33.0, 54.0)	107	59.0 (49.0, 79.0)	107	41.0 (32.0, 53.0)
Low leg strength	172	67.5 (61.0, 77.8)	170	99.0 (77.8, 141.3)	166	38.0 (25.0, 65.2)	164	56.1 (45.0, 78.5)	161	79.0 (61.5, 103.0)	160	57.5 (48.0, 87.8)
p-value		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †
Good push-ups stamina	153	63.0 (56.0, 72.0)	153	77.0 (59.0, 100.0)	153	27.0 (20.0, 42.5)	151	45.0 (34.9, 56.0)	151	64.0 (51.0, 88.0)	150	43.7 (33.9, 58.3)
Low push-up stamina	126	70.0 (62.5, 80.0)	124	101.5 (80.2, 144.2)	120	38.0 (25.2, 60.0)	120	58.0 (47.4, 83.0)	117	80.0 (64.0, 103.0)	117	62.0 (50.0, 88.5)

http://etd.uwc.ac.za/

p-value		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †
Good sit-ups stamina	151	63.0 (56.0, 71.0)	153	80.9 (60.5, 101.0)	152	27.0 (19.0, 42.8)	151	46.0 (35.0, 59.0)	151	63.0 (49.8, 89.0)	151	48.0 (34.0, 64.0)
Low push-ups stamina	126	71.0 (61.8, 80.3)	124	100.0 (75.3, 141.3)	121	38.0 (25.0, 55.5)	120	38.0 (25.0, 55.5)	117	79.0 (67.2, 103.0)	116	57.0 (43.3, 85.8)
p-value		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †
Good flexibility	148	65.0 (57.4, 75.0)	147	83.0 (64.0, 119.0)	147	29.1 (20.0, 48.0)	146	47.2 (37.0, 66.3)	146	70.0 (54.0, 96.0)	146	50.0 (37.0, 77.3)
Low flexibility	131	66.0 (60.0, 76.0)	130	88.9 (67.5, 111.3)	126	34.5 (21.8, 53.0)	125	53.2 (42.7, 72.0)	122	74.0 (57.8, 99.3)	121	53.0 (41.0, 77.5)
p-value		0.384		0.540		0.371		0.038 *		0.336		0.393
Cardiovascular health												
Aged	77	69.0 (62.9, 82.0)	75	102 (80.0, 135.0)	73	38.0 (25.5, 53.0)	72	58.0 (45.0, 82.9)	70	82 (60.0, 103.3)	70	56.5 (46.7, 82.1)
Young	202	64.0 (57.0, 74.0)	202	81.5 (62.9, 106.3)	200	30.0 (20.0, 48.0)	199	48.0 (37.0, 61.6)	198	70.0 (54.0, 92.0)	197	50.0 (35.6, 70.0)
p-value		<0.001 †		<0.001 †		0.062		<0.001 †		0.004 **		0.003 **
Obesity	73	75 (63.0, 91.0)	71	102 (69.0, 157.7)	69	38.0 (25.0, 58.0)	69	58.0 (45.5, 86.6)	68	81.5 (60.5, 119.8)	67	57.0 (45.8, 90.2)
Normal	206	64.5 (57.0, 72.3)	206	83.5 (65.8, 107.3)	204	29.6 (20.0, 47.0)	202	48.1 (38.0, 62.3)	200	70.0 (53.2, 92.0)	200	50.0 (37.0, 69.8)
p-value		<0.001 †		0.003 **		0.037 *		0.001 **		<0.001 †		0.008 **
Central obesity	135	71 (63.0, 80.0)	133	93.0 (68.5.0, 141.5)	130	35.2 (22.5, 55.5)	130	55.0 (42.8, 79.2)	129	77.0 (59.0, 102.5)	128	55.2 (41.0, 85.8)
Normal	144	64.0 (57.0, 71.0)	144	82.0 (63.0, 103.4)	143	30.0 (20.0, 43.3	141	47.0 (37.0, 59.0)	139	68.0 (52.0, 90.0)	139	48.0 (37.0, 66.0)
p-value		<0.001 †		0.002 **		0.112		<0.001 †		0.003 **		0.006 **
Hypertension	128	66.5 (60.0, 77.5)	126	84.4 (66.0, 118.5)	124	31.2 (23.0, 47.0)	123	51.8 (40.0, 68.0)	122	71.5 (55.0, 00.3)	121	50.0 (27.5, 71.5)
Normal	151	65.0 (57.0, 75.)	151	88.6 (66.0, 115.0)	149	32.0 (20.0, 53.5)	148	50.0 (39.0, 67.0)	146	73.4 (55.0, 93.5)	146	51.0 (39.0, 78.5)
p-value		0.196		0.761		0.837		0.635		0.647		0.842
Dyslipidaemia	90	68.5 (60.0, 80.0)	89	93.0 (67.5, 134.5)	88	34.4 (22.7, 53.8)	87	55.0 (42.0, 84.0)	86	76.0 (55.8, 105.8)	86	53.5 (38.0, 86.3)
Normal	189	65.0 (58.0, 74.9)	188	83.5 (65.0, 107.8)	185	31.0 (20.0, 47.5)	184	49.7 (39.0, 61.9)	182	70.0 (54.8, 92.3)	184	50.6 (38.0, 70.0)
p-value		0.125		0.039 *		0.281		0.074		0.104		0.218
Diabetes	13	65.0 (60.0, 91.5)	12	108.9 (76.8, 138.3)	12	35.5 (26.8, 53.0)	12	56.5 (38.0, 69.0)	12	84.5 (63.5, 102.5)	12	56.0 (37.6, 92.8)
Normal	66	65.5 (58.0, 75.0)	265	86.0 (66.0, 114.5)	261	32.0 (21.0, 48.5)	259	50.0 (40.0, 67.0)	256	72.0 (55.0, 96.0)	255	50.6 (38.0, 77.0)
p-value		0.340		0.238		0.431		0.624		0.197		0.575
Physical inactivity	177	67.0 (60.0, 78.0)	176	95.0 (70.0, 133.5)	172	36.9 (24.0, 54.8)	170	55.0 (44.0, 74.0)	168	76.0 (59.0, 100.0)	167	55.0 (43.4, 83.0)
Active	102	63.0 (57.0, 73.0)	101	79.0 (61.0, 97.5)	101	26.0 (19.0, 36.5)	101	45.0 (34.4, 56.5)	100	63.0 (49.2, 84.8)	100	43.0 (33.9, 57.8)
p-value		0.018 *		<0.001 †		<0.001 †		<0.001 †		<0.001 †		<0.001 †

http://etd.uwc.ac.za/

Cigarette smoker	98	65.0 (60.0, 74.0)	98	85.4 (66.8, 110.0)	97	33.7 (22.3, 53.0)	97	51.8 (40.0, 67.0)	97	51.8 (40.0, 67.0)	97	54.0 (41.5, 74.0)
Non-Smoker	181	66.0 (58.0, 76.0)	179	86.0 (65.0, 118.0)	176	31.7 (20.3, 47.0)	174	50.0 (39.0, 67.3)	171	73.8 (53.0, 97.0)	170	50.0 (37.0, 77.3)
p-value		0.850		0.220		0.594		0.786		0.783		0.311
Poor diet	74	64.0 (57.2, 76.5)	73	82.0 (65.5, 112.5)	72	30.0 (21.0, 49.1)	71	50.0 (40.5, 58.0)	71	70.0 (57.8, 87.0)	71	50.0 (40.0, 65.1)
Normal	205	66.3 (59.5, 75.0)	204	87.0 (66.0, 115.8)	201	33.0 (21.3, 48.5)	200	50.0 (39.3, 73.0)	197	74.0 (54.6, 99.0)	196	51.0 (37.5, 78.0)
p-value		0.210		0.437		0.731		0.365		0.342		0.557
Good CVHI	85	71.0 (60.0, 80.0)	84	92.5 (69.1, 138.4)	83	36.0 (25.0, 55.0)	83	58.0 (44.0, 84.0)	83	78.0 (60.0, 102.0)	83	62.0 (42.0, 89.0)
Intermediate	160	64.3 (58.0, 74.9)	159	82.0 (63.0, 108.0)	156	28.5 (20.0, 45.5)	154	46.0 (36.8, 58.3)	151	69.0 (49.8, 91.0)	150	47.5 (34.0, 62.3)
Poor CVHI	32	66.0 (58.3, 72.8)	32	89.0 (79.5, 124.3)	32	34.5 (24.5, 68.0)	32	49.0 (45.3, 55.8)	32	78.0 (58.3, 102.0)	32	54.5 (44.0, 83.8)
p-value		0.105		0.014 *		0.028*		<0.001 †		0.003 **		<0.001 †
Musculoskeletal health												
MSI	116	69.0 (60.3, 78.0)	114	85.0 (65.0, 124.5)	111	35.0 (21.0, 55.0)	110	53.0 (38.0, 71.0)	110	74.5 (55.0, 100.0)	110	55.0 (37.8, 83.0)
No MSI	162	64.8 (57.2, 74.0)	162	86.5 (66.0, 110.3)	161	31.0 (21.0, 46.0)	160	50.0 (42.0, 66.0)	157	71.0 (55.0, 94.0)	156	50.0 (38.1, 69.8)
p-value		0.018 *		0.371		0.362		0.711		0.394		0.143
UBMSI	58	70.0 (60.8, 79.3)	56	94.0 (75.3, 136.2)	54	76.5 (59.0, 102.3)	54	56.1 (42.5, 79.7)	55	38.0 (24.0, 60.0)	54	57.5 (38.6, 86.8)
No UBMSI	221	65.0 (58.0, 74.9)	221	86.0 (65.5, 111.5)	214	71.0 (55.0, 95.0)	217	49.0 (40.0, 66.0)	218	30.7 (20.0, 47.0)	213	50.0 (38.0, 70.0)
p-value		0.043*		0.105		0.216		0.103		0.035*		0.085
LBMSI	65	69.0 (61.0, 78.5)	65	90.0 (63.5, 125.5)	63	76.0 (52.0, 100.0)	63	49.0 (37.0, 68.0)	63	31.3 (20.0, 47.0)	63	54.0 (35.0, 78.0)
No LBMSI	214	65.0 (58.0, 75.0)	212	85.5 (66.0, 110.8)	205	51.0 (55.0, 95.5)	208	51.0 (41.1, 67.0)	210	32.0 (21.5, 52.3)	204	50.6 (39.0, 76.5)
p-value		0.074		0.482		0.597		0.380		0.742		0.943
LoBMSI	22	73.3 (64.5, 87.5)	21	108.0 (80.5, 144.5)	20	91.5 (59.3, 118.5)	20	60.3 (36.3, 87.8)	21	46.0 (27.0, 60.0)	20	63.5 (39.0, 95.0)
No LoBMSI	257	65.0 (58.0, 75.0)	256	84.4 (66.0, 112.0)	248	71.0 (55.0, 95.0)	251	50.0 (40.0, 66.0)	252	31.2 (20.3, 47.0)	247	50.6 (38.0, 74.3)
p-value		0.010*		0.013*		0.083		0.279		0.027*		0.112
MSD	116	66.0 (58.1, 75.8)	115	86.0 (65.0, 118.0)	113	34.0 (21.8, 53.0)	111	51.7 (39.0, 68.0)	111	70.6 (55.0, 100.0)	110	53.0 (37.8, 81.0)
No MSD	163	65.0 (58.0, 75.0)	162	86.0 (66.9, 115.0)	160	30.2 (20.3, 48.0)	160	50.0 (40.0, 67.0)	157	74.0 (55.0, 94.0)	157	50.0 (38.2, 71.5)
p-value		0.884		0.916		0.333		0.969		0.956		0.458
UBMSD	99	65.0 (57.3, 78.0)	98	85.0 (65.0, 116.3)	97	34.4 (21.3, 54.5)	96	52.5 (39.3, 70.3)	96	70.0 (53.3, 99.5)	95	55.0 (38.0, 81.0)
No UBMSD	180	65.5 (59.0, 75.0)	179	86.0 (66.9, 115.0)	176	30.7 (21.0, 46.0)	175	50.0 (40.0, 67.0)	172	74.0 (57.0, 95.8)	172	50.0 (38.1, 73.9)
p-value		0.933		0.891		0.287		0.287		0.640		0.260

http://etd.uwc.ac.za/

LBMSD	67	65.0 (57.0, 75.0)	67	82.0 (62.4, 118.0)	65	32.0 (21.3, 43.0)	64	48.0 (37.5, 62.3)	64	65.0 (50.3, 96.5)	64	49.8 (34.3, 81.0)
No LBMSD	212	66.0 (58.6, 76.0)	210	87.9 (67.8, 115.0)	208	32.0 (21.0, 51.8)	207	51.8 (40.0, 68.0)	204	74.5 (57.1, 96.8)	203	51.0 (39.0, 74.3)
p-value		0.476		0.337		0.773		0.382		0.123		0.560
LoBMSD	59	68.0 (58.4, 80.0)	59	90.0 (65.0, 136.6)	57	75.0 (54.0, 108.4)	57	53.2 (40.0, 79.3)	58	38.0 (23.8, 63.5)	56	57.5 (37.5, 95.8)
No LoBMSD	220	65.0 (58.0, 75.0)	218	86.0 (66.0, 112.5)	211	72.0 (55.0, 96.0)	214	50.0 (39.8, 66.0)	215	31.0 (20.0, 46.0)	211	50.0 (38.0, 70.0)
p-value		0.302		0.362		0.699		0.287		0.046*		0.093

Note: * indicates statistically significance <0.05; ** indicates statistical significance <0.01; † − indicates statistical significance <0.001.
MSI − musculoskeletal injury; UBMSI − upper body musculoskeletal injury; LBMSI − lower body musculoskeletal injury; LoBMSI − lower back musculoskeletal injury; MSD − musculoskeletal discomfort; UBMSD − upper body musculoskeletal discomfort; LBMSD − lower body musculoskeletal discomfort; LoBMSD − lower back musculoskeletal injury.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

In Table 12.2 we indicate the association between demographic characteristics, physical fitness, cardiovascular health and occupational-specific task performance. Multivariable analyses indicated that an increase in ab$\dot{V}$O2max was associated with a shorter completion time for the step-up, charged hose drag and pull, forcible entry, equipment carry, ladder raise and extension and the rescue drag completion times. An increase in grip and leg strength was associated with a shorter completion time for the charged hose drag and pull, forcible entry and equipment carry completion times. In addition, grip strength was associated with shorter ladder raise and extension and rescue drag completion times. An increase in push-ups and sit-ups capacity was associated with a shorter completion time for the step-up, charged hose drag and pull, forcible entry, equipment carry, forcible entry and rescue drag completion times. An increase in LBM was associated with a shorter completion time in the charged hose drag and pull, forcible entry, equipment carry and rescue drag tasks.

For CVH, in the multivariable analyses, an increase in age was associated with an increase in the completion times of the step-up, charged hose drag and pull, ladder raise and extension, equipment carry, forcible entry and the rescue drag. An increase in height was associated with a decrease in completion times for the step-up, charged hose drag and pull, ladder raise and extension, equipment carry, forcible entry and the rescue drag. An increase in BMI and BF% was associated with an increase in the step-up completion time, only. An increase in SBP was associated with a shorter completion time in the charged hose drag and pull, only. An increase in weekly MET minutes was associated with a shorter completion time in the charged hose drag and pull, forcible entry, equipment carry and rescue drag, respectively. An increase in HRV, SDNN and RMSSD was associated with shorter completion times for all occupational-specific tasks (all $p < 0.01$). After adjustment for age, sex, height and weekly MET minutes, HRV and SDNN remained significantly associated with shorter completion times for all occupational-specific tasks.

http://etd.uwc.ac.za/

Table 12.2: Linear association between physical fitness, cardiovascular and musculoskeletal health and physical ability test task performance in firefighters.

	Step-up		Charged hose drag and pull		Forcible entry		Equipment carry		Ladder raise and extension		Rescue drag	
	Model 1 [a] β (R^2)	Model 2 [b] β (R^2)	Model 1 [a] β (R^2)	Model 2 [b] β (R^2)	Model 1 [a] β (R^2)	Model 2 [b] β (R^2)	Model 1 [a] β (R^2)	Model 2 [b] β (R^2)	Model 1 [a] β (R^2)	Model 2 [b] β (R^2)	Model 1 [a] β (R^2)	Model 2 [b] β (R^2)
Model: Demographics												
Age (years)	0.25 (0.06) †	0.25 (0.21) †	0.32 (0.09) †	0.32 (0.45) †	0.17 (0.03)**	0.16 (0.22)**	0.30 (0.09) †	0.28 (0.37) †	0.17 (0.03)**	0.16 (0.22)**	0.27 (0.07) †	0.26 (0.36) †
YoE (years)	0.27 (0.07) †	0.44 (0.25) †	0.29 (0.08) †	0.29 (0.47)**	0.15 (0.02)**	0.14 (0.23)	0.28 *0.08)	0.29 (0.39)*	0.15 (0.02)**	0.14 (0.23)	0.22 (0.05) †	0.14 (0.36)
Weight (kg)	0.04 (0.00)	0.15 (0.23)*	-0.17 (0.03) †	-0.07 (0.45)	-0.21 (0.04) †	-0.13 (0.24)*	-0.12 (0.01)	-0.03 (0.37)	-0.21 (0.04) †	-0.13 (0.24)*	-0.19 (0.04)**	-0.12 (0.37)
Height (cm)	-0.34 (0.12) †	-0.23 (0.21) †	-0.54 (0.29)**	-0.43 (0.45) †	-0.38 (0.14) †	-0.30 (0.22) †	-0.45 (0.19) †	-0.35 (0.37)	-0.38 (0.14) †	-0.30 (0.22) †	-0.46 (0.21) †	-0.35 (0.36) †
Model: Physical fitness												
V̇O2max (L•min)	-0.22 (0.05) †	-0.22 (21)	-0.44 (0.19) †	-0.17 (0.47) †	-0.38 (0.14) †	-0.22 (0.27) †	-0.43 (0.19) †	-0.18 (0.39)**	-0.38 (0.14) †	-0.22 (0.27) †	-0.43 (0.18) †	-0.19 (0.38) †
V̇O2max (mL•kg•min)	-0.14 (0.02)*	-0.19 (0.24)**	0.01 (0.00)	-	0.07 (0.01)	-	-0.05 (0.00)	-	0.07 (0.01)	-	0.02 (0.00)	-
Grip strength (kg)	-0.31 (0.09) †	-0.10 (0.22)	-0.53 (0.28) †	-0.27 (0.49) †	-0.37 (0.14) †	-0.20 (0.25)**	-0.43 (0.19) †	-0.22 (0.40) †	-0.37 (0.14) †	-0.20 (0.25)**	-0.50 (0.25) †	-0.31 (0.42) †
Leg strength (kg)	-0.31 (0.09) †	-0.11 (0.22)	-0.52 (0.27) †	-0.26 (0.50) †	-0.39 (0.16) †	-0.23 (0.26) †	-0.43 (0.19) †	-0.18 (0.39)**	-0.39 (0.16) †	-0.23 (0.26) †	-0.49 (0.24) †	0.26 (0.41)
Push-ups (rpm)	-0.33 (0.11) †	0.25 (0.26) †	-0.44 (0.19) †	-0.35 (0.54) †	-0.29 (0.09) †	0.24 (0.27) †	-0.42 (0.17) †	-0.32 (0.45) †	-0.29 (0.09) †	0.24 (0.27) †	-0.41 (0.17) †	-0.32 (0.44) †
Sit-ups (rpm)	-0.41 (0.17) †	0.09 (0.31) †	-0.39 (0.16) †	-0.28 (0.51) †	-0.26 (0.07) †	-0.21 (0.26) †	-0.34 (0.12) †	-0.24 (0.42) †	-0.26 (0.07) †	-0.21 (0.26) †	-0.35 (0.12) †	-0.25 (0.41) †
Sit-and-reach (cm)	-0.09 (0.01)	-0.12 (0.23)*	-0.04 (0.00)	-0.05 (0.45)	-0.04 (0.00) †	-0.05 (0.22)	-0.13 (0.02)		-0.04 (0.00) †	-0.05 (0.22)	-0.07 (0.01)	
Lean body Mass (kg)	-0.27 (0.07) †	-0.08 (0.22)	-0.44 (0.19) †	-0.18 (0.46)**	-0.38 (0.14) †	-0.27 (0.26) †	-0.37 (0.14) †	-0.18 (0.39)*	-0.38 (0.14) †	-0.27 (0.26) †	-0.43 (0.18) †	-0.27 (0.39) †
Model: Cardiovascular health												
Body mass index (kg•m^{-2})	0.23 (0.06) †	0.13 (0.22)*	0.11 (0.01)		-0.01 (0.00)		0.12 (0.01)		-0.01 (0.00)		0.06 (0.00)	
Bodyfat percentage (%)	0.35 (0.12) †	0.16 (0.23)**	0.29 (0.08) †	-0.03 (0.45)	0.14 (0.02) *	-0.04 (0.22)	0.28 (0.08) †	0.05 (0.37)	0.14 (0.02)*	-0.04 (0.22)	0.26 (0.07) †	-0.01 (0.36)
Waist circumference (cm)	0.16 (0.03)**	0.26 (0.23)*	0.05 (0.00)	-	-0.02 (0.00)	-	0.12 (0.02)	-	-0.02 (0.00)	-	0.03 (0.00)	-
SBP (mmHg)	-0.01 (0.00)	-	-0.14 (0.02)*	-0.09 (0.45)*	-0.09 (0.01)	-	-0.03 (0.00)	-	-0.09 (0.01)	-	-0.07 (0.01)	-
DBP (mmHg)	0.21 (0.04) †	0.13 (23)*	0.11 (0.01)	-	0.06 (0.00)	-	0.18 (0.03)	-	0.06 (0.00)	-	0.08 (0.01)	-
TC (mmol•L^{-1})	0.07 (0.00)	-	0.09 (0.01)	-	0.02 (0.00)	-	0.07 (0.01)	-	0.02 (0.00)	-	0.03 (0.00)	-
LDL-C (mmol•L^{-1})	0.05 (0.00)	-	0.08 (0.01)	-	0.05 (0.00)	-	0.06 (0.00)	-	0.05 (0.00)	-	0.02 (0.00)	-
HDL-C (mmol•L^{-1})	-0.06 (0.00)	-	0.04 (0.00)	-	-0.01 (0.00)	-	-0.01 (0.00)	-	-0.01 (0.00)	-	0.02 (0.00)	-
Triglycerides (mmol•L^{-1})	0.13 (0.02)*	0.11 (0.23)	0.07 (0.00)	-	0.02 (0.00)	-	0.09 (0.01)	-	0.02 (0.00)	-	0.07 (0.01)	-
NFBG (mmol•L^{-1})	0.03 (0.00)	-	-0.00 (0.00)	-	-0.05 (0.00)	-	0.02 (0.00)	-	-0.05 (0.00)	-	0.04 (0.00)	-
MET minutes (min)	-0.07 (0.01)	-	-0.18 (0.03)**	-0.11 (0.45)*	-0.23 (0.05) †	-0.19 (0.22) †	-0.29(0.09) †	-0.23 (0.37) †	-0.23 (0.05) †	-0.19 (0.22) †	-0.24 (0.06) †	-0.18 (0.36) †
Framingham risk score	0.14 (0.02)*	0.09 (0.22)	0.19 (0.04)**	0.12 (0.45)	0.09 (0.01)	-	0.19 (0.04) †	0.07 (0.37)	0.09 (0.01)	-	0.15 (0.02)*	0.07 (0.36)
Model: Heart rate variability												

http://etd.uwc.ac.za/

Heart rate variability (ms)	-0.17 (0.03)**	-0.13 (0.23)*	-0.17 (0.03)**	-0.09 (0.46)	-0.16 (0.02)*	-0.08 (0.22)	-0.24 (0.06) †	0.14 (0.39)**	-0.16 (0.02)*	-0.08 (0.22)	-0.19 (0.03)**	-0.09 (0.36)
SDNN (ms)	-0.27 (0.07) †	-0.18 (25)**	-0.28 (0.08) †	-0.14 (0.46)**	-0.15 (0.02)*	-0.04 (0.22)	-0.33 (0.11) †	-0.17 (0.39)**	-0.15 (0.02)*	-0.04 (0.22)	-0.22 (0.05) †	-0.07 (0.35)
RMSSD (ms)	-0.21 (0.05) †	-0.15 (0.24)**	-0.21 (0.05) †	-0.10 (0.45)*	-0.09 (0.01)	-	-0.29 (0.08) †	-0.16 (0.29)	-0.09 (0.01)	-	-0.17 (0.03)**	0.05 (0.35)
LF (Hz)	-0.122 (0.02) †	-0.02 (0.22)	-0.19 (0.04)**	-0.05 (0.46)	-0.09 (0.01)	-	-0.16 (0.02)	-	-0.09 (0.01)	-	-0.15 (0.02)*	-0.02 (0.36)
HF (Hz)	-0.01 (0.00)	-	0.11 (0.01)	-	0.07 (0.00)	-	0.02 (0.00)	-	0.07 (0.00)	-	0.07 (0.01)	-
LF/HF (Hz)	-0.01 (0.00)	-	-0.01 (0.00)	-	-0.06 (0.00)	-	0.07 (0.01)	-	-0.06 (0.00)	-	-0.00 (0.00)	-

Note: * − Indicates statistical significance <0.05; ** − Indicates statistical significance <0.01; † − indicates statistical significance <0.001.
a – univariable models using linear regression; b – Multivariable linear regression adjusted for covariates::age, sex, height and weekly metabolic equivalent minutes; kg•m^{-2} – kilogram per meter squared; cm – centimetre; % – percentage; mm Hg – millimetres of mercury; mmol•L^{-1} – millimole per litre; MET – metabolic equivalents; ms – millisecond; Hz – hertz; BMI – body mass index; WC – Waist circumference; SBP – systolic blood pressure; DBP – diastolic blood pressure; NFBG – non-fasting blood glucose; TC – total cholesterol; LDL-C – low-density lipoprotein; HDL-C – high-density lipoprotein; SDNN – standard deviation of all normal-to-normal; RMSSD – root-mean-square of successive differences; LF – low-frequency; HF – high frequency; LF/HF – low and high frequency ratio; rpm − repetitions per minute.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

In Table 12.3 we describe the associations between physical fitness, CVH and pass rates, using the predetermined cut-off times for each of the individual tasks. Firefighters who had a good ab$\dot{V}O_{2max}$ had increased odds of passing the step-up (OR = 4.0), equipment carry (OR = 2.9), ladder raise and extension (OR = 2.8) and the rescue drag (OR = 1.9), respectively. Firefighters with good leg strength had increased odds of passing the forcible entry (OR = 11.6), equipment carry (OR = 1.9) and ladder raise and extension (OR = 1.9), respectively. Firefighters with good push-ups capacity had increased odds of passing the equipment carry (OR = 3.1), ladder raise and extension (OR = 3.1) and rescue drag (OR = 3.1). Firefighters with good sit-ups capacity had increased odds of passing step-up (OR = 3.6), equipment carry (OR = 2.2), ladder raise and extension (OR = 4.3) and rescue drag (OR = 2.4), respectively. For CVH, in the multivariable analyses, obese firefighters had decreased odds of passing the step-up task, those with a high BF% had decreased odds of passing the step-up (OR = 0.3), ladder raise and extension (OR = 0.4) and rescue drag (OR = 0.4) respectively. Physically inactive firefighters had decreased odds of passing the step-up (OR = 0.1), ladder raise and extension (OR = 0.5) and the rescue drag (OR = 0.3), respectively. Firefighters with an intermediate CVHI had increased odds of passing the equipment carry (OR = 2.1), ladder raise and extension (OR = 1.6) and the rescue drag (OR = 2.9), respectively, compared to firefighters with a poor CVHI. For MSH, upper body injuries (OR = 0.5) and low back injuries (OR = 0.3) decreased the odds of passing the rescue drag task. Firefighters that reported MSD and lower limb discomfort had decreased odds of passing the step-up (OR = 0.4 and 0.2), respectively. Low back discomfort decreased the odds of firefighters passing the rescue drag (OR = 0.4).

http://etd.uwc.ac.za/

Table 12.3: Logistic regression investigating the association between physical fitness, cardiovascular and musculoskeletal health and physical ability test task pass rates in firefighters.

	Step-up		Charged hose drag and pull		Forcible entry		Equipment carry		Ladder raise and extension		Rescue drag	
	Model 1 [a]	Model 2 [b]	Model 1 [a]	Model 2 [b]	Model 1 [a]	Model 2 [b]	Model 1 [a]	Model 2 [b]	Model 1 [a]	Model 2 [b]	Model 1 [a]	Model 2 [b]
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Model: Demographics												
Age	2.1 (0.9, 4.8)	-	0.5 (0.2, 1.8)	-	0.8 (0.4, 1.7)	-	0.4 (0.3, 0.8) **	0.5 (0.2, 1.5)	0.54 (0.3, 0.9) *	0.4 (0.1, 0.9) *	1.6 (0.9, 2.9)	-
YoE (0-10 years)	0.9 (0.9, 0.9) †	0.8 (0.7, 0.9) †	-	-		-						
11-20 years	0.45 (0.14, 1.43)	-	0.1 (0.0, 0.6) *	0.1 (0.0, 1.4)	0.6 (0.3, 1.2)	-	0.6 (0.3, 1.2)	-	1.0 (0.6, 1.8)	-	0.6 (0.3, 1.0)	-
21-30 years	0.2 (0.1, 0.8) *	0.1 (0.0, 0.6) *	0.2 (0.0, 0.6)	-	1.4 (0.5, 3.9)	-	0.5 (0.3, 1.1)	-	0.8 (0.4,1.7)	-	0.8 (0.4, 1.7)	-
31 years and over	0.1 (0.0, 0.4) †	0.01 (0.0, 0.2) **	0.2 (0.0, 1.4)	-	0.4 (0.1, 0.9)	-	0.1 (0.1, 0.4) †	0.1* (0.0, 0.9)	0.3 (0.2, 0.9)	-	0.1 (0.0, 0.3) †	0.1 (0.0, 0.6) *
Model: Physical fitness												
Ab. CRF	2.9 (1.3, 6.9) *	4.0 (1.2, 13.2) *	3.8 (1.2, 11.8) *	0.6 (0.1, 3.5)	2.9 (1.5, 5.7) **	1.4 (0.7, 3.1)	4.9 (2.8, 8.8) †	2.8 (1.4, 5.4) **	3.2 (1.9, 5.4) †	1.9 (1.1, 3.5) *	3.5 (2.0, 5.9) †	1.9 (1.1, 3.7) *
Rel. CRF	0.4 (0.2, 1.0)	-	1.1 (0.4, 2.8)	-	1.6 (0.9, 3.1)	-	0.9 (1.0, 1. 7)	-	1.3 (0.8, 2.2)	-	1.0 (0.1, 1.7)	-
Grip strength	1.4 (0.6, 3.2)	-	6.9 (1.5, 30.4) *	0.9 (0.1, 8.4)	3.6 (1.7, 7.6) †	2.2 (0.9, 5.1)	2.9 (1.6, 5.0) †	1.7 (0.9, 3.4)	3.9 (2.3, 6.6) †	2.6 (1.4, 4.6) **	2.5 (1.5, 4.2) †	1.3 (0.7, 2.5)
Leg strength	2.5 (0.9, 6.4)	-	11.9 (1.6, 90.5) *	1.4 (0.1, 21.5)	19.7 (4.7, 83.1) †	11.6 (2.7, 50.8) **	4.9 (2.6, 9.3) †	2.1 (1.0, 4.4) *	3.9 (2.3, 6.7) †	2.4 (1.4, 4.4) **	3.6 (2.0, 6.3) †	1.5 (0.8, 2.9)
Push-ups	4.1 (1.7, 10.1) **	2.4 (0.8, 6.7)	6.8 (1.9, 24.2) **	7.9 (0.8, 75.9)	2.1 (1.1, 4.0) *	1.8 (0.8, 4.0)	3.7 (2.1, 6.4) †	3.1 (1.5, 6.2) **	2.9 (1.7, 5.1) †	3.1 (1.6, 6.1) †	3.4 (2.0, 5.8) †	3.1 (1.5, 6.0) **
Sit-ups	5.2 (2.0, 13.1) †	3.6 (1.3, 10.1) *	4.7 (1.5, 14.7) **	4.9 (0.7, 32.6)	1.5 (.8, 2.9)	-	2.5 (1.5, 4.3) †	2.2 (1.1, 4.1) *	3.8 (2.2, 6.6) †	4.3 (2.2, 8.1) †	2.5 (1.5, 4.1) †	2.4 (1.3, 4.5) **
Flexibility	1.2 (0.5, 2.5)	-	1.2 (0.4, 2.9)	5.4 (0.9, 33.3)	1.2 (0.6, 2.2)	-	1.2 (0.7, 2.1)	-	1.5 (0.9, 2.5)	-	1.0 (0.6, 1.6)	-
Model: Cardiovascular health												
Obesity	0.2 (0.1, 0.4) †	0.2 (0.1, 0.6) **	0.2 (0.1, 0.4) †	0.2 (0.0, 1.2)	0.8 (0.4, 1.5)	-	0.5 (0.3, 0.9) *	0.9 (0.4, 1.8)	0.5 (0.3, 0.9) *	0.7 (0.3, 1.4)	0.5 (0.3, 0.9) *	0.8 (0.4, 1.5)
Central obesity	0.3 (0.1, 0.6) **	0.5 (0.2, 1.3)	0.3 (0.1, 0.8) *	0.6 (0.1, 3.3)	0.8 (0.4, 1.5)	-	0.5 (0.3, 0.8) **	0.7 (0.4, 1.4)	0.6 (0.4, 1.1)	-	0.5 (0.3, 0.8) **	0.8 (0.4, 1.5)
High BF%	0.2 (0.1, 0.4) †	0.3 (0.1, 0.8) *	0.1 (0.0, 0.3) †	0.3 (0.1, 1.6)	0.6 (0.3, 1.1)	-	0.5 (0.3, 0.8) **	0.9 (0.4, 1.8)	0.3 (0.1, 0.6) †	0.4 (0.2, 0.9) *	0.3 (0.2, 0.5) †	0.4 (0.2, 0.9) *
Hypertension	0.8 (0.4, 1.8)	-	0.5 (0.2, 1.3)	-	0.6 (0.3, 1.1)	-	0.9 (0.6, 1.6)		0.9 (0.6, 1.7)	-	1.1 (0.7, 1.9)	-
Diabetes	0.4 (0.1, 10.4)	-	0.0 (0.0)	-	0.4 (0.1, 3.4)	-	0.6 (0.2, 1.9)		0.6 (0.2, 2.2)	-	0.8 (0.2, 2.5)	-
Dyslipidaemia	0.6 (0.3, 1.3)	-	0.5 (0.2, 1.2)	-	1.1 (0.6, 2.1)	-	0.6 (0.3, 0.9) *	0.8 (0.4, 1.6)	0.8 (0.5, 1.4)	-	0.6 (0.4, 1.1)	-
High LDL-C	1.1 (0.5, 2.7)	-	0.9 (0.3, 2.7)	-	0.8 (0.4, 1.8)	-	0.7 (0.4, 1.3)		0.1 (0.5, 1.6)	-	0.9 (0.5, 1.7)	-
High HDL-C	1.1 (0.4, 3.1)	-	0.2 (0.0, 1.8)	-	1.4 (0.2, 10.9)	-	0.9 (0.5, 1.8)		0.9 (0.5, 1.8)	-	0.9 (0.5, 1.9)	-
Hypertriglyceridemia	1.3 (0.6, 3.1)	-	0.2 (0.0, 0.9) *	-	0.4 (0.2, 0.9)	-	0.8 (0.5, 1.3)		0.9 (0.6, 1.6)	-	0.8 (0.5, 1.4)	-
Physical inactivity	0.3 (0.1, 0.9) *	0.1 (0.1, 0.7) *	0.0 (0.0)	-	0.3 (0.2, 0.7) **	0.5 (0.1, 1.2)	0.4 (0.2, 0.7) †	0.6 (0.3, 1.2)	0.4 (0.2, 0.7) †	0.5 (0.2, 0.9) *	0.3 (0.2, 0.5) †	0.3 (0.1, 0.6) **

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Cigarette smoking	2.1 (0.8, 5.5)		0.5 (0.2, 1.6)	-	0.8 (0.4, 1.6)	-	0.9 (0.6, 1.6)		0.7 (0.5, 1.5)	-	0.8 (0.5, 1.3)	0.5 (0.3, 0.9) *
CVHI (Poor)												
Intermediate CVHI	1.4 (0.6, 3.2)	-	2.2 (0.8, 5.9)	-	1.3 (0.7, 2.7)	-	2.5 (1.4, 4.4) **	2.1 (1.1, 4.1) *	1.9 (1.1, 3.5) *	1.6 (.9, 3.0) *	2.9 (1.6, 5.8) **	2.9 (1.6, 5.8) **
Good CVHI	2.2 (0.5, 10.4)	-	3.6 (0.4, 29.8)	-	0.7 (0.3, 1.8)	-	1.7 (7.0, 4.0)		1.1 (0.4, 2.6)		1.6 (0.7, 3.6)	
Model: Musculoskeletal health												
UBMSI	0.8 (0.3, 1,9)		0.6 (0.2, 1.9)	-	0.8 (0.3, 1.8)	-	0.6 (0.3, 1,2)	-	0.6 (0.3, 1.2)	-	0.5 (0.3, 0.9) *	0.5 (0.2, 0.9) *
LBMSI	0.9 (0.4, 2.2)		0.8 (0.3, 2.3)	-	1.5 (0.7, 3.5)	-	1.0 (0.5, 1.9)	-	0.8 (0.5, 1.5)	-	0.8 (0.4, 1.4)	-
LoBMSI	0.3 (0.1, 0.9) *	0.3 (0.1, 1.0)	0.6 (0.1, 2.9)	-	0.9 (0.3, 2.7)	-	0.4 (0.2, 1.0)	-	0.6 (0.2, 1.7)	-	0.3 (0.1, .9) *	0.3 (0.1, .8) *
Musculoskeletal discomfort	0.5 (0.2, 1.2)	0.4 (0.1, 0.9) *	0.7 (0.3, 1.9)	-	0.9 (0.6, 1.6)	-	1.3 (0.7, 2.1)	-	0.9 (0.6, 1.6)	-	0.7 (0.4, 1.2)	-
ULMSD	1.2 (0.5, 2.7)	-	0.7 (0.3, 1.8)	-	0.7 (0.4, 1.5)	-	1.1 (0.6, 2.2)	-	1.1 (0.7, 1.9)	-	0.6 (0.4, 1.0)	-
LLMSD	0.2 (0.1, 0.9) *	0.2 (0.0, 0.7) *	1.2 (0.4, 3.5)	-	0.8 (0.4, 1.8)	-	0.7 (0.4, 1.3)	-	0.7 (0.4, 1.2)	-	1.0 (0.6, 1.8)	-
LoBMSD	0.8 (0.3, 1.9)	-	0.3 (0.1, 0.8) *	0.4 (0.1, 1.9) *	0.5 (0.2, 1.0)	-	0.8 (0.4, 1.4)	-	0.8 (0.5, 1.6)	-	0.5 (0.3, 0.9) *	0.4 (0.2, 0.9) *

Note: * − Indicates statistical significance <0.05; ** − Indicates statistical significance <0.01; † − indicates statistical significance <0.001.
a – univariable models using logistic regression; b – Multivariable logistic models adjusted for covariates: age, sex, height and weekly metabolic equivalent minutes; LDL-C – low-density lipoprotein; HDL-C – high-density lipoprotein; BF − body fat; UBMSI − upper body musculoskeletal injury; LBMSI − lower body musculoskeletal injury; LoBMSI − lower body musculoskeletal injury; ULMSD − upper limb musculoskeletal discomfort; LBMSD − lower body musculoskeletal discomfort; LoBMSD − lower back musculoskeletal discomfort.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

In Table 12.4, the LASSO results for key indicators of physical fitness and CVH associated with occupational-specific task performance in firefighters are delineated. The results of the LASSO regression reported that ab$\dot{V}O_{2max}$, grip strength, sit-ups, LBM, BF% and DBP were significant indicators for step-up completion times, explaining 26.6% of the variance. For the charged hose drag and pull, ab$\dot{V}O_{2max}$, grip strength, leg strength, push-ups, sit-ups, LBM, age, BMI and weekly MET minutes were significant indicators and explained 55.6% of the variance in the task. For the forcible entry, ab$\dot{V}O_{2max}$, grip strength, leg strength, sit-ups, LBM and weekly MET minutes remained significant indicators of completion time in the task, explaining 26.2% of the variance. Ab$\dot{V}O_{2max}$, grip strength, leg strength, push-ups, sit-ups, sit-and-reach, LBM, age, BMI, BF%, HDL-C and weekly MET minutes were significant indicators of performance on the equipment carry and explained 45.3% of the variance in the task. For the ladder raise and extension ab$\dot{V}O_{2max}$, grip strength, leg strength, sit-ups, LBM BF% and Weekly MET minutes were significant indicators of task completion times and explained 42.1% of the variance in the task. For the rescue drag, ab$\dot{V}O_{2max}$, grip strength, leg strength, push-ups, sit-ups, LBM, age and weekly MET minutes explain 47.2% of the variance in the task performance.

UNIVERSITY of the
WESTERN CAPE

Table 12.4: LASSO-derived multivariable linear regression coefficients to discern key physical fitness and CVH parameters most associated with task performance in firefighters.

Model summary	Step-up	CHDP	FE	EC	LRE	RD
Prediction	0.791	0.463	0.757	0.574	0.629	0.561
Estimate	0.832	0.507	0.814	0.614	0.709	0.618
R^2	0.266	0.556	0.292	0.453	0.421	0.472
Variables						
ab$\dot{V}O_{2max}$ (L•min)	-0.007	-0.092	-0.106	-0.191	-0.108	-0.065
rel$\dot{V}O_{2max}$ (mL•kg•min)	-	-	-	-	-	-
Grip strength (kg)	-0.072	-0.169	-0.064	-0.138	-0.201	-0.168
Leg strength (kg)	-	-0.134	-0.105	-0.036	-0.053	-0.105
Push-ups (rpm)	-	-0.117	-	-0.136	-	-0.151
Sit-ups (rpm)	-0.177	-0.086	-0.037	-0.059	-0.137	-0.068
Sit-and-reach (cm)	-	-	-	-0.003	-	-

http://etd.uwc.ac.za/

Lean body Mass (kg)	-0.066	-0.278	-0.121	-0.112	-0.134	-0.185
Age (years)	-	0.093	-	0.043	-	0.022
Body mass index (kg•m^{-2})	-	0.073	-	0.001	-	-
Waist circumference (cm)	-	-	-	-	-	-
Body fat percentage (%)	0.092	-	-	0.091	0.077	-
Systolic blood pressure (mmHg)	-	-	-	-	-	-
Diastolic blood pressure (mmHg)	0.018	-	-	-	-	-
Non-fasting blood glucose (mmol•L^{-1})	-	-	-	-	-	-
Total cholesterol (mmol•L^{-1})	-	-	-	-	-	-
Low-density lipoprotein cholesterol (mmol•L^{-1})	-	-	-	-	-	-
High-density lipoprotein cholesterol (mmol•L^{-1})	-	-	-	-0.001	-	-
Triglycerides (mmol•L^{-1})	-	-	-	-	-	-
Weekly MET minutes (MET•min)	-	-0.009	-0.028	-0.112	-0.051	-0.068
Framingham risk score (%)	-	-	-	-	-	-

Note: R^2 − R squared. CHDP − charged hose drag and pull; FE − forcible entry; EC − equipment carry; LRF − ladder raise and extension; RD − rescue drag; kg•m^{-2} – kilogram per meter squared; cm – centimetre; % – percentage; mm Hg – millimetres of mercury; mmol•L^{-1} – millimole per litre; MET – metabolic equivalents; BMI – body mass index; WC – Waist circumference; SBP – systolic blood pressure; DBP – diastolic blood pressure; NFBG – non-fasting blood glucose; TC – total cholesterol; LDL-C – low-density lipoprotein; HDL-C – high-density lipoprotein; rpm − repetitions per minute.

12.4. Discussion

The results of the study indicated that firefighters with higher levels of absolute cardiorespiratory fitness, muscle strength and endurance and favourable body composition, performed all occupational-specific tasks significantly faster and were more likely to pass each task. This is consistent with previous studies where higher levels of physical fitness was related to better occupational-specific task performance in firefighters [3,5,6,46]. In addition, the results indicated that firefighters aged 45 years and older who had a BMI over 30 kg•m^{-2} and those that had higher blood pressure, worse lipid profile and a low HRV were the poorest performers on all the individual occupational-specific tasks. These results corroborate previous research where older and obese firefighters had poorer performance on most occupational tasks [3,5,6]. Moreover, higher levels of blood pressure and worse lipid profile have been shown to be associated with lower levels of physical fitness [47–49], providing a potential explanation for poorer performance on the individual tasks in this group. In the present study, firefighters that reported sustaining an MSI performed the rescue drag task significantly slower and those

http://etd.uwc.ac.za/

that reported more MSD performed the step-up, charged hose drag and pull and the rescue drag task significantly slower. This is consistent with previous studies where MSH was related to more physical and work functioning restrictions [26,27,30].

In the current study, an increase in absolute cardiorespiratory fitness was associated with faster completion times for all occupational-specific tasks and a key indicator in the performance of all occupational-specific tasks. However, relative cardiorespiratory fitness was related to faster completion times for the step-up task, only. Schonfeld et al. [50] reported that rel$\dot{V}O_{2max}$ was inversely related to a stair climb (r = -0.627), chopping task (r = -0.324) and the victim rescue (r = -0.447) tasks in firefighters. Similarly, Chizewski et al. [3] found estimated rel$\dot{V}O_{2max}$ was inversely related to the self-contained breathing apparatus (SCBA) crawl (r = -0.530), victim rescue (r = -0.342), hose advance (r = -0.266) and the equipment carry (r = -0.361) tasks. Rhea et al. [6] used the Cooper 12-minute run test to estimate cardiorespiratory in fitness. found that cardiorespiratory fitness had a tendency to be inversely related to the hose pull (r = -0.05), victim drag (r = -0.33), stair climb (r = -0.36) and the equipment host (r = -0.12) in firefighters, but none of these correlations achieved significance, perhaps owing to the small sample size. The authors noted that this lack of association could also be due to the extended break periods between tasks, which reduced the need for higher cardiorespiratory fitness levels. The findings of Rhea were supported by Skinner et al. [18] who reported that rel$\dot{V}O_{2max}$ was not related to individual task performance; however, it was related to overall occupational-specific tasks. The absence of significance in the association between cardiorespiratory fitness and individual task completion time may be due to the relatively fit and homogenous group of firefighters that were recruited to participate. In contrast, Williford et al. [5] found that more distance covered on the on the 1.5-mile run, which was used to estimate cardiorespiratory fitness, was significantly and positively related to the forcible entry (r = 0.25), equipment hoist (r = 0.30),

http://etd.uwc.ac.za/

victim rescue (r = 0.23) and the stair climb (r = 0.38). This indicates that occupational tasks that require more time to complete, that are also more strenuous, require higher levels of cardiorespiratory fitness to perform them adequately [3,5,6,46].Moreover, we found that after adjustment for age, sex, height and weekly MET minutes, absolute cardiorespiratory fitness remained significantly related to all tasks. Furthermore, absolute cardiorespiratory fitness, rather than relative cardiorespiratory fitness, contributed more significantly toward overall occupational-specific task performance. A study by Perroni et al. [51] also found that absolute cardiorespiratory fitness was more correlated to performance of the Queens College Step Field test compared to relative cardiorespiratory fitness (r = 0.76 vs r = 0.54) while performing the test wearing full PPE. The authors noted that using absolute oxygen may be a useful tool when evaluating cardiovascular strain in firefighters while firefighters are in PPE [51]. It is possible that absolute cardiorespiratory fitness may be a valuable measure while firefighters are wearing full PPE, as higher levels of relative oxygen consumption may not necessarily relate to better performance if firefighters lack the necessary muscle mass and strength needed to overcome the additional weight [51,52]. This may be a possible explanation for the results in the present study. Although being leaner may be more favourable in many cases, a higher overall LBM reflecting a greater muscular mass/strength and a greater ability to utilize oxygen (absolute oxygen utilisation) [53], may explain more favourable performances on each of the occupational-specific tasks. This would suggest that firefighters with a higher LBM, regardless of body weight, and a higher absolute $\dot{V}O_{2max,}$ would perform significantly better, likely due to greater oxygen uptake and additional muscular strength to overcome the weight of their PPE [3,33,38,54–56]. The current study found that firefighters that were more physically active performed significantly better (shorter performance time) on the charged hose drag and pull, ladder raise and extension, equipment carry, forcible entry and the rescue drag. Firefighters that are more physically active would, inherently, have a higher level of physical fitness

http://etd.uwc.ac.za/

[22,23,57]. And, as physical fitness has been significantly related to better occupational performance, this would relate to better performance on all the occupational performance tasks [3,34,55,58].

In the present study, as the tasks progressed, cardiorespiratory fitness became more significant in completion of the occupational simulation tasks. This may be due to the increase in cardiorespiratory workload, and subsequent increase in cardiovascular fatigue, particularly for occupational simulation protocols that are longer and encompass more tasks, requiring higher levels of oxygen consumption for an extended period [6,59,60]. Von Heimburg reported that the faster firefighters consumed oxygen at a higher rate than slower ones, however, due to them having an extended time for completing the test, accumulated $\dot{V}O_2$ was higher. This suggests that as the occupational-specific tasks progressed, cardiorespiratory fitness becomes increasingly more important for completion of the simulation protocol. Another study by Von Heimburg et al. [56] found that peak $\dot{V}O_2$ could accurately predict occupational performance and more so when expressed as absolute cardiorespiratory fitness rather than relative cardiorespiratory fitness. Possibly peak $\dot{V}O_2$ (absolute) may be important for faster occupational performance, and for slower, less fit firefighters, accumulated $\dot{V}O_2$ or the ability to sustain a minimum $\dot{V}O2$ may be crucial in completing their occupational-specific tasks. Fernhall et al. [61] noted that intermittent vigorous-intensity firefighting activity over a three-hour period induced significant cardiac fatigue, likely resulting in reduced occupational performance. This highlights the importance of cardiorespiratory fitness in all firefighting duty-related tasks, particularly when performed over an extended period. Although the present study used a much shorter time period for testing, the cardiovascular strain may be comparable to Fernhall et al. [61], where the same cardiac fatigue may have been induced due to the shorter, but more intense cardiovascular workloads.

http://etd.uwc.ac.za/

We found that higher muscular strength and muscular endurance was associated with shorter completion times for all individual occupational-specific tasks. Michaelides et al. [55] reported that push-ups stamina was related to the stair climb (r = -0.39) and rolled hose lift and move (r = -0.30) and sit-ups were inversely related to the stair climb (r = -0.50), the rolled hose lift and move (r = -0.52) and the charged hose advance (r = -0.30). In addition, bench press was inversely related to rolled hose lift and move (r = -0.30), Keiser sled (r = -0.41) and rescue drag (r = -0.31), squat strength was related to the Keiser sled (r = -0.39) and grip strength was related to the Keiser Sled task (r = -0.30), hose pull hydrant hook-up (r = -0.36) and rescue drag tasks (r = -0.41) [55]. Similarly, Rhea et al. [6] found that squat strength, was inversely related to the hose pull only, and the bench press and hand grip strength was negatively related to the hose pull, victim drag, stair climb and equipment hoist. Moreover, muscular endurance in the row, bench press, shoulder press and biceps curl were related to better performance on most of the individual firefighting tasks. Williford et al. [5] corroborated these findings, reporting that grip strength was negatively related to the forcible entry task (r = -0.53), equipment hoist (r = -0.55) hose advance (r = -0.41), victim rescue (r = -0.59) and stair climb tasks (r = -0.39). In addition, firefighters with higher push-ups capacity performed better on all tasks, and firefighters with a higher sit-ups capacity performed better on all tasks, except the hose advance task. This was further supported by Skinner et al. [18] who reported that higher strength levels in the bench press (r = -0.471) and higher endurance capacity in the push-ups (r = -0.385) were negatively related to the hose drag task. A study by von Heimburg et al. [56] noted that there was a minimum standard of muscular strength and endurance are required to perform the occupational tasks acceptably and muscular strength exceeding this point had progressively less impact on the performance of each task. Moreover, overweight and obese firefighters with higher strength levels did not perform better than lighter fighters that had sufficient strength to

http://etd.uwc.ac.za/

overcome the task [56], which had been a finding that was reported by Phillips et al. [17]. Chizewski et al. [3] noted that after a 7-week intervention, as strength levels increased, the relationship between strength and individual task performance became stronger, however, the relationship between muscular endurance became weaker in most tasks. This suggests that stronger firefighters require less effort to perform each task, leading to a lower emphasis being placed on firefighters having higher levels of muscular endurance. Nonetheless, higher levels of muscular strength and endurance have been consistently reported to be related to better occupational performance and are integral to ensure firefighters are capable of performing their duties effectively [5,18,46] In the present study, we found that higher sit-and-reach scores were associated to lower completion times on the equipment carry task. A systematic review [46] reported that there was a significant effect for flexibility on the stair climb task in firefighters. However, results for the relationship between flexibility and task performance are inconsistent in the literature [3,18,46,54].

The results showed that firefighters that had a higher LBM had significantly shorter completion times on all occupational-specific tasks. Williford et al. [5] reported that fat-free weight was significantly and inversely related to the forcible entry (r = -0.54), equipment hoist (r = -0.45), hose advance (r = -0.36), victim rescue (r = -0.54), but not the stair climb task. In addition, fat-free weight was a significant contributor to the model predicting overall occupational performance. Similarly, Davis et al. [34] reported that LBM was associated with lower occupational performance times (r = -0.460) and was retained in the model predicting occupational performance in firefighters. Skinner et al.[18] found that LBM was not related to individual task performance, however, was negatively related to overall occupational performance in firefighters. Henderson et al. [52] found that in 306 firefighters that LBM was positively related to axe power task (r = 0.19) and combat test times (r = 0.52). It is likely

http://etd.uwc.ac.za/

firefighters with a higher LBM are taller and heavier, with more muscle mass, which has all been shown to be related to better performance on all tasks [5,17,38].

In the current study we found that as age (and hence years of experience increased), the completion times for each of the occupational-specific performance tasks increased. Williford et al. [5] reported that an increase in age was related to an increase in the stair climb (r = 0.52) task completion time. Similarly, Chizewski et al. [3] reported that age was positively correlated with the SCBA crawl task. Skinner et al. [18] found that age was positively related with the dummy drag (r = 0.389) completion times. Although, in previous studies, age was not consistently reported to decrease performance on all individual occupational-specific tasks, age has been shown to be associated with slower overall occupational performance times [34,38,62,63]. Researchers have argued that older and more experienced firefighters have learned superior techniques that could, at least partially, counteract the age-related decrease in cardiorespiratory fitness [38]. However, in the present study, an increase in age was associated with an increase in the completion times of all tasks, except the forcible entry task. While our results are generally consistent with earlier studies showing that older firefighters performed certain tasks slower than younger firefighters [3,5,18], our results show that older firefighters consistently performed worse on all occupational-specific tasks. This may be due to the natural age-related decrease in cardiorespiratory fitness, muscular strength and endurance, negatively affecting occupational performance in firefighters [64–67].

We found that an increase in BF% and BMI were associated with significantly slower completion times for all occupational-specific tasks in firefighters. Williford et al. [5] reported that BF% was significantly and positively related to forcible entry completion times (r = 0.21), equipment hoist (r = 0.23), victim rescue (r = 0.25) and stair climb tasks (r = 0.52) completion

http://etd.uwc.ac.za/

times. Similarly, Chizewski et al. [3] reported that BMI was positively related to the SCBA crawl task completion time (r = 0.379). However, after an exercise intervention, BMI was inversely related to the hose drag advance (r = -0.272) and the ladder raise (r = -0.274) task completion times. This may be due to an increase in LBM and muscles strength, in the absence of a loss in body fat, leading to an increase in BMI, that is related to better task performance [68]. Schonfeld et al. [50] that reported that BF% was positively related to the stair climb task completion time (r = 0.535). Similarly, Ebersole et al. [69] reported that in a sample of 17 firefighter recruits, BF% was positively related to the stair climb task completion time (r = 0.563). Skinner et al. [18] noted that BF% was not related to individual task performance but was positively related to overall occupational completion times (r = 0.481). In contrast, Rhea et al. [6] reported that there were no significant relationships between BF% and the completion times of any occupational tasks; however, this may be due to the small cohort (include sample size) used in the study. An increase in body fat represents non-functional mass that increases the effort firefighters are required to exert to successfully complete each task, which, subsequently, increases the time taken to complete each task [46,54,55]. It is also plausible that obese firefighters ambulate more slowly and less efficiently [70], extending the time to complete each task that requires continual movement, such as the hose drag, equipment carry or victim drag, while also requiring additional time moving from task to task. In addition, it is likely that obese firefighters' fatigue quicker, consequently reducing their overall occupational performance [5,69,71].

We found that taller and heavier firefighters performed significantly better than their lighter and shorter counterparts. This was consistent with a study conducted by Phillips et al. [17] that reported heavier and, subsequently, taller, firefighters performed favourably on all simulation tasks, except the ladder climb test. Similarly, Williford et al. [5] reported that height and weight

http://etd.uwc.ac.za/

were significantly related to all occupational performance task completion times. Taller firefighters, inherently, would have a higher LBM, consequently, a higher overall muscle mass and $\dot{V}O_{2max}$ [17,18,72]. Taller firefighters may have an additional biomechanical advantage, requiring a lower leg lift for the step-up, having a greater stride length for the charged hose drag and pull, being more stable when pitching the ladder and having a larger swing arc for the forcible entry [17,73]. Von Heimburg et al. [38] separated participants into fast and slow performers, and found that those who performed a rescue operation fastest were taller (9 cm) and heavier (10 kg more) than those who performed the task more slowly.

We found that an increase in HRV, SDNN and RMSSD was associated with faster completion times for all occupational-specific tasks, and LF range was associated with better performance on all tasks, except the forcible entry. A study by Lesniak et al. [74] reported that SDNN was negatively related to the hose drag (r = -0.745), ladder raise (r = -0.738) and rescue (r = -0.738) tasks and LF/HF ratio was negatively related to the forcible entry task (r = -0.718). Previous studies have also found that firefighters that had higher HRV was related to higher physical performance [75,76], sleepiness and higher levels of fatigue [77], and cardiovascular health [78]. Theoretically, Firefighters with higher HRV indices would be fitter, and healthier, consequently performing better on of all the occupational-specific tasks. The LF range has been reported to be associated with the physical fitness levels, the stress state and baroreceptor functioning in individuals [79]. This suggests that firefighters that are in lower stress states are fitter and may perform their duties more efficiently than those that are in a more stressed state, which has been a proposed theory explaining the reasons for performance decrements in firefighters [79–81]. This becomes particularly evident as firefighters age and become more stressed, as a result of being in the profession for a longer period [82,83]. The use of HRV may provide a new, and relatively cost-effective, criterion to assist in assessing the physical health

http://etd.uwc.ac.za/

and occupational performance in firefighters. This was the first study conducted in Africa using HRV to assess occupational-specific task performance, and few studies exist investigating the association between HRV and occupational performance in firefighters. More research needs to be conducted in this area.

The findings of the present study indicated that a higher blood pressure was associated with an increase in the step-up, the charged hose drag and pull and the equipment carry completion times. Similarly, Davis et al. [34] reported that diastolic blood pressure was positively related to occupational task performance (r = 0.233) in firefighters. In the present study, the step-up, charged hose drag and pull and the equipment carry tasks involved strong isometric and isotonic contractions, which leads to an exaggerated blood pressure response [20,84].

Firefighters that reported MSIs had slower completion times for the step-up and rescue drag tasks and those with MSD, particularly in the lower back region, had slower completion times for the step-up, charged hose drag and pull and rescue drag tasks. McDermid et al. [27] reported that MSD was not significantly related to the completion times of the stair climb or hose drag tasks. However, firefighters with severe discomfort took 10 seconds longer to perform the stair climb compared to those without discomfort. Similarly, Nazari et al. [85] reported that spine pain was related to firefighters reporting the most physical and work limitations. In addition, the current study showed that firefighters who experienced more overall MSD and, those specifically experiencing MSD in the shoulder, upper back, wrist and hand regions took significantly longer to complete the forcible entry task. Since the forcible entry task requires firefighters to swing a sledgehammer with maximal force [3,5], it is unsurprising that firefighters with MSD in the shoulder, upper back and wrist and hand regions would have the most physical limitations leading to worse performance. Azmi and Masuri [30] reported that

http://etd.uwc.ac.za/

MSD in the upper back, lower back, left wrist and left thigh contributed to 50% of the limitation to functional status in firefighters. Limitations, caused by previous injury or current discomfort, may contribute toward firefighters guarding the injured or discomforted area [26,86]. Moreover, pain or previous injury may contribute toward reduced force production contributing toward worse performance on each task, particularly those requiring weight bearing, placing stain on the lower limbs and low back, such as the step-up, charged hose drag and pull and the rescue drag, as seen in the present study [87].

The results of the LASSO analysis indicated that firefighters with higher cardiorespiratory fitness, muscle endurance capacity, who are stronger, more physically active and had a lower BF% and higher LBM had the shortest completion time on the step-up, charged hose drag and pull, forcible entry, equipment carry, ladder raise and extension and the rescue drag tasks. Previous studies are consistent with these findings, and have shown that stronger, fitter and leaner firefighters performed the stair climb, hose drag and pull, forcible entry, equipment carry, ladder raise and rescue drag tasks significantly quicker than weaker, overweight/obese and less fit firefighters [3,6,18,34,55]. In a study that used a similar approach to ours, but with some different occupational tasks, Lindberg et al. [88] reported that measures of physical fitness, particularly those related to cardiorespiratory fitness, grip strength, grip endurance explained 82% of the variance in the stair climb task, 79% of the variation in the hose pulling task, 69% of the variance in the demolition task and 77% of the variance in the victim rescue task. Nazari et al. [89] reported that age, right-hand grip strength, left-hand grip strength, sex and resting HR explained 24% of the variance in the hose drag completion times. In addition, leg strength, age, sex and resting HR explained 25% of the variance in high-rise pack completion times. Henderson et al. [52] reported that muscular strength, rel$\dot{V}O_{2max}$ and sit-ups explained 54% of the variance in the roof ladder placement task, 45% of the variance in the

http://etd.uwc.ac.za/

axe rating task, and 63% of the variance in the combat speed ability test. In aggregate, previous studies are consistent with the current findings indicating that hose drag and pull times were significantly shorter for firefighters that were stronger, fitter and leaner [3,5].

Strengths and Limitations

This was the first study to investigate the association between physical fitness, cardiovascular and musculoskeletal health in relation to occupational-specific task performance through a physical ability test performed by firefighters in the CoCTFRS, adding novel findings, particularly in a South African context. The measures for physical fitness, cardiovascular health, and occupational-specific task performance were objectively measured by trained researchers, using standardized and validated instruments [35]. There are, however, several limitations to the present study. The first limitation is the cross-sectional study design which precludes the inference of causal relationships. A second limitation was that female firefighters were underrepresented, limiting the generalizability to the female firefighter population. Cardiorespiratory fitness was measured using a non-exercise estimation, not using lab or field testing. Lastly, the multiple comparisons on the relatively small sample size may have increased the possibility of spurious findings.

12.5. Conclusion

The present study showed that multiple parameters of physical fitness, cardiovascular health, and musculoskeletal health were related to better occupational-specific task performance in firefighters. Fitter, more active, stronger, and leaner firefighters who had a more favourable cardiovascular health profile, and without MSH concerns were the best performers on each occupational-specific task. Moreover, firefighters with higher HRV showed faster performance

http://etd.uwc.ac.za/

in all occupational-specific tasks, providing novel findings on the relationship between cardiovascular autonomic functioning and work performance in firefighters. Municipal fire departments may use the study's findings to emphasize the necessity for physical fitness and CVH standards to improve firefighters' occupational performance, as well as to protect CVH and MSH of firefighters, and increase the longevity of their careers. Fire departments can enhance the services they offer, lower the risk of civilian casualties, and prevent damage to vital infrastructure by instituting regular physical exercise programs and enforcing a basic fitness standard for all firefighters.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

References

[1] Smith DL, Barr DA, Kales SN. Extreme sacrifice: Sudden cardiac death in the US Fire Service. *Extrem Physiol Med.* 2013;2:1–9. https://doi.org/10.1186/2046-7648-2-6.

[2] Smith DL, DeBlois JP, Kales SN, Horn GP. Cardiovascular strain of firefighting and the risk of sudden cardiac events. *Exerc Sport Sci Rev.* 2016;44:90–7. https://doi.org/10.1249/JES.0000000000000081.

[3] Chizewski A, Box A, Kesler R, Petruzzello SJ. Fitness fights fires: Exploring the relationship between physical fitness and firefighter ability. *Int J Environ Res Public Health.* 2021;18. https://doi.org/10.3390/ijerph182211733.

[4] Smith DL, Haller JM, Korre M, Sampani K, Porto LGG, Fehling PC, et al. The Relation of Emergency Duties to Cardiac Death Among US Firefighters. *American Journal of Cardiology.* 2019;123:736–41. https://doi.org/10.1016/j.amjcard.2018.11.049.

[5] Williford HN, Duey WJ, Olson MS, Howard R, Wang N. Relationship between fire fighting suppression tasks and physical fitness. *Ergonomics.* 1999;42:1179–86. https://doi.org/10.1080/001401399185063.

[6] Rhea MR, Alvar BA, Gray R. Physical fitness and job performance of firefighters. *J Strength Cond Res.* 2004;18:348–52. https://doi.org/10.1519/r-12812.1.

[7] Soteriades ES, Smith DL, Tsismenakis AJ, Baur DM, Kales SN. Cardiovascular disease in US firefighters: A systematic review. *Cardiol Rev.* 2011;19:202–15. https://doi.org/10.1097/CRD.0b013e318215c105.

[8] Ras J, Leach L. Prevalence of coronary artery disease risk factors in firefighters in the city of Cape Town fire and rescue service – A descriptive study. *J Public Health Res.* 2021;10. https://doi.org/10.4081/jphr.2021.2000.

[9] Risavi BL, Staszko J. Prevalence of Risk Factors for Coronary Artery Disease in Pennsylvania (USA) Firefighters. *Prehosp Disaster Med.* 2015;31:102–7. https://doi.org/10.1017/S1049023X15005415.

[10] Martin ZT, Schlaff RA, Hemenway JK, Coulter JR, Knous JL, Lowry JE, et al. Cardiovascular Disease Risk Factors and Physical Fitness in Volunteer Firefighters. *Int J Exerc Sci.* 2019;12:764–76.

[11] Smith DL, Graham E, Stewart D, Mathias KC. Cardiovascular Disease Risk Factor Changes over 5 Years among Male and Female US Firefighters. *J Occup Environ Med.* 2020;62:398–402. https://doi.org/10.1097/JOM.0000000000001846.

[12] Mathias KC, Bode ED, Stewart DF, Smith DL. Changes in Firefighter Weight and Cardiovascular Disease Risk Factors over Five Years. *Med Sci Sports Exerc.* 2020;52:2476–82. https://doi.org/10.1249/MSS.0000000000002398.

[13] Vicente MM, Herrero DC, Prieto JP. Cardiorespiratory Fitness in Spanish Firefighters. *J Occup Environ Med.* 2021;63:e318–22. https://doi.org/10.1097/JOM.0000000000002199.

http://etd.uwc.ac.za/

[14] Donovan R, Nelson T, Peel J, Lipsey T, Voyles W, Israel RG. Cardiorespiratory fitness and the metabolic syndrome in firefighters. *Occup Med (Chic Ill).* 2009;59:487–92. https://doi.org/10.1093/occmed/kqp095.

[15] Li K, Lipsey T, Leach HJ, Nelson TL. Cardiac health and fitness of Colorado male/female firefighters. *Occup Med (Chic Ill).* 2017;67:268–73. https://doi.org/10.1093/occmed/kqx033.

[16] Baur DM, Christophi CA, Tsismenakis AJ, Cook EF, Kales SN. Cardiorespiratory fitness predicts cardiovascular risk profiles in career firefighters. *J Occup Environ Med.* 2011;53:1155–60. https://doi.org/10.1097/JOM.0b013e31822c9e47.

[17] Phillips DB, Scarlett MP, Petersen SR. The Influence of Body Mass on Physical Fitness Test Performance in Male Firefighter Applicants. *J Occup Environ Med.* 2017;59:1101–8. https://doi.org/10.1097/JOM.0000000000001145.

[18] Skinner TL, Kelly VG, Boytar AN, Peeters G (Geeske), Rynne SB. Aviation Rescue Firefighters physical fitness and predictors of task performance. *J Sci Med Sport.* 2020;23:1228–33. https://doi.org/10.1016/j.jsams.2020.05.013.

[19] Feairheller DL. Blood pressure and heart rate responses in volunteer firefighters while wearing personal protective equipment. *Blood Press Monit.* 2015;20:194–8. https://doi.org/10.1097/MBP.0000000000000120.

[20] Lin G-M, Tsai K-Z, Lin C-S, Han C-L. Physical Fitness and Long-term Blood Pressure Variability in Young Male Military Personnel. *Curr Hypertens Rev.* 2019;16:156–60. https://doi.org/10.2174/1573402115666191023111351.

[21] Fahs CA, Smith DL, Horn GP, Agiovlasitis S, Rossow LM, Echols G, et al. Impact of Excess Body Weight on Arterial Structure , Function , and Blood Pressure in Firefighters. *AJC* 2009;104:1441–5. https://doi.org/10.1016/j.amjcard.2009.07.009.

[22] Durand G, Tsismenakis AJ, Jahnke SA, Baur DM, Christophi CA, Kales SN. Firefighters' physical activity: relation to fitness and cardiovascular disease risk. *Med Sci Sports Exerc.* 2011;43:1752–9. https://doi.org/10.1249/MSS.0b013e318215cf25.

[23] Yu CCW, Au CT, Lee FYF, So RCH, Wong JPS, Mak GYK, et al. Association Between Leisure Time Physical Activity, Cardiopulmonary Fitness, Cardiovascular Risk Factors, and Cardiovascular Workload at Work in Firefighters. *Saf Health Work.* 2015;6:192–9. https://doi.org/https://doi.org/10.1016/j.shaw.2015.02.004.

[24] Poplin GS, Roe DJ, Peate W, Harris RB, Burgess JL. The Association of Aerobic Fitness With Injuries in the Fire Service. *American Journal of Epidemiology.* 2013; 179(2):149-155. https://doi.org/10.1093/aje/kwt213.

[25] Vaulerin J, d'Arripe-Longueville F, Emile M, Colson SS. Physical exercise and burnout facets predict injuries in a population-based sample of French career firefighters. *Appl Ergon.* 2016;54:131–5. https://doi.org/10.1016/j.apergo.2015.12.007.

[26] Nazari G, Osifeso TA, MacDermid JC. Distribution of Number, Location of Pain and Comorbidities, and Determinants of Work Limitations among Firefighters. *Rehabil Res Pract.* 2020;2020:1942513. https://doi.org/10.1155/2020/1942513.

http://etd.uwc.ac.za/

[27] MacDermid JC, Tang K, Sinden KE, D'Amico R. Work Functioning Among Firefighters: A Comparison Between Self-Reported Limitations and Functional Task Performance. *J Occup Rehabil*. 2019;29:194–204. https://doi.org/10.1007/s10926-018-9778-6.

[28] Park K, Rosengren KS, Horn GP, Smith DL, Hsiao-Wecksler ET. Assessing gait changes in firefighters due to fatigue and protective clothing. *Saf Sci*. 2011;49:719–26. https://doi.org/https://doi.org/10.1016/j.ssci.2011.01.012.

[29] Park K, Sy JF, Horn GP, Kesler RM, Petrucci MN, Rosengren KS, et al. Assessing gait changes in firefighters after firefighting activities and while carrying asymmetric loads. *Appl Ergon*. 2018;70:44–50. https://doi.org/https://doi.org/10.1016/j.apergo.2018.01.016.

[30] Azmi NLAM, Masuri MG. Work-related musculoskeletal disorder (WMSDs) and functional status of firefighters in Klang Valley. Healthscope: The Official Research Book of Faculty of Health Sciences, *UiTM*. 2019;2.

[31] Kodom-Wiredu JK. The Relationship between Firefighters' Work Demand and Work-related Musculoskeletal Disorders: The Moderating Role of Task Characteristics. *Saf Health Work*. 2019;10:61–6. https://doi.org/10.1016/j.shaw.2018.05.004.

[32] Stevenson RDM, Siddall AG, Turner PFJ, Bilzon JLJ. Implementation of Physical Employment Standards for Physically Demanding Occupations. *J Occup Environ Med*. 2020;62:647–53. https://doi.org/10.1097/JOM.0000000000001921.

[33] Sothmann MS, Gebhardt DL, Baker TA, Kastellos GM, Sheppard VA. Performance requirements of physically strenuous occupations: Validating minimum standards for muscular strength and endurance. *Ergonomics*. 2004;47:864–75. https://doi.org/10.1080/00140130410001670372.

[34] Davis PO, Dotson CO, Santa Maria DL. Relationship between simulated fire fighting tasks and physical performance measures. *Med Sci Sports Exerc*. 1982;14.

[35] Ras J, Smith DL, Soteriades ES, Kengne AP, Leach L. A Pilot Study on the Relationship between Cardiovascular Health, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters. *Eur J Investig Health Psychol Educ*. 2022;12:1703–18. https://doi.org/10.3390/ejihpe12110120.

[36] Liguori G, Medicine AC of S, Fountaine CJ. ACSM's Guidelines for Exercise Testing and Prescription. Tenth Edition. Philadelphia. Wolters Kluwer; 2021.

[37] Ras J, Smith DL, Soteriades ES, Kengne AP, Leach L. Association between Physical Fitness and Cardiovascular Health in Firefighters. *Int J Environ Res Public Health*. 2023;20. https://doi.org/10.3390/ijerph20115930.

[38] von Heimburg ED, Rasmussen AKR, Medbø JI. Physiological responses of firefighters and performance predictors during a simulated rescue of hospital patients. *Ergonomics*. 2006;49:111–26. https://doi.org/10.1080/00140130500435793.

[39] D'Agostino RB, Vasan RS, Pencina MJ, Wolf PA, Cobain M, Massaro JM, et al. General Cardiovascular Risk Profile for Use in Primary Care. *Circulation* 2008;117:743–53. https://doi.org/10.1161/CIRCULATIONAHA.107.699579.

http://etd.uwc.ac.za/

[40] Lloyd-Jones DM, Leip EP, Larson MG, D'Agostino RB, Beiser A, Wilson PWF, et al. Prediction of Lifetime Risk for Cardiovascular Disease by Risk Factor Burden at 50 Years of Age. *Circulation.* 2006;113:791–8. https://doi.org/10.1161/CIRCULATIONAHA.105.548206.

[41] Lloyd-Jones DM, Braun LT, Ndumele CE, Smith SC, Sperling LS, Virani SS, et al. Use of Risk Assessment Tools to Guide Decision-Making in the Primary Prevention of Atherosclerotic Cardiovascular Disease: A Special Report From the American Heart Association and American College of Cardiology. *Circulation*. 2019;139:e1162–77. https://doi.org/10.1161/CIR.0000000000000638.

[42] Ras J, Soteriades ES, Smith DL, Kengne AP, Leach L. Association between Cardiovascular and Musculoskeletal Health in Firefighters. *J Occup Environ Med.* 2023 65(7):e496–e505.

[43] Hedge A, Morimoto S, Mccrobie D. Effects of keyboard tray geometry on upper body posture and comfort. *Ergonomics.* 1999;42:1333–49. https://doi.org/10.1080/001401399184983.

[44] Crawford JO. The Nordic Musculoskeletal Questionnaire. *Occup Med (Chic Ill)* 2007;57:300–1. https://doi.org/10.1093/occmed/kqm036.

[45] Templeton GF. A two-step approach for transforming continuous variables to normal: Implications and recommendations for IS research. *Communications of the Association for Information Systems*. 2011;28:41–58. https://doi.org/10.17705/1cais.02804.

[46] Ras J, Kengne AP, Smith DL, Soteriades ES, November R V, Leach L. Effects of Cardiovascular Disease Risk Factors, Musculoskeletal Health, and Physical Fitness on Occupational Performance in Firefighters: A Systematic Review and Meta-Analysis. *Int J Environ Res Public Health.* 2022;19. https://doi.org/10.3390/ijerph191911946.

[47] Strauss M, Foshag P, Jehn U, Brzęk A, Littwitz H, Leischik R. Higher cardiorespiratory fitness is strongly associated with lower cardiovascular risk factors in firefighters : a cross - sectional study in a German fire brigade. *Sci Rep.* 2021:1–7. https://doi.org/10.1038/s41598-021-81921-1.

[48] Seyedmehdi SM, Attarchi M, Cherati AS, Hajsadeghi S, Tofighi R, Jamaati H. Relationship of aerobic fitness with cardiovascular risk factors in firefighters. *Work.* 2016;55:155–61. https://doi.org/10.3233/WOR-162375.

[49] Espinoza F, Delgado-Floody P, Martínez-Salazar C, Jerez-Mayorga D, Guzmán-Guzmán IP, Caamaño-Navarrete F, et al. The influence of cardiometabolic risk factors on cardiorespiratory fitness in volunteer Chilean firefighters. *American Journal of Human Biology.* 2019;31. https://doi.org/10.1002/ajhb.23280.

[50] Schonfeld BR, Doerr DF, Convertino VA. An Occupational Performance Test Validation Program for Fire Fighters at the Kennedy Space Center. *J Occup Environ Med*. 1990;32.

[51] Perroni F, Guidetti L, Cignitti L, Baldari C. Absolute vs. weight-related maximum oxygen uptake in firefighters: Fitness evaluation with and without protective clothing and self-contained breathing apparatus among age group. *PLoS One.* 2015;10. https://doi.org/10.1371/journal.pone.0119757.

http://etd.uwc.ac.za/

[52] Henderson N, Berry M, Matic T. Field Measures of Strength and Fitness Predict Firefighter Performance on Physically Demanding Tasks. *Pers Psychol.* 2007;60:431–73. https://doi.org/https://doi.org/10.1111/j.1744-6570.2007.00079.x.

[53] Lee J, Zhang XL. Physiological determinants of VO2max and the methods to evaluate it: A critical review. *Sci Sports*. 2021;36:259–71. https://doi.org/https://doi.org/10.1016/j.scispo.2020.11.006.

[54] Michaelides MA, Parpa KM, Thompson J, Brown B. Predicting performance on a firefghter's ability test from fitness parameters. *Res Q Exerc Sport.* 2008;79:468–75. https://doi.org/10.1080/02701367.2008.10599513.

[55] Michaelides MA, Parpa KM, Henry LJ, Thompson GB, Brown BS. Assessment of Physical Fitness Aspects and Their Relationship to Firefighters' Job Abilities. *The Journal of Strength & Conditioning Research.* 2011;25(4):956-65.

[56] von Heimburg E, Medbø JI, Sandsund M, Reinertsen RE. Performance on a work-simulating firefighter test versus approved laboratory tests for firefighters and applicants. *International Journal of Occupational Safety and Ergonomics.* 2013;19:227–43. https://doi.org/10.1080/10803548.2013.11076981.

[57] Barry AM, Lyman KJ, Dicks ND, Landin KD, McGeorge CR, Hackney KJ, et al. Firefighters' Physical Activity and Waist Circumference as Predictors of. *J Occup Environ Med.* 2019;61:849–53. https://doi.org/10.1097/JOM.0000000000001690.

[58] Skinner TL, Kelly VG, Boytar AN, Peeters G (Geeske), Rynne SB. Aviation Rescue Firefighters physical fitness and predictors of task performance. *J Sci Med Sport*. 2020;23:1228–33. https://doi.org/10.1016/j.jsams.2020.05.013.

[59] Siddall, A; Standage, M; Stokes, K and Bilzon J. Development of Occupational Fitness Standards for the UK Fire and Rescue Services (FRS). *University of Bath*. 2014:59. https://doi.org/10.13140/RG.2.1.4616.4646.

[60] Stevenson RDM, Siddall AG, Turner PJF, Bilzon JLJ. Validity and Reliability of Firefighting Simulation Test Performance. *J Occup Environ Med.* 2019;61:479–83. https://doi.org/10.1097/JOM.0000000000001583.

[61] Fernhall B, Fahs CA, Horn G, Rowland T, Smith D. Acute effects of firefighting on cardiac performance. *Eur J Appl Physiol.* 2012;112:735–41. https://doi.org/10.1007/s00421-011-2033-x.

[62] Myhre LG, Tucker DM, Bauer DH, Fisher Jr JR, Grimm WH. Relationship Between Selected Measures of Physical Fitness and Performance of a Simulated Fire Fighting Emergency Task. *Armstrong Lab Brooks AFB TX*; 1997.

[63] Saari AI, Renz G, Davis P, Abel MG. The Influence of Age on Firefighter Combat Challenge Performance and Exercise Training Habits. *J Strength Cond Res.* 2020:2500–6.

[64] Walker A, Driller M, Argus C, Cooke J, Rattray B. The ageing Australian firefighter: An argument for age-based recruitment and fitness standards for urban fire services. *Ergonomics.* 2014;57:612–21. https://doi.org/10.1080/00140139.2014.887790.

http://etd.uwc.ac.za/

[65] Findley BW, Brown LE, Whitehurst M, Gilbert R, Apold SA. Age-Group Performance and Physical Fitness in Male Firefighters. *The Journal of Strength & Conditioning Research*. 1995;9.

[66] Perroni F, Guidetti L, Cignitti L, Baldari C. Age-related changes in upper body strength and lower limb power of professional Italian firefighters. *Sport Sci Health*. 2015;11:279–85. https://doi.org/10.1007/s11332-015-0236-y.

[67] Saari AI, Renz G, Davis P, Abel MG. The Influence of Age on Firefighter Combat Challenge Performance and Exercise Training Habits. *J Strength Cond Res.* 2020:2500–6.

[68] Kales SN. Agreement between BMI and body fat obesity definitions in a physically active population. *Arch. Endocrinol. Metab*. 2016;60(6). https://doi.org/10.1590/2359-3997000000220.

[69] Ebersole KT, Tesch CS, Flees RJ, Haischer MH, Smith EK, Cornell DJ, et al. 2054 Physical Factors Associated with Tower Stair Climbing In Firefighter Recruits 2055 June 1 9 : 30 AM - 11 : 30 AM Cardiovascular Risk Factor Characterization and Isokinetic Muscle Strength in Overweight and Obese Male Firefighters June 1 9 : 30 AM - 1 2018:8673.

[70] Cornell DJ, Gnacinski SL, Zamzow A, Mims J, Ebersole KT. Influence of body mass index on movement efficiency among firefighter recruits. *Work*. 2016;54:679–87. https://doi.org/10.3233/WOR-162306.

[71] Crawford K, Fleishman K, Abt JP, Sell TC, Lovalekar M, Nagai T, et al. Less Body Fat Improves Physical and Physiological Performance in Army Soldiers. *Mil Med*. 2011;176:35–43. https://doi.org/10.7205/MILMED-D-10-00003.

[72] Misner JE, Plowman SA, Boileau RA. Performance Differences between Males and Females on Simulated Firefighting Tasks. *J Occup Med*. 1987; (10):801-5.

[73] Misner JE, Boileau RA, Plowman SA, Elmore BG, Gates MA, Gilbert JA, et al. Leg Power Characteristics of Female Firefighter Applicants. *J Occup Med*. 1988 30(5):433-7.

[74] Lesniak AY, Sell KM, Morris C, Abel MG. Relationship Between Heart Rate Variability Vs. Occupational Performance, Physical Activity and Fitness Measures in Structural Firefighters. *Journal of Sport and Human Performance*. 2022;10:56–72. https://doi.org/10.12922/jshp.v10i1.169.

[75] Porto LGG, Schmidt ACB, de Souza JM, Nogueira RM, Fontana KE, Molina GE, et al. Firefighters' basal cardiac autonomic function and its associations with cardiorespiratory fitness. *Work*. 2019;62:485–95. https://doi.org/10.3233/WOR-192883.

[76] Marcel-Millet P, Ravier G, Esco MR, Groslambert A. Does firefighters' physical fitness influence their cardiac parasympathetic reactivation? Analysis with post-exercise heart rate variability and ultra-short-term measures. *International Journal of Occupational Safety and Ergonomics*. 2020:1–9. https://doi.org/10.1080/10803548.2020.1738689.

[77] Jeklin AT, Perrotta AS, Davies HW, Bredin SSD, Paul DA, Warburton DER. The association between heart rate variability, reaction time, and indicators of workplace fatigue in wildland firefighters. *Int Arch Occup Environ Health*. 2021. https://doi.org/10.1007/s00420-020-01641-3.

http://etd.uwc.ac.za/

[78] Yook YS. Firefighters' occupational stress and its correlations with cardiorespiratory fitness, arterial stiffness, heart rate variability, and sleep quality. *PLoS One*. 2019;14:1–9. https://doi.org/10.1371/journal.pone.0226739.

[79] Ras J, Leach L. Use of Mobile Technology in Assessing Occupational Performance and Stress in Firefighters. In: Mentor D, editor. Handbook of Research on New Media, Training, and Skill Development for the Modern Workforce, Hershey, PA, USA: IGI Global; 2022, p. 150–86. https://doi.org/10.4018/978-1-6684-3996-8.ch008.

[80] Bugajska J, Zużewicz K, Szmauz-Dybko M, Konarska M. Cardiovascular stress, energy expenditure and subjective perceived ratings of fire fighters during typical fire suppression and rescue tasks. *International Journal of Occupational Safety and Ergonomics*. 2007;13:323–31. https://doi.org/10.1080/10803548.2007.11076730.

[81] Rodrigues S, Dias D, Paiva JS, Cunha JPS. Psychophysiological Stress Assessment Among On-Duty Firefighters. *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2018, p. 4335–8. https://doi.org/10.1109/EMBC.2018.8513250.

[82] Almeida-Santos MA, Barreto-Filho JA, Oliveira JLM, Reis FP, da Cunha Oliveira CC, Sousa ACS. Aging, heart rate variability and patterns of autonomic regulation of the heart. *Arch Gerontol Geriatr*. 2016;63:1–8. https://doi.org/10.1016/j.archger.2015.11.011.

[83] Shin JH, Lee JY, Yang SH, Lee MY, Chung IS. Factors related to heart rate variability among firefighters. *Ann Occup Environ Med*. 2016;28:1–9. https://doi.org/10.1186/s40557-016-0111-6.

[84] Mazic S, Suzic Lazic J, Dekleva M, Antic M, Soldatovic I, Djelic M, et al. The impact of elevated blood pressure on exercise capacity in elite athletes. *Int J Cardiol*. 2015;180:171–7. https://doi.org/10.1016/j.ijcard.2014.11.125.

[85] Nazari G, Osifeso TA, Macdermid JC. Distribution of Number , Location of Pain and Comorbidities, and Determinants of Work Limitations among Firefighters. *Rehabilitation Research and Prcactice*. 2020(2020).

[86] MacDermid JC, Tang K, Sinden KE, D'Amico R. Work Functioning Among Firefighters: A Comparison Between Self-Reported Limitations and Functional Task Performance. *J Occup Rehabil*. 2019;29:194–204. https://doi.org/10.1007/s10926-018-9778-6.

[87] Ras J, Smith DL, Kengne AP, Soteriades EE, Leach L. Cardiovascular Disease Risk Factors, Musculoskeletal Health, Physical Fitness, and Occupational Performance in Firefighters: A Narrative Review. *J Environ Public Health*. 2022;2022:7346408. https://doi.org/10.1155/2022/7346408.

[88] Lindberg AS, Oksa J, Antti H, Malm C. Multivariate statistical assessment of predictors of firefighters' muscular and aerobic work capacity. *PLoS One*. 2015;10. https://doi.org/10.1371/journal.pone.0118945.

[89] Nazari G, MacDermid JC, Sinden KE, Overend TJ. The Relationship between Physical Fitness and Simulated Firefighting Task Performance. *Rehabil Res Pract*. 2018;2018:1–7. https://doi.org/10.1155/2018/3234176.

http://etd.uwc.ac.za/

CHAPTER THIRTEEN: SUMMARY, DISCUSSION, CONCLUSION AND RECOMMENDATIONS

13.1. Introduction

The purpose of this chapter is to summarise the main findings of the previous chapters and to provide recommendations for future research. The aim of the doctoral study was to assess the relationship between cardiovascular health (CVH) metrics and risk profile, musculoskeletal health (MSH), physical fitness and occupational performance in firefighters.

13.2. Summary of Findings

The literature review entailed a range of different types of reviews that resulted in the production of the first four (4) peer-reviewed publications from chapters two to five of the thesis, as well as a peer-reviewed publication as a book chapter in Appendix X. The research data collected in the doctoral study was used to produce a range of manuscripts that resulted in a total of seven (7) peer-reviewed publications from chapters six to twelve of the thesis.

Chapter Two reported that there were significant relationships between CVD risk factors, MSH, physical fitness and occupational performance. Firefighters who were aged, obese, cigarette smokers and physically unfit and inactive were at the highest risk for CVD and musculoskeletal health complications, and produced unsatisfactory occupational performance. In **Chapter Three**, a protocol for a systematic review and meta-analysis was presented to

http://etd.uwc.ac.za/

ensure the methodology for the systematic review followed a rigorous process. The systematic review in **Chapter Four** reported that age and gender were positively related to occupational performance and occupational tasks, while cardiorespiratory fitness, upper body endurance, abdominal endurance, handgrip strength, and both upper and lower body strength were inversely related to occupational performance completion time. The second systematic review in **Chapter Five** found that selected physiological markers, obesity and ageing were inversely related to cardiorespiratory fitness in firefighters.

Chapter Six reported the shoulder was the most common injury site, with approximately 70% of firefighters not meeting the minimum physical activity recommendations. While those who were more physically active were more likely to report MSIs. **Chapter Seven** was a pilot study that reported a high correlation (>0.9) for repeated measures of equipment and testers, and the questionnaires to be reliable for data collection. In **Chapter Eight**, the results indicated that age, BMI, BF%, DBP, TC and the Framingham risk score all increased the odds of firefighters reporting MSIs. Moreover, an increase in TC, LDL-C, HRV (SDNN and RMSSD) increased the odds of firefighters reporting MSD. **Chapter Nine** found that cardiorespiratory fitness, muscular strength and muscular endurance were significantly associated with cardiovascular health, and that relative $\dot{V}O_{2max}$ was a key physical fitness parameter of good CVH in firefighters. The results of **Chapter Ten** showed that higher levels of physical fitness reduced the odds of firefighters reporting MSIs, but that higher levels of physical fitness were also associated with more frequent MSD. **Chapter Eleven** reported physical fitness, CVH and MSH as significant predictors of occupational performance in firefighters. Absolute $\dot{V}O_{2max}$, handgrip strength, leg strength, push-ups, sit-ups, lean body mass, age, BF%, weekly MET minutes and HVR were associated with PAT completion times. In addition, most of the variance in occupational performance was explained by weekly MET minutes, BF%, absolute

http://etd.uwc.ac.za/

$\dot{V}O_{2max}$, handgrip strength, leg strength and sit-ups. The results of **Chapter Twelve** showed that absolute $\dot{V}O_{2max}$, handgrip strength, leg strength, push-ups, sit-ups, LBM and HRV were inversely related to all occupational-specific performance tasks in firefighting. The key predictors of task performance were absolute $\dot{V}O_{2max}$, handgrip strength, leg strength, sit-ups, lean body mass, BF% and weekly MET minutes.

13.3. Discussion

This section discusses the relationship between cardiovascular and musculoskeletal health, physical fitness and occupational performance in firefighters in the CoCTFRS and the contribution of each paper in addressing the aims and objectives of the study (Figure 14.1). This section also provides suggestions on improving the cardiovascular and musculoskeletal health and physical fitness of firefighters in order to benefit occupational performance.

13.3.1. Cardiovascular and Musculoskeletal Health

The results from both Chapters Two (narrative literature review) and Eight (original research publication three) showed that CVH was significantly associated with MSH in firefighters. Older, obese firefighters with more years of experience were at risk of reporting MSIs and MSD. These results were consistent with previous literature [1–6]. The combination of an increase in non-essential fat mass and the natural deterioration in MSH with aging may significantly predispose firefighters to injury [7–9]. Moreover, firefighters who were longer in service were more likely to be placed in physically strenuous or dangerous situations, where the likelihood of injury increased significantly [8–10]. Chapter Eight was the first study conducted which investigated that association between CVH and MSH in firefighters and provided novel findings in a research area that has not been investigated previously. This is

http://etd.uwc.ac.za/

particularly important for firefighters in South Africa, as it is a historically understudied population. The findings of Chapters Two and Eight highlighted that firefighters with poor CVH were at potential risk for sustaining MSIs and MSD and indicated the need for more research focused on the relationship between CVH and MSH, which may be linked to the high prevalence of injury-related absenteeism and early retirement in firefighters [7,11]. In addition, the results in Chapter Eight found that high lipid concentrations, particularly TC and LDL-C, were significantly related to poor MSH, that was likely the result of aging which negatively affected tissue health, and weakened tendons and ligaments. This finding is consistent with the results of a systematic review by Tilley et al. [12] which noted that lipid concentrations negatively affected connective tissue health. Furthermore, in Chapter Eight firefighters who experienced MSD were more likely to have elevated lipid concentrations. A novel finding in Chapter Eight was that an increase in HRV was associated with an increase of MSD, which is in contrast to a study conducted by Chuang et al. [13] who reported that higher HRV was related to lower feelings of musculoskeletal pain and discomfort.

In Chapter Ten, firefighters with higher levels of physical fitness reported MSD more frequently. Higher cardiorespiratory fitness was associated with higher HRV, and provided a possible explanation for these novel findings [14–16]. Moreover, the narrative literature review in Chapter Two indicated that cigarette smokers had poorer MSH than those that did not smoke cigarettes [17]. However, this finding was not supported by the results of Chapter Eight, where cigarette smoking had no relation to MSH in firefighters. It is important to note that cigarette smokers in this cohort tended to be more physically active than non-smokers. In addition, both the narrative review and the publication in Chapter Eight showed that physically inactive firefighters were more likely to report MSIs. Regardless of the reason, firefighters should remain physically active as a means to maintaining their cardiovascular and musculoskeletal

http://etd.uwc.ac.za/

health [18–20]. In addition, physical activity has been shown to improve LDL-C and HDL-C concentrations, especially in older individuals [21,22], which may have the added benefit of maintaining the health of their musculoskeletal system.

13.3.2. Physical Fitness and Cardiovascular Health

The systematic review (Chapter Four) was the first systematic review to investigate the relationship between cardiorespiratory fitness and CVH in firefighters. In addition, the publication in Chapter Nine was the first to investigate the relationship between multiple physical fitness parameters and CVH in firefighters, particularly in South Africa, and the first to use CVHI as a classification tool for firefighter CVH, globally. The publication in Chapter Nine was the first to report physical fitness, particularly cardiorespiratory fitness, as crucial for the cardiovascular health of firefighters, in the CoCTRFS. Moreover, LASSO-derived multivariable analysis found that cardiorespiratory fitness was a key indicator for optimal CVH, followed by leg strength and upper body endurance. This is consistent with previous research and highlighted the importance of cardiorespiratory fitness in maintaining good CVH [2–4]. Cardiorespiratory fitness is related to better functioning of the cardiovascular system, particularly maximal oxygen uptake [23,24]. Thus, firefighters with a better cardiorespiratory fitness also had a better cardiorespiratory system, and the latter may be considered the most important variable in firefighters remaining fit for duty [25–27]. Furthermore, the results in Chapter Nine also showed that muscular endurance and muscular strength were significantly associated with fewer markers for CVD risk factors, and a more favourable CVHI, particularly total blood cholesterol and triglyceride concentrations. Most fatalities in firefighters occurred when they were on active duty and were related to overexertion [28]. Firefighters should remain physically active throughout their career, and maintain or improve all aspects of physical fitness. This will not only improve their CVH, particularly as they age, but also reduce the

http://etd.uwc.ac.za/

physical and cardiovascular strain associated with firefighting as well as the incidents of MSIs and the development of MSD in firefighters.

13.3.3. Physical Fitness and Musculoskeletal Health

The results from the publication in Chapter Ten showed that firefighters with a higher level of physical fitness were less likely to report MSIs than less fit firefighters. These results were consistent with previous research [9,19,29,30]. However, age-related deterioration in MSH and the "wear and tear" of firefighting played a significant role in precipitating occupational injuries in firefighters. Firefighters should take precautions to reduce the incidence of MSIs by remaining physical fit [19,31–33]. In addition, the findings in Chapter Ten showed that stronger firefighters, with more muscular stamina, were more likely to report MSD. It may be possible that firefighters who were more physically active were experiencing MSD that was primarily related to occupational overload and overexertion. The results suggested that there was a "sweet spot", where the volume of physical activity helped maintain the MSH of firefighters, and reduced the likelihood of injury and MSD. On a precautionary note, firefighters who are physically active recreationally, should monitor their workloads carefully to ensure that they are not participating in excessive amounts physical activity and, thereby, overloading their musculoskeletal system and predisposing it to injury and MSD.

13.3.4. Effect of Cardiovascular and Musculoskeletal Health and Physical Fitness on Occupational Performance in Firefighters

The systematic review (Chapter Four) was the first that used a meta-analysis to determine the effects of CVH, MSH and physical fitness on occupational performance. The publication in Chapter Eleven was the first to investigate the collective effects of CVH, MSH and physical

http://etd.uwc.ac.za/

fitness on occupational performance in firefighters. The results of Chapters Four and Eleven were similar, which indicated that all measures of physical fitness, except flexibility, were significantly related to total completion times of performance tasks in firefighting. In addition, higher levels of physical fitness were related to better performance on all tasks in the PAT. This was consistent with previous research and indicated that physical fitness may be the most important factor associated with firefighters' fitness for duty and optimal occupational performance [34–38]. The results of Chapter Eleven showed that absolute cardiorespiratory fitness and leg strength were the most significant factors that contributed to better PAT performance in firefighters. Perroni et al. [39] noted that absolute cardiorespiratory fitness may be a better determining factor of performance in firefighters, due to the additional weight of their PPE. In addition, the PAT may favour lower body strength, due to the testing protocol focusing on lower extremity strength and endurance [40]. This suggested that occupational performance protocols in different regions may favour certain components of health-related physical fitness over others [34,35,37,41], which should be considered when prescribing intervention programmes to positively impact fitness for duty in firefighters.

UNIVERSITY of the
WESTERN CAPE

The results in Chapter Four also showed that firefighters who were aged, female and obese had longer total test completion times, and performed poorer on each of the occupational tasks, which was consistent with the results in Chapter Eleven. Chapters Eight to Ten reported that aging and obesity were significantly related to poorer CVH, MSH and physical fitness, and that older and obese firefighters, especially females with significantly lower body mass, LBM and muscular strength performed worse on the PAT. Previous studies reported similar results, where aging and obese firefighters were the lowest performers on occupational performance simulation protocols [34,36,38,42]. In addition, taller and heavier firefighters performed significantly better than shorter and lighter firefighters, indicating that height and weight may

http://etd.uwc.ac.za/

be important in performing firefighters' tasks. This is consistent with the literature which indicated that taller and heavier firefighters were the best performers [43,44].

The results in Chapters Eleven and Twelve also found that the Framingham risk score and diastolic blood pressure were inversely related to overall occupational performance, and the Framingham risk score was also inversely related to the firefighters' performances on most PAT tasks. In addition, firefighters with a better CVHI performed better on the equipment carry, the ladder raise and extension, and the rescue drag. These results suggested that firefighters with better CVH performed significantly better, which was supported by the literature [44–47]. Furthermore, the results from these chapters indicated that HRV was positively associated with overall occupational performance, as well as with each occupational-specific task.

In Chapter Twelve, the results indicated that MSH was also significantly related to occupational-specific task performance, specifically, the step-up, the charged hose drag and pull, the ladder raise and extension, and the rescue drag. Previous literature showed firefighters with MSH complaints reported more work and performance limitations [46,48–52]. However, to the best of the authors knowledge, there have not been a previous study conducted using objective measures to assess the affect of poor MSH on occupational-specifc task performance, making this the first study of this nature. Remaining physically active and participating in regular leisure-time physical activity may help improve and/or maintain firefighters' MSH [8,32,53,54] and thereby, improve their performance on occupational-specific tasks [44,47,55]. Monitoring overall workload has been showed to be integral to ensuring optimal MSH [33,56,57] and occupational-specific task performance [51,52].

http://etd.uwc.ac.za/

For optimal occupational performance and overall occupational well-being, firefighters should maintain or improve their level of physical fitness which, in turn, would promote their CVH and MSH. In addition, firefighters should ensure that they maintain good body composition and regular physical activity, particularly as they age. Also, firefighters should monitor their overall weekly workload to ensure adequate recovery and minimal risk for MSIs and MSD. The results reported that firefighters with good levels of physical fitness, CVH and MSH performed their duties with the greatest vigour, intensity and consistency.

13.3.5. Effect of Age, Sex, Weight, Height and Weekly Physical Activity on Occupational Performance in Firefighters

From the original publications (Chapters Six to Twelve), ageing had a significant influence on CVH, MSH, physical fitness and occupational performance. Older firefighters had poorer CVH, lower physical fitness and were more likely to report MSIs. This was supported by similar results in previous studies [34,35,37,38]. The first systematic review (Chapter Four) and the results from publications in Chapters Eleven and Twelve found that older firefighters performed poorer on the PAT, which was related to them having lower CVH and physical fitness scores [51,52,56]. It has been presumed that previous injuries or current discomfort may result in firefighters guarding the injured or discomforted site, reducing the force output or effort generated to perform that occupational-specific task, as a protective mechanism. It is paramount that aged firefighters maintain good CVH, MSH and physical fitness in order to comply with occupational readiness for duty.

Heavier firefighters performed poorer on the step-up task, which was similar to the results reported by Phillips et al. [43] that heavier firefighters performed worse on tasks that required them to lift their body weight. Furthermore, taller firefighters may have a biomechanical

http://etd.uwc.ac.za/

advantage over shorter firefighters in performing certain tasks [58,59].

Furthermore, occupational performance differed across sex, as female firefighters had lower levels of muscular strength and endurance and lower absolute $\dot{V}O_{2max}$, but were more flexible, had a higher relative $\dot{V}O_{2max}$, and were more likely to report MSIs compared to the male firefighters. This was consistent with previous literature as well [44,60,61]. Female firefighters were more likely to have better CVH compared to male firefighters. However, female firefighters may need more specific exercise programmes that are designed to improve their muscular strength and muscular endurance to ensure that they had the required muscular stamina for firefighting [44,60,62].

In general, firefighters who were more physically active had good CVH and higher levels of physical fitness compared to less active firefighters. However, an increase in weekly MET minutes and physical fitness were also related to an increase in MSD. This may be due to firefighters being predisposed to musculoskeletal overload, due to not monitoring their overall levels of physical activity [33,56,57]. Previous literature found that either excessive or insufficient amounts of physical activity were important factors in determining MSIs [31–33,57] and MSD [48–50,63]. Although, physical activity and physical fitness were quintessential elements for firefighting, however, excessive or inadequate amounts of activity may increase the risk of firefighters experiencing injury [33,57].

The results in the publication in Chapter Twelve found that height and weight were particularly important for firefighters performing well on the PAT. Previous studies noted that heavier and taller firefighters performed better compared to lighter and shorter firefighters [43,44]. It is probable that taller firefighters were also heavier with a higher lean body and muscle mass that

http://etd.uwc.ac.za/

resulted in better occupational performance [34,35,37,38]. However, heavier firefighters performed poorer on the step-up task, which was similar to the results reported by Phillips et al. [43] that heavier firefighters performed worse on tasks that required them to lift their body weight, along with the equipment. Two tasks used frequently in firefighter occupational performance simulations are the crawl task and the search task, and ladder climbs, requiring firefighters to ambulate in small and confined spaces, which favour smaller and lighter firefighters [37,58,64]. The PAT does not include tasks such as the crawl and search tasks, which may explain why taller and heavier firefighters were the best performers [65–67].

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

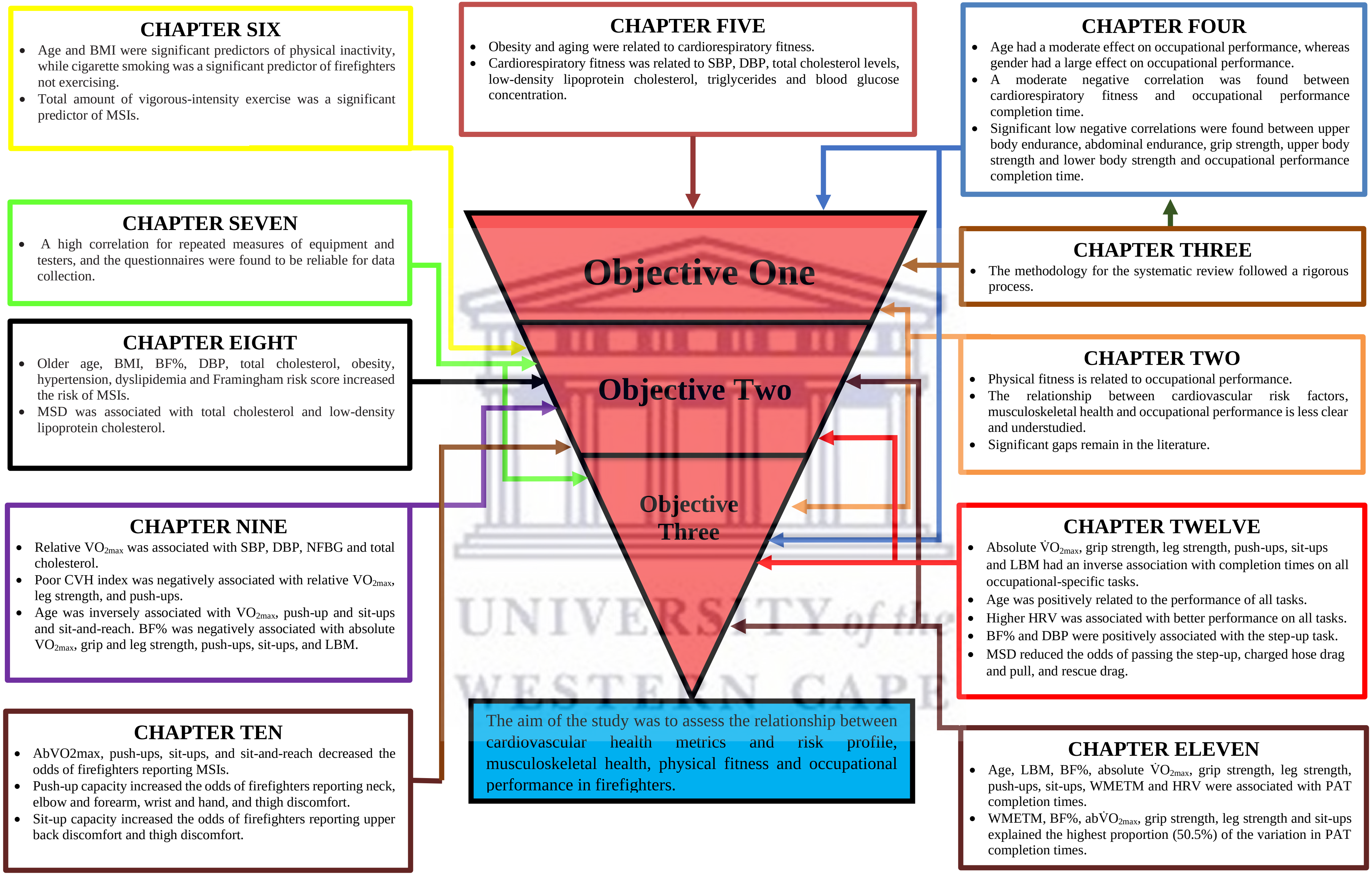


Figure 13.1: Organogram highlighting the key findings from the various publications that contributed to answering the study research question.
$\dot{V}O_{2max}$ – maximal oxygen consumption; LBM – lean body mass; BMI – body mass index, BF% – body fat percentage; SBP – systolic blood pressure; BDP – diastolic blood pressure; NFBG – non-fasting blood glucose; HRV – heart rate variability; MSI – musculoskeletal injury; MSD – musculoskeletal discomfort; WMETM – weekly metabolic equivalent minutes.

http://etd.uwc.ac.za/

13.4. Contribution of the Thesis

This was the first study investigating the association between CVH, MSH, physical fitness and occupational performance in firefighters in South Africa. This thesis contributed significantly to identifying the factors that affected occupational performance in firefighters, which is particularly important in an African context, given the scarcity of research on the continent. In addition, this was the first study to investigate MSH and physical fitness in firefighters in the CoCTFRS. Therefore, the results of the present study may contribute meaningfully to informing policymakers on the need for developing policies and legislation that encourages firefighters in the CoCTFRS to either maintain or improve their CVH, MSH and physical fitness to perform their occupational tasks.

This thesis makes an important contribution to contemporary knowledge on the interrelationship between CVH, MSH and physical fitness, which has not been studied previously, while also provides novel findings on specific factors that predispose firefighters to poor CVH and MSI, which is problematic in this population and which may explain the high cardiac-related fatalities and injury-related early retirement observed in this population. This thesis highlights the current physical and occupational well-being of firefighters in the CoCTFRS and the need for further research on this population.

UNIVERSITY of the WESTERN CAPE

13.4.1. Strengths and Limitations of the Study

A strength of this thesis is that it includes two systematic reviews and meta-analyses that synthesised high-level evidence and contributed significantly to consolidating the contemporary knowledge on the relationship between CVH, MSH physical fitness and occupational performance. In addition, a pilot study ensures the reliability of all the research

http://etd.uwc.ac.za/

instruments and the inter-tester and intra-tester reliability. Moreover, the relatively large sample size is an additional strength providing sufficient power for the study.

There are, however, several limitations to the present study. Because this was a cross-sectional study, it precluded all assumptions of causality in this population. Female firefighters constituted a relatively small proportion of the total sample size (~10%) that significantly reduced the generalizability of the results to the broader population of female firefighters. Another limitation is the absence of research theory and qualitative research methods to explain the results of the various studies that warrants further investigation. Lastly, although a pilot study had been conducted, inaccuracies may have been present when firefighters completed the IPAQ and that due to consistency in pre-test instructions, when measuring body compoisition inaccuracies may have incurred when using the BIA.

13.5. Conclusion

The current study reported significant associations between CVH, MSH, physical fitness and occupational performance in firefighters. Poorer CVH, particularly, lipid profile, aging and obesity were significantly related to impaired MSH, predisposing firefighters to MSIs and MSD. Physical fitness was significantly related to better CVH, and firefighters with good levels of physical fitness, had more favourable CVH, particularly cardiorespiratory fitness, muscular strength and endurance. In addition, high levels of physical fitness reduced the odds of firefighters reporting MSIs. However, fitter firefighters were more likely to report MSD, especially those who were stronger and with higher muscular stamina. Taller and heavier firefighters had an advantage on the PAT. However, older obese firefighters, especially females, were predisposed to reduced occupational performance. This highlighted the need for individualised intervention programmes, especially for females to ensure firefighters remained

http://etd.uwc.ac.za/

fit for duty and maintained good health throughout their careers. In addition, firefighters should engage in regular, but not excessive, amounts of physical activity, focusing on cardiorespiratory fitness, muscular endurance and muscular strength, while maintaining a good CVHI and CVD risk profile, especially as they aged.

13.6. Recommendations

Future Research

Further research with a larger cohort of especially female firefighters is recommended. In addition, it is recommended that more longitudinal and intervention studies be implemented to discern the effect of regular physical activity, specifically cardiorespiratory fitness, muscular strength and endurance, on CVH, MSH and occupational performance in firefighters. In addition, it may be that there is an ideal level of physical fitness that is conducive to reducing MSIs which should be further studied. Furthermore, intervention studies focusing on the benefits of behaviour change in firefighters, particularly for improving CVH, MSH, and physical fitness, is warranted in this population.

Firefighting Departments and Policymakers

It is recommended that fire departments and policymakers implement mandatory physical activity or exercise programmes to ensure that firefighters become fit and remain physically fit throughout their careers. These programmes should be designed to improve cardiorespiratory fitness, muscular strength and muscular endurance, as well as MSH. In addition, enforcing minimum standards of physical fitness and threshold criteria for CVH parameters, such as blood pressure, lipid concentrations and adiposity are warranted. It is recommended that the PAT becomes mandated annually, with appropriate interventions put in place to assist firefighters in improving their CVH and physical fitness to ensure that they are fit and safe for

http://etd.uwc.ac.za/

duty.

Health Professionals

Of paramount importance is the need for a multidisciplinary team approach in the CoCTFRS that enforces regular medical check-ups and physical fitness testing to assist firefighters in developing optimal CVH, MSH and/or physical fitness. Proper rehabilitative care by a physiotherapist should be provided to firefighters' post-injury to ensure that they returned safely to work and performed their duties at their pre-injury levels. Sport psychologists involved in behaviour change are also needed to assist firefighters in adopting new healthier behaviours, particularly those related to physical activity and diet. Future research should employ a mixed-method approach with interviews and educational strategies to assess the firefighters' likelihood for health behaviour change.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

References

[1] Vicente MM, Herrero DC, Prieto JP. Cardiorespiratory Fitness in Spanish Firefighters. *J Occup Environ Med*. 2021;63:e318–22. https://doi.org/10.1097/JOM.0000000000002199.

[2] Donovan R, Nelson T, Peel J, Lipsey T, Voyles W, Israel RG. Cardiorespiratory fitness and the metabolic syndrome in firefighters. *Occup Med (Chic Ill)*. 2009;59:487–92. https://doi.org/10.1093/occmed/kqp095.

[3] Baur DM, Christophi CA, Tsismenakis AJ, Cook EF, Kales SN. Cardiorespiratory fitness predicts cardiovascular risk profiles in career firefighters. *J Occup Environ Med*. 2011;53:1155–60. https://doi.org/10.1097/JOM.0b013e31822c9e47.

[4] McAllister MJ, Gonzalez DE, Leonard M, Martaindale MH, Bloomer RJ, Pence J, et al. Firefighters with higher cardiorespiratory fitness demonstrate lower markers of cardiovascular disease risk. *J Occup Environ Med*. 2022; 64(12):p 1036-1040.

[5] Strauss M, Foshag P, Jehn U, Brzęk A, Littwitz H, Leischik R. Higher cardiorespiratory fitness is strongly associated with lower cardiovascular risk factors in firefighters: a cross-sectional study in a German fire brigade. *Sci Rep*. 2021;11. https://doi.org/10.1038/s41598-021-81921-1.

[6] Espinoza F, Delgado-Floody P, Martínez-Salazar C, Jerez-Mayorga D, Guzmán-Guzmán IP, Caamaño-Navarrete F, et al. The influence of cardiometabolic risk factors on cardiorespiratory fitness in volunteer Chilean firefighters. *American Journal of Human Biology*. 2019;31. https://doi.org/10.1002/ajhb.23280.

[7] Poston WSC, Jitnarin N, Haddock CK, Jahnke SA, Tuley BC. Obesity and injury-related absenteeism in a population-based firefighter cohort. *Obesity*. 2011;19:2076–81. https://doi.org/10.1038/oby.2011.147.

[8] Phelps SM, Drew-Nord DC, Neitzel RL, Wallhagen MI, Bates MN, Hong OS. Characteristics and predictors of occupational injury among career firefighters. *Workplace Health Saf*.

http://etd.uwc.ac.za/

2018;66:291–301.

[9] Frost DM, Beach TAC, Crosby I, McGill SM. Firefighter injuries are not just a fireground problem. *Work.* 2015;52:835–42. https://doi.org/10.3233/WOR-152111.

[10] Jahnke SA, Poston WSC, Haddock CK, Jitnarin N. Injury among a population based sample of career firefighters in the central USA. *Injury Prevention.* 2013:injuryprev-2012-040662. https://doi.org/10.1136/injuryprev-2012-040662.

[11] Frost DM, Beach TAC, Crosby I, McGill SM. The cost and distribution of firefighter injuries in a large Canadian Fire Department. *Work.* 2016;55:497–504. https://doi.org/10.3233/WOR-162420.

[12] Tilley BJ, Cook JL, Docking SI, Gaida JE. Is higher serum cholesterol associated with altered tendon structure or tendon pain? A systematic review. *Br J Sports Med.* 2015;49:1504. https://doi.org/10.1136/bjsports-2015-095100.

[13] Chuang C-C, Chung W-Y, Shu C, Chen M-W. Pain Assessment in Musculoskeletal Pain Patients by Heart Rate Variability. *J Musculoskelet Pain.* 2007;15:67–74. https://doi.org/10.1300/J094v15n04_08.

[14] Tomes C, Schram B, Orr R. Relationships Between Heart Rate Variability, Occupational Performance, and Fitness for Tactical Personnel: A Systematic Review. *Front Public Health.* 2020;8. https://doi.org/10.3389/fpubh.2020.583336.

[15] Lesniak AY, Sell KM, Morris C, Abel MG. Relationship Between Heart Rate Variability Vs. Occupational Performance, Physical Activity and Fitness Measures in Structural Firefighters. *Journal of Sport and Human Performance.* 2022;10:56–72. https://doi.org/10.12922/jshp.v10i1.169.

[16] Porto LGG, Schmidt ACB, De Souza JM, Nogueira RM, Fontana KE, Molina GE, et al. Firefighters' basal cardiac autonomic function and its associations with cardiorespiratory fitness. *Work.* 2019;62:485–95. https://doi.org/10.3233/WOR-192883.

UNIVERSITY of the WESTERN CAPE
http://etd.uwc.ac.za/

[17] Ras J, Smith DL, Kengne AP, Soteriades EE, Leach L. Cardiovascular Disease Risk Factors, Musculoskeletal Health, Physical Fitness, and Occupational Performance in Firefighters: A Narrative Review. *J Environ Public Health.* 2022;2022:7346408. https://doi.org/10.1155/2022/7346408.

[18] Durand G, Tsismenakis AJ, Jahnke SA, Baur DM, Christophi CA, Kales SN. Firefighters' physical activity: relation to fitness and cardiovascular disease risk. *Med Sci Sports Exerc.* 2011;43:1752–9. https://doi.org/10.1249/MSS.0b013e318215cf25.

[19] Nowak AM, Molik B, Wójcik A, Rutkowska I, Nowacka-Dobosz S, Kowalczyk M, et al. Physical activity and injuries relating to physical fitness of professional firefighters. *Advances in Rehabilitation.* 2018;32:13–22. https://doi.org/10.5114/AREH.2018.77933.

[20] Yu CCW, Au CT, Lee FYF, So RCH, Wong JPS, Mak GYK, et al. Association Between Leisure Time Physical Activity, Cardiopulmonary Fitness, Cardiovascular Risk Factors, and Cardiovascular Workload at Work in Firefighters. *Saf Health Work.* 2015;6:192–9. https://doi.org/https://doi.org/10.1016/j.shaw.2015.02.004.

[21] Vega GL, Grundy SM, Barlow CE, Leonard D, Willis BL, DeFina LF, et al. Association of triglyceride-to-high density lipoprotein cholesterol ratio to cardiorespiratory fitness in men. *J Clin Lipidol.* 2016;10:1414-1422.e1. https://doi.org/https://doi.org/10.1016/j.jacl.2016.09.008.

[22] Morgan AE, Mooney KM, Wilkinson SJ, Pickles NA, Mc Auley MT. Cholesterol metabolism: A review of how ageing disrupts the biological mechanisms responsible for its regulation. *Ageing Res Rev.* 2016;27:108–24. https://doi.org/10.1016/j.arr.2016.03.008.

[23] Macdonald H V, Pescatello LS. Cardiorespiratory Fitness in Cardiometabolic Diseases. *Health.* 2019; 12(4). https://doi.org/10.1007/978-3-030-04816-7.

[24] Parto P, Lavie CJ, Swift D, Sui X. The role of cardiorespiratory fitness on plasma lipid levels. *Expert Rev Cardiovasc Ther.* 2015;13:1177–83. https://doi.org/10.1586/14779072.2015.1092384.

http://etd.uwc.ac.za/

[25] Ras J, Smith DL, Soteriades ES, Kengne AP, Leach L. Association between Physical Fitness and Cardiovascular Health in Firefighters. *Int J Environ Res Public Health*. 2023;20. https://doi.org/10.3390/ijerph20115930.

[26] Smith DL, Barr DA, Kales SN. Extreme sacrifice: Sudden cardiac death in the US Fire Service. *Extrem Physiol Med*. 2013;2:1–9. https://doi.org/10.1186/2046-7648-2-6.

[27] Smith DL, Haller JM, Korre M, Fehling PC, Sampani K, Grossi Porto LG, et al. Pathoanatomic Findings Associated With Duty-Related Cardiac Death in US Firefighters: A Case–Control Study. *J Am Heart Assoc*. 2018;7:e009446. https://doi.org/10.1161/JAHA.118.009446.

[28] Smith DL, Haller JM, Korre M, Sampani K, Porto LGG, Fehling PC, et al. The Relation of Emergency Duties to Cardiac Death Among US Firefighters. *American Journal of Cardiology*. 2019;123:736–41. https://doi.org/10.1016/j.amjcard.2018.11.049.

[29] Yoon J-H, Kim Y-K, Kim KS, Ahn Y-S. Characteristics of Workplace Injuries among Nineteen Thousand Korean Firefighters. *J Korean Med Sci*. 2016;31:1546. https://doi.org/10.3346/jkms.2016.31.10.1546.

[30] Butler RJ, Contreras M, Burton LC, Plisky PJ, Goode A, County O, et al. Modifiable risk factors predict injuries in firefighters during training academies. *Work*. 2013;00:1–7. https://doi.org/10.3233/WOR-121545.

[31] Poplin GS, Roe DJ, Peate W, Harris RB, Burgess JL. The Association of Aerobic Fitness With Injuries in the Fire Service. *American Journal of Epidiomiology*. 2013;46(1):11-7. https://doi.org/10.1093/aje/kwt213.

[32] Poplin GS, Roe DJ, Burgess JL, Peate WF, Harris RB. Fire fit: assessing comprehensive fitness and injury risk in the fire service. *Int Arch Occup Environ Health*. 2016;89:251–9. https://doi.org/10.1007/s00420-015-1068-4.

[33] Vaulerin J, d’Arripe-Longueville F, Emile M, Colson SS. Physical exercise and burnout facets predict injuries in a population-based sample of French career firefighters. *Appl Ergon*.

http://etd.uwc.ac.za/

2016;54:131–5. https://doi.org/10.1016/j.apergo.2015.12.007.

[34] Williford HN, Duey WJ, Olson MS, Howard R, Wang N. Relationship between fire fighting suppression tasks and physical fitness. *Ergonomics.* 1999;42:1179–86. https://doi.org/10.1080/001401399185063.

[35] Rhea MR, Alvar BA, Gray R. Physical fitness and job performance of firefighters. *J Strength Cond Res.* 2004;18:348–52. https://doi.org/10.1519/r-12812.1.

[36] Michaelides MA, Parpa KM, Thompson J, Brown B. Predicting performance on a firefghter's ability test from fitness parameters. *Res Q Exerc Sport* 2008;79:468–75. https://doi.org/10.1080/02701367.2008.10599513.

[37] Chizewski A, Box A, Kesler R, Petruzzello SJ. Fitness fights fires: Exploring the relationship between physical fitness and firefighter ability. *Int J Environ Res Public Health.* 2021;18. https://doi.org/10.3390/ijerph182211733.

[38] Skinner TL, Kelly VG, Boytar AN, Peeters G (Geeske), Rynne SB. Aviation Rescue Firefighters physical fitness and predictors of task performance. *J Sci Med Sport.* 2020;23:1228–33. https://doi.org/10.1016/j.jsams.2020.05.013.

[39] Perroni F, Guidetti L, Cignitti L, Baldari C. Absolute vs. weight-related maximum oxygen uptake in firefighters: Fitness evaluation with and without protective clothing and self-contained breathing apparatus among age group. *PLoS One.* 2015;10. https://doi.org/10.1371/journal.pone.0119757.

[40] Ras J, Smith DL, Kengne AP, Soteriades ES, Leach L. Physical fitness, cardiovascular and musculoskeletal health, and occupational performance in firefighters. *Front Public Health.* 2023;11:1241250..

[41] Schonfeld BR, Doerr DF, Convertino VA. An Occupational Performance Test Validation Program for Fire Fighters at the Kennedy Space Center. *J Occup Environ Med.* 1990;32.

[42] Michaelides MA, Parpa KM, Henry LJ, Thompson GB, Brown BS. Assessment of Physical

http://etd.uwc.ac.za/

Fitness Aspects and Their Relationship to Firefighters' Job Abilities. *The Journal of Strength & Conditioning Research*. 2011;25(4):p 956-965.

[43] Phillips DB, Scarlett MP, Petersen SR. The Influence of Body Mass on Physical Fitness Test Performance in Male Firefighter Applicants. *J Occup Environ Med*. 2017;59:1101–8. https://doi.org/10.1097/JOM.0000000000001145.

[44] von Heimburg E, Medbø JI, Sandsund M, Reinertsen RE. Performance on a work-simulating firefighter test versus approved laboratory tests for firefighters and applicants. *International Journal of Occupational Safety and Ergonomics*. 2013;19:227–43. https://doi.org/10.1080/10803548.2013.11076981.

[45] von Heimburg E, Ingulf Medbø J. Energy cost of the trondheim firefighter test for experienced firefighters. *International Journal of Occupational Safety and Ergonomics*. 2013;19:211–25. https://doi.org/10.1080/10803548.2013.11076980.

[46] Firoozeh M, Saremi M, Kavousi A, Maleki A. Demographic and occupational determinants of the work ability of firemen. *J Occup Health*. 2017;59:81–7. https://doi.org/10.1539/joh.15-0296-FS.

[47] Ras J, Kengne AP, Smith DL, Soteriades ES, November R V, Leach L. Effects of Cardiovascular Disease Risk Factors, Musculoskeletal Health, and Physical Fitness on Occupational Performance in Firefighter: A Systematic Review and Meta-Analysis. *Int J Environ Res Public Health*. 2022;19. https://doi.org/10.3390/ijerph191911946.

[48] Airila A, Hakanen J, Punakallio A, Lusa S, Luukkonen R. Is work engagement related to work ability beyond working conditions and lifestyle factors? *Int Arch Occup Environ Health*. 2012;85:915–25. https://doi.org/10.1007/s00420-012-0732-1.

[49] Kodom-Wiredu JK. The Relationship between Firefighters' Work Demand and Work-related Musculoskeletal Disorders: The Moderating Role of Task Characteristics. *Saf Health Work*. 2019;10:61–6. https://doi.org/10.1016/j.shaw.2018.05.004.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

[50] Azmi NLAM, Masuri MG. Work-related musculoskeletal disorder (WMSDs) and functional status of firefighters in Klang Valley. Healthscope: The Official Research Book of Faculty of Health Sciences, *UiTM*. 2019;2.

[51] Nazari G, Osifeso TA, MacDermid JC. Distribution of Number, Location of Pain and Comorbidities, and Determinants of Work Limitations among Firefighters. *Rehabil Res Pract*. 2020;2020:1942513. https://doi.org/10.1155/2020/1942513.

[52] MacDermid JC, Tang K, Sinden KE, D'Amico R. Work Functioning Among Firefighters: A Comparison Between Self-Reported Limitations and Functional Task Performance. *J Occup Rehabil*. 2019;29:194–204. https://doi.org/10.1007/s10926-018-9778-6.

[53] Ras J, Soteriades ES, Smith DL, Kengne AP, Leach L. Association between Cardiovascular and Musculoskeletal Health in Firefighters. *J Occup Environ Med*. 2023; 65(7): e496–e505.

[54] Nazari G, Macdermid JC, Sinden K, D'Amico R. Prevalence of musculoskeletal symptoms among Canadian firefighters. *Work*. 2020;67:185–91. https://doi.org/10.3233/WOR-203264.

[55] Siddall AG, Stevenson RDM, Turner PJF, Bilzon JLJ. Physical and Physiological Performance Determinants of a Firefighting Simulation Test. *J Occup Environ Med*. 2018;60.

[56] Ras J, Soteriades ES, Smith DL, Kengne AP, Leach L. Association between physical fitness and musculoskeletal health in firefighters. *Front Physiol*. 2023;14: 1210107.

[57] Ras J, Leach L. Relationship Between Physical Activity, Coronary Artery Disease Risk Factors and Musculoskeletal Injuries in the City of Cape Town Fire and Rescue Service. *INQUIRY: The Journal of Health Care Organization, Provision, and Financing*. 2022;59:00469580221084485. https://doi.org/10.1177/00469580221084485.

[58] Heimburg E von, Ingulf Medbø J, Sandsund M, Reinertsen RE. Performance on a Work-Simulating Firefighter Test Versus Approved Laboratory Tests for Firefighters and Applicants. *International Journal of Occupational Safety and Ergonomics*. 2013;19:227–43. https://doi.org/10.1080/10803548.2013.11076981.

http://etd.uwc.ac.za/

[59] von Heimburg ED, Rasmussen AKR, Medbø JI. Physiological responses of firefighters and performance predictors during a simulated rescue of hospital patients. *Ergonomics.* 2006;49:111–26. https://doi.org/10.1080/00140130500435793.

[60] Misner JE, Plowman SA, Boileau RA. Performance Differences between Males and Females on Simulated Firefighting Tasks. *J Occup Med.* 1987;29(10):801-5.

[61] Li K, Lipsey T, Leach HJ, Nelson TL. Cardiac health and fitness of Colorado male/female firefighters. *Occup Med (Chic Ill).* 2017;67:268–73. https://doi.org/10.1093/occmed/kqx033.

[62] Misner JE, Boileau RA, Plowman SA, Elmore BG, Gates MA, Gilbert JA, et al. Leg Power Characteristics of Female Firefighter Applicants. *J Occup Med.* 1988;30(5):433-7.

[63] Fiodorenko-Dumas Ż, Kurkowska A, Paprocka-Borowicz M. Spine pain in the firefighter profession. *Med Pr.* 2018;69:365–73. https://doi.org/10.13075/mp.5893.00679.

[64] Sheaff AK, Bennett A, Hanson ED, Kim Y-S, Hsu J, Shim JK, et al. Physiological determinants of the candidate physical ability test in firefighters. *J Strength Cond Res.* 2010;24:3112–22. https://doi.org/10.1519/JSC.0b013e3181f0a8d5.

[65] Lindberg AS, Oksa J, Gavhed D, Malm C. Field Tests for Evaluating the Aerobic Work Capacity of Firefighters. *PLoS One*. 2013;8. https://doi.org/10.1371/journal.pone.0068047.

[66] Lindberg A, Oksa J, Malm C. Laboratory or Field Tests for Evaluating Firefighters' Work Capacity ? *PLoS One.* 2014; 9(3): e91215. https://doi.org/10.1371/journal.pone.0091215.

[67] Williams-Bell FM, Villar R, Sharratt MT, Hughson RL. Physiological demands of the firefighter candidate physical ability test. *Med Sci Sports Exerc.* 2009;41:653–62. https://doi.org/10.1249/MSS.0b013e31818ad117.

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

APPENDICES

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Appendix I: Ethical Clearance Letter

http://etd.uwc.ac.za/

UNIVERSITY *of the* WESTERN CAPE

60 YEARS *of hope, action & knowledge*

29 November 2021

Mr J Ras
Sport, Recreation and Exercise Science
Faculty of Community and Health Sciences

Ethics Reference Number:	BM21/10/9
Project Title:	Relationship between Cardiovascular Health Metrics and Risk Profile, Musculoskeletal Health, Physical Fitness, and Occupational Performance in Firefighters.
Approval Period:	**19 November 2021 – 19 November 2024**

I hereby certify that the Biomedical Science Research Ethics Committee of the University of the Western Cape approved the scientific methodology and ethics of the above mentioned research project and the requested amendment to the project.

Any further amendments, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

Please remember to submit a progress report annually by 30 November for the duration of the project.

For permission to conduct research using student and/or staff data or to distribute research surveys/questionnaires please apply via:
https://sites.google.com/uwc.ac.za/permissionresearch/home

The permission letter must then be submitted to BMREC for record keeping purposes.

The Committee must be informed of any serious adverse event and/or termination of the study.

Ms Patricia Josias
Research Ethics Committee Officer
University of the Western Cape

Appendix II: Information Sheet

http://etd.uwc.ac.za/

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville, 7535, South Africa

Tel: +27 21-959 2409 Fax: 27 21-959 3688

E-mail: 3405618@myuwc.ac.za

INFORMATION SHEET

Project Title: **Relationship Between Cardiovascular Health Metrics and Risk Profile, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters**

What is this study about?

This is a research project being conducted by Jaron Ras from the University of the Western Cape. We are inviting you to participate in this research project in order to establish your current cardiovascular health and risk profile, musculoskeletal health, physical fitness and occupational ability. This will give you an indication of the areas that you need to focus on in order to improve your future results, as well as contributing to research which could benefit other firefighters in future, when looking at common health issues amongst firefighters regarding cardiovascular risk, musculoskeletal health, physical fitness and occupational ability.

What will I be asked to do if I agree to participate?

You will be asked to complete a consent form before any form of information and data may be recorded. Participation may range from completing a questionnaire to participating in a cardiovascular risk assessment, physical fitness assessment and occupational performance assessment in order to gather the relevant information. This will be done in a private area within the relevant fire stations for the convenience of those firefighters on duty. The duration of each assessment will be about 20 – 60 minutes. Questions will include information, such as date of birth, sex, core job description, work experience, marital status, highest educational qualification, cigarette smoking, a family history of heart disease, medical history and musculoskeletal injury/disorders. Health risk assessments will include measurements such as resting blood pressure (BP), fasting blood glucose, total cholesterol, waist and hip circumferences, body stature, body mass, and heart rate variability. Physical fitness assessments will include handgrip strength, leg strength, push-ups, sit-ups and sit-and-reach. The physical ability test (PAT) protocol will be used to gather cardiorespiratory fitness and occupational performance data.

Would my participation in this study be kept confidential?

All your personal information will be kept strictly confidential. To help protect your confidentiality, we will have all assessments done in a secure, private location within

http://etd.uwc.ac.za/

the comfort of the fire station. All recorded data will be kept confidential by replacing individuals' names with numeric codes, and saving the information within a private folder, which will be reviewed only by the researcher and supervisor. If we write a report or article about this study, your identity will be protected.

Would my confidentiality be readdressed for any reason?

In the instance that you may be at risk of self-harm or place others at risk, you will be referred to a suitably qualified health professional (medical doctor, psychologist, etc.) or, with your permission, you will be put in touch with the necessary professional services in an attempt to provide emotional or mental support, where necessary.

What are the risks of this research?

There may be some risks from participating in this research study. Much like any activity or assessment there are risks which can be described as both expected and unexpected. Possible expected risks of an emotional and psychological nature may include feeling self-conscious, embarrassed, or anxiety due to having fears of predicted negative outcomes. Unexpected risks include physical aspects, such as increased heart rate and blood pressure and discomfort during assessments. Risks associated with finger-prick blood sampling, such as potential infection will be prevented by using gloves when administrating blood samples and adhering to the universal precautions of safety. Physical fitness and PAT assessments may cause muscular discomfort, such as delayed onset muscle soreness, a day or two post-testing, however, this will subside over time.

What are the benefits of this research?

The benefits to you include personal enrichment and awareness of your current cardiovascular risk and musculoskeletal health, as well as your current physical fitness levels and PAT performance. As a firefighter, you will be able to establish which areas of your lifestyle need to be altered in order to maintain health and well-being, as well as improve future assessment results.

UNIVERSITY of the WESTERN CAPE

Do I have to be in this research and may I stop participating at any time?

Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. If you decide not to participate in this study or if you stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify.

Is any assistance available if I am negatively affected by participating in this study?

If negative effects occur, medical support will be contacted immediately to provide assistance. Safety precautions will be taken to manage the individual, until medical help arrives.

What COVID-19 prevention steps will be taken?

In accordance with the World Health Organization (WHO, 2007) COVID-19 safety guidelines, the following precautions will be taken: (1) personal protective equipment (PPE) will be worn by the researchers at all times (disposable gloves covering the hands, a mask covering the nose and mouth, goggles or visor covering the eyes and

http://etd.uwc.ac.za/

face, and a gown or lab coat worn over the researchers clothing, which will be washed and disinfected after each day of testing); (2) Hand hygiene will be ensured through hand washing, as well as frequent hand sanitization with an alcohol-based sanitizer, before and after each participant is tested; and, (3) Equipment hygiene will be ensured through disinfecting the equipment, before and after each use, with an alcohol-based sanitizer.

What if I have questions?
This research is being conducted by Jaron Ras from the University of the Western Cape. If you have any questions about the research study itself, please contact Jaron Ras on 3405618@myuwc.ac.za.

Should you have any questions regarding this study and your rights as a research participant or if you wish to report any problems you have experienced related to the study, please contact:

Head of Department: Prof. Andre Travill
University of the Western Cape
Private Bag X17
Bellville 7535
Email: atravill@uwc.ac.za

Dean CHS: Prof Anthea Rhoda
Address: Faculty of Community and Health Sciences, University of the Western Cape, Private Bag X17, Bellville, 7535
Email: chs-deansoffice@uwc.ac.za

This research has been approved by the University of the Western Cape's Biomedical Research Ethics Committee/Humanities and Social Sciences Research Ethics Committee)

(REFERENCE NUMBER: ______________________)

Biomedical/Humanities and Social Sciences Research Ethics Committee
University of the Western Cape
Private Bag X17
Bellville
7535
Tel: 021 959 4111
e-mail: research-ethics@uwc.ac.za

Appendix III: Consent Form

http://etd.uwc.ac.za/

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville, 7535, South Africa

Tel: +27 21-959 2409 Fax: 27 21-959 3688

E-mail: 3405618@myuwc.ac.za

CONSENT FORM

Title of Research Project: **Relationship between Cardiovascular Health Metrics and Risk Profile, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters**

The study has been described to me in language that I understand and I freely and voluntarily agree to participate. My questions about the study have been answered. I understand that my identity will not be disclosed and that I may withdraw from the study without giving a reason at any time and this will not negatively affect me in any way.

Participant's name: ……………………………………………………..

Participant's signature: ……………………………………………………

Date: ……………………………………………………

Appendix IV: Data Collection Sheet

http://etd.uwc.ac.za/

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville, 7535, South Africa

Tel: +27 21-959 2409 Fax: 27 21-959 3688

E-mail: 3405618@myuwc.ac.za

Data Recording Sheet

Project Title: **Relationship between Cardiovascular Health Metrics and Risk Profile, Musculoskeletal Health, Physical Fitness and Occupational Performance in Firefighters**

	DATA RECORDING SHEET	
	Alpha-numeric code:	
Participant Information	Surname	
	First Name	
	Sex (Male=1, female=2)	
	Date of Birth	
	Core Job Description (fire suppression, accidents, paramedic officer, station commander, etc.)	
	Years of Experience	
	Marital Status (Married, Single, Divorced)	
	Highest Educational Qualification	
Medical Information	1. Do you have any past or present medical conditions? Please state it any.	Yes ☐ No ☐ State: ______________
	2. Are you currently taking any medication? Please state it any.	Yes □ No □ State: ______________
	3. Do you have a family history of heart disease?*	Yes □ No □ State: ______________
	4. Do you presently have any physical (orthopaedic) injuries?	Yes □ No □ State: ______________
	5. If you answered yes to question 4 above, did this injury occur while on-duty? Please state the mechanism which caused the injury, movement, or duty performed.	Yes □ No □ State: ______________
	6. If you answered positively in question 5 above, are you currently receiving treatment for the physical injuries?	Yes □ No □ State: ______________

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

7.	Do you have any musculoskeletal disorders diagnosed by a medical doctor?	Yes □ No □ State: ________________________________
8.	Do you currently have any musculoskeletal pain?	Yes □ No □ State: ______________________________

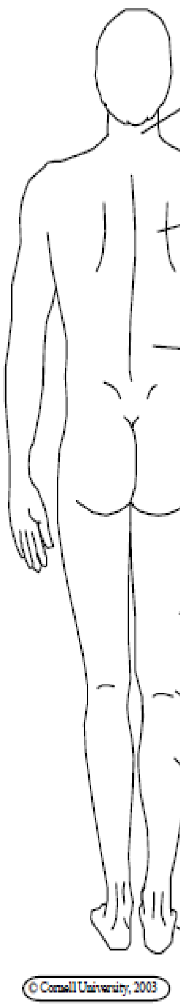
*Refers to myocardial infarction, coronary revascularization, or sudden death before 55 years in father or other male first-degree relative (i.e., brother or son) or before 65 years in mother or other female first-degree relative (i.e., sister or daughter

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Musculoskeletal disorder/health Information	Using the diagram below, tick the boxes for musculoskeletal pain/injuries/disorders that you are currently experiencing.	

The diagram below shows the approximate position of the body parts referred to in the questionnaire. Please answer by marking the appropriate box.

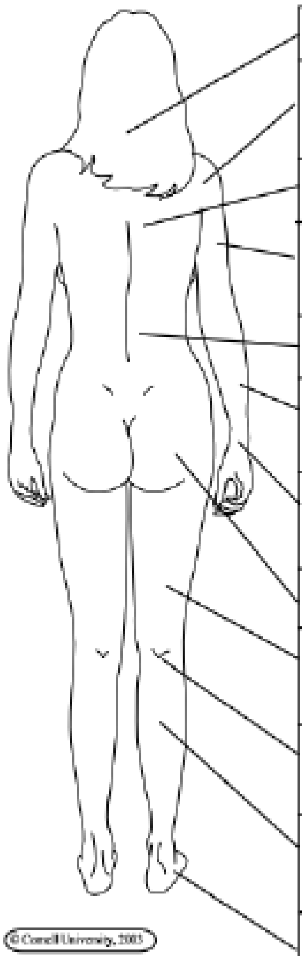


		During the last work <u>week</u> how often did you experience ache, pain, discomfort in:					If you experienced ache, pain, discomfort, how uncomfortable was this?			If you experienced ache, pain, discomfort, did this interfere with your ability to work?		
		Never	1-2 times last week	3-4 times last week	Once every day	Several times every day	Slightly uncomfortable	Moderately uncomfortable	Very uncomfortable	Not at all	Slightly interfered	Substantially interfered
Neck		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Shoulder	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Upper Back		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Upper Arm	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower Back		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Forearm	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wrist	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hip/Buttocks		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thigh	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Knee	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower Leg	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Foot	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

The diagram below shows the approximate position of the body parts referred to in the questionnaire. Please answer by marking the appropriate box.



Body part		During the last work week how often did you experience ache, pain, discomfort in:					If you experienced ache, pain, discomfort, how uncomfortable was this?			If you experienced ache, pain, discomfort, did this interfere with your ability to work?		
		Never	1-2 times last week	3-4 times last week	Once every day	Several times every day	Slightly uncomfortable	Moderately uncomfortable	Very uncomfortable	Not at all	Slightly interfered	Substantially interfered
Neck		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Shoulder	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Upper Back		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Upper Arm	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower Back		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Forearm	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wrist	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hip/Buttocks		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thigh	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Knee	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower Leg	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Foot	(Right)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	(Left)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Lifestyle Information	1. Do you currently smoke?	Yes ☐ No ☐ If yes, please state the average number of cigarettes or packets you smoke per day: Number of cigarettes:_____ Number of packets: ______
	1. For previous cigarette smokers, if you currently do not smoke, have you quit in the last 6 months?	Yes ☐ No ☐ Not applicable ☐ State: ______________________________
	2. Do you currently drink alcohol?	Yes ☐ No ☐ If yes, please state the common type(s)

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

	Type(s) of Alcohol:______________________ ______________________
3. If you drink alcohol, what is your average consumption?	Number of Drinks/tots/shots: (e.g., 1 can of beer/tot/glasses) ______ per day or ______ per week or ______ per month
4. What is your daily intake of fruits and vegetable?	☐ Less than two (2) servings a day ☐ Two to four (2 – 4) servings a week ☐ More than five (5) servings a day
5. What is your weekly serving of fish?	☐ No servings of fish a week ☐ One (1) palm size serving of fish a week ☐ Two (2) palm size servings of fish a week ☐ More than two (>2) palm size servings a week
6. What is your daily intake of fibre rich whole grains? i.e., brown bread, oats, rye bread, brown rice, etc.	☐ No servings of fibre rich whole grains ☐ One (1) serving a day ☐ Two (2) servings a day ☐ More than three (>3) servings a day
7. What is your daily intake of salt?	☐ More than one teaspoon of salt a day ☐ half a teaspoon of salt a day ☐ Less than half a teaspoon a day
8. What is your weekly intake of sugar-sweetened beverages, i.e., soda, cool-drink, coffee or tea with sugar etc.	☐ Less than half a litre a week ☐ Half a litre to 1 litre per week ☐ More than 1 Litre a week.
9. Do you presently exercise in your leisure time? Example, go to the gym, play sport, go running, walking, etc.	Yes ☐ No ☐ If yes, state what you do: _______________ If more than one, state all of them. _____________________________________ How often: _______ days per week How long: _______ minutes per day How hard: low intensity ☐ (You don't sweat) Moderate intensity ☐ (You sweat lightly) Vigorous intensity: ☐

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

	(You sweat heavily) If more than one, state the others below: How often: _______ days per week How long: _______ minutes per day How hard: low intensity ☐ Moderate intensity ☐ Vigorous intensity: ☐
10. Do you presently participate in yard or gardening activities	Yes □ No □ If yes, state what you do: _______________ If more than one, state all of them. ________________________________ How often: _______ days per week How long: _______ minutes per day How hard: low intensity ☐ (You don't sweat) Moderate intensity ☐ (You sweat lightly) Vigorous intensity: ☐ (You sweat heavily) If more than one, state the others below: ________________________________ How often: _______ days per week How long: _______ minutes per day How hard: low intensity ☐ Moderate intensity ☐ Vigorous intensity: ☐
11. Does your occupation require high amounts of physical activity? E.g. standing for long periods, walking continuously, heavy lifting etc.	Yes □ No □ If yes, state what you do: _______________ If more than one, state all of them. ________________________________ How often: _______ days per week How long: _______ minutes per day How hard: low intensity ☐ (You don't sweat) Moderate intensity ☐ (You sweat lightly) Vigorous intensity: ☐ (You sweat heavily) If more than one, state the others below: ________________________________ How often: _______ days per week How long: _______ minutes per day How hard: low intensity ☐

http://etd.uwc.ac.za/

	Moderate intensity ☐ Vigorous intensity: ☐
12. How many minutes (If any) transportation related physical activity do you do?	Yes ☐ No ☐ If yes, state what you do: _______________ If more than one, state all of them. ____________________________________ How often: _______ days per week How long: _______ minutes per day How hard: low intensity ☐ (You don't sweat) Moderate intensity ☐ (You sweat lightly) Vigorous intensity: ☐ (You sweat heavily) If more than one, state the others below: ___________________________________ How often: _______ days per week How long: _______ minutes per day How hard: low intensity ☐ Moderate intensity ☐ Vigorous intensity: ☐
13. Total minutes of physical activity per week **FOR TESTER TO COMPLETE**	Low intensity:_____________ Moderate intensity:_____________ vigorous Intensity:______________ Average minutes of exercise per week: _______________

UNIVERSITY of the
WESTERN CAPE

TEST DATA	**Date of Measurement:**	________________________________			
	Time of Measurement: _____h_____	**Measure**	**Measure**	**Measure**	**Final**
	Measurements	1	2	3	**Measure**
	Body mass (kg)				
	Stretch stature (cm)				
	Waist girth (min.) (cm)				
	Hip girth (max.) (cm)				

	Body fat percentage				
	Lean body mass				
	Systolic blood pressure (mm Hg)				
	Diastolic blood pressure (mm Hg)				
	Non-fasting blood glucose (mmol·L^{-1})				
	Total cholesterol (mmol·L^{-1})				
	Low density lipoprotein cholesterol (mmol·L^{-1})				
	High density lipoprotein cholesterol (mmol·L^{-1})				
	Triglycerides (mmol·L^{-1})				
Heart Rate Variability	Standard deviation of NN intervals (SDNN)				
	Root mean square of successive RR interval differences (RMSSD)				
	Low frequency power (LF)				
	High frequency power (HF)				
	Ratio of LF-to-HF power (LF/HF)				

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Physical Fitness and PAT	**Date of Measurement:**	______________________________		
	Time of Measurement: _____h_____	**Measure 1**	**Measure 2**	**Final Measure**
Physical Fitness	**Measurements**			
Cardiorespiratory fitness	Bleep test			
Muscle Strength	Handgrip strength	L = R =	L = R =	L = R =
	Leg strength			
Muscular endurance	Push-up			
	Sit-up			
Flexibility	Sit-and-reach			
	Shoulder flexibility (Aply's scratch)	L = R =	L = R =	L = R =
Physical Ability Test			Time (s)	
	1) Step up (s)			
	2) Charged hose drag and pull (s)			
	3) Ladder raise and extension (s)			
	4) Equipment carry (s)			
	5) Forcible entry (s)			
	6) Rescue drag (s)			
	Total time (s)			

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Appendix V: Letter of Permission from the City of Cape Town to Conduct the Study

CITY OF CAPE TOWN
ISIXEKO SASEKAPA
STAD KAAPSTAD

Date	: 8 April 2022
To	: Director: Policy & Strategy
Reference	: PSRR- 0524

Research Approval Request

In terms of the City of Cape Town System of Delegations (March 2022) - Part 13, No 3 Subsections 4, 5 and 6 "Research:

(4) To consider any request for the commissioning of an organizational wide research report in the City and to approve or refuse such a request.

(5) To grant authority to external parties that wish to conduct research within the City of Cape Town and/or publish the results thereof.

(6) To after consultation with the relevant Executive Director: grant permission to employees of the City of Cape Town to conduct research, surveys etc. related to their studies, within the relevant directorate

The Director: Policy & Strategy is hereby requested to consider, in terms of sub-section 5, the request received from

Name	Jaron Ras
Designation	Ph.D. candidate
Affiliation	University of the Western Cape
Research Title	Relationship Between Cardiovascular Health Metrics and Risk Profile, Musculoskeletal Health, Physical Fitness, and Occupational Performance in Firefighters

Taking into account the recommendations below (see Annexure for detailed review):

Recommendations

That the CCT via the Director: Policy & Strategy grants permission to Jaron Ras, a Ph.D. candidate at the Department of Sport, Recreation and Exercise Science, University of Western Cape, to conduct research subject to the following conditions:

- All National, Provincial and CCT COVID—19 pandemic response requirements are to be adhered to at all times in the implementation of the research project;
- Where face-to-face is inevitable, social distancing to be maintained at all times, and protective gear to be worn and used continuously during face-to-face engagements;
- Full compliance to the POPIA;
- Fire Services staff access and participation, including access to Fire Station Chiefs, are provisionally approved and researcher to liaise with Divisional Commander, Ian Bell via Ian.Bell@capetown.gov.za;
- Engagement with Fire services staff are subject to operational availability and responses to be limited to accommodate any emergency response;
- Provisional approval is granted to the researcher to access the research location and for staff survey completion;
- Due to work commitments, request for data, interviews and observations are not granted;
- The willingness and/or availability of the CCT officials to participate in the research, in a voluntary capacity;
- In compliance with POPIA legislation, invitations to participate in the research to be disseminated by the relevant/nominated Fire Services officials but remains the responsibility of the researcher to collect completed survey questionnaires;
- Clear acknowledgment in the report that the analysis derived from the various data collection approaches are not regarded as official CCT policy;
- City officials and their inputs to be anonymised and the conditions of anonymity be adhered to in the research report;
- The use of direct quotations of CCT participants in the report is not permitted unless with prior agreement of the respondents and authorised in writing by the relevant City official, prior to commencement of the interview, and the final draft text of any direct quotation and/or paraphrasing to be submitted to the respondent for verification and sign-off;
- In the event of access to a City facility, the City is indemnified against any damage, loss or injury that the researcher may experience;

http://etd.uwc.ac.za/

- Due to the operational nature of the site, the researcher is not permitted to access the site without prior approval from the Fire Chief and must be accommodated by a City official at all times;
- Approval is limited to this research request and the publications indicated only and does not include any future research, publication(s) and/or presentation(s) permissions, which should be sought from the City in a separate request;
- The data, research and outcomes of the research findings to be shared and presented to the Fire & Rescue Department on an agreed upon platform;
- The City branding and logo not being used in the research report;
- Submission of the completed research report to the Chief Fire Officer, the Director: Policy & Strategy Department and the Manager: Research Branch, Policy & Strategy Department, within 3 months of completion of the research report.

Delegated authority:	**Acceptance by Applicant:**
Approved ☒ Comment: note above conditions and potential constraints	I, Jaron Ras, confirm that I agree to abide by the conditions as stipulated above.
Not Approved ☐ Comment: ____________	Jaron Ras Date: 2022.04.13
Hugh Cole: Dir: Policy & Strategy: ____________	**Applicant**: ____________
Date: Daniel Sullivan Digitally signed by Daniel Sullivan Date: 2022.04.08 18:22:45 +02'00'	**Date**: 13/04/2022
CCT departments: No interviews or data to be provided without proof of acceptance of the conditions under which the research permission is granted.	*Kindly return signed copy to* *sivuyilevuyo.rilityana@capetown.gov.za*

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Appendix VI: Eligibility Screening Form for the Systematic Review

General information	
Title	
Author	
Study type	
Exposure assessed	
Outcome relevance	
Notes:	

UNIVERSITY of the
WESTERN CAPE

Study eligibility			
Study characteristics	Eligibility criteria met		
	Yes	No	Unclear
Type of Study			
Type of participants			
Type of exposure			
Type of comparison			

http://etd.uwc.ac.za/

Types of outcome measures			
INCLUDE	EXCLUDE		
Reason for exclusion:			

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Appendix VII: Systematic Review Data extraction Form

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville 7535, South Africa

Tel: +27 21-959 2653, Fax: 27 21-959 3686,

E-mail: lleach@uwc.ac.za

DATA EXTRACTION SHEETS

General Description

Author	Target Population	Geographical Location	Aim	Problem Statement

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

UNIVERSITY OF THE WESTERN CAPE
Private Bag X 17, Bellville 7535, South Africa
Tel: +27 21-959 2653, Fax: 27 21-959 3686,
E-mail: lleach@uwc.ac.za

Srudy Methodology of Included Studies

Author	Study Design	Theoretical Underpinnings	Sampling Method and Size	Data Collection Methods and Instruments

http://etd.uwc.ac.za/

http://etd.uwc.ac.za/

UNIVERSITY OF THE WESTERN CAPE
Private Bag X 17, Bellville 7535, South Africa
Tel: +27 21-959 2653, Fax: 27 21-959 3686,
E-mail: lleach@uwc.ac.za

Findings and Analysis

Author	Methods of Data Analysis	Study Findings	Author's Conclusions

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Appendix VIII: Supplementary Materials for Systematic Review

Publication: Association between Cardiovascular Disease Risk Factors and Cardiorespiratory Fitness in Firefighters

Search syntax in different databases

PubMed:

#1 “firefighter” OR “fire and rescue personnel” OR “fire fighters” OR “fire fighter” OR “firefight”

#2 "cardiovascular system"[MeSH] OR ("cardiovascular" [All Fields] AND "system" [All Fields]) OR "cardiovascular system" [All Fields] OR "cardiovascular*" [All Fields] OR "cardiovascular abnormalities" [MeSH] OR “HRV” [All Fields] OR “heart rate variability” [All Fields] OR “Heart Rate Interval” [All Fields] OR “RR variability” [All Fields] OR “cycle length variability” [All Fields] OR “heart period variability” [All Fields] OR “autonomic function” [All Fields] OR “vagal control” [All Fields] OR “lipid profile” [All Fields] OR “cholesterol” [MeSH] OR “dyslipidaemia” OR “hypercholesteremia” OR “diabetes” AND “mellitus” OR “blood glucose” OR “age” OR “obesity” OR “hypertension” OR “blood pressure” OR “metabolic syndrome” OR “hyperglycaemia”

#3 "physical fitness"[MeSH] OR “exercise” [All Fields] OR “physical exertion” [All Fields] OR “muscular strength” OR “muscular endurance” OR “aerobic fitness” OR “cardiorespiratory fitness” OR “cardiorespiratory capacity” OR “$\dot{V}O_2$max” OR “aerobic fitness” OR “power”

#4 (#1 AND #2) OR (#1 AND #3) OR (#1 AND #2 AND #3)

Scopus

#1 (TITLE-ABS-KEY “firefighter*”) + OR AND TITLE-ABS-KEY ("fire and rescue" OR firefighters OR fire fighter OR firefight OR firemen)

#2 AND "cardiovascular" OR “cardiovascular abnormalities” OR “HRV*” OR “heart rate variability*” OR "heart rate interval" OR “aging” OR “RR variability” OR “cycle length variability” OR “heart period variability” OR “autonomic function” OR “vagal control” OR “lipid profile” OR “cholesterol” OR “diabetes” AND “mellitus” OR “blood glucose” OR “age” OR “obesity” OR “central obesity” OR “waist

http://etd.uwc.ac.za/

circumference” OR “hypertension” OR “high blood pressure” OR “blood pressure” OR “metabolic syndrome” OR “hyperglycaemia” OR “cardiometabolic” OR “metabolic syndrome” OR “MetSyn” AND (EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "cp") OR EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "bk"))

#3 AND “physical fitness” OR “exercise” OR “physical exertion” OR “muscular strength” OR “muscular endurance” OR “aerobic fitness*” OR “cardiorespiratory fitness*” OR “cardiorespiratory capacity*” OR “cardiorespiratory capacity” OR “$\dot{V}O_2max$” OR “aerobic fitness” OR “power” OR “anaerobic power” OR “aerobic capacity” OR “anaerobic capacity” AND (EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "cp") OR EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "bk"))

#4 (#1 AND #2) OR (#1 AND #3) OR (#1 AND #2 AND #3)

Web of sciences

#1 TOPIC:(Firefighter*)/ ("fire and rescue" OR firefighters OR fire fighter OR firefight OR firemen)

#2 AND TOPIC:("cardiovascular" OR “cardiovascular abnormalities” OR “HRV*” OR “heart rate variability*” OR "heart rate interval" OR “aging” OR “RR variability” OR “cycle length variability” OR “heart period variability” OR “autonomic function” OR “vagal control” OR OR “lipid profile” [All Fields] OR “cholesterol” [MeSH] OR “dyslipidaemia” OR “dyslipidaemia” OR “hypercholesteremia” OR “diabetes” AND “mellitus” OR “blood glucose” OR “age” OR “aging” OR “age-group” OR “obesity” OR “central obesity” OR “waist circumference” OR “hypertension” OR “high blood pressure” OR “blood pressure” OR “metabolic syndrome” OR “hyperglycaemia” OR “cardiometabolic” OR “metabolic syndrome” OR “MetSyn”)Refined by: [excluding] DOCUMENT TYPES: (PROCEEDINGS PAPER OR BOOK CHAPTER OR NOTE OR MEETING ABSTRACT)

#3 AND TOPIC:("physical fitness" OR “exercise” OR “physical exertion” OR “muscular strength” OR “muscular endurance” OR “aerobic fitness” OR “cardiorespiratory fitness” OR “cardiorespiratory capacity” OR $\dot{V}O_2max$” OR “aerobic fitness” OR “power” OR “anaerobic power” OR “aerobic capacity” OR “anaerobic capacity”) Refined by: [excluding] DOCUMENT TYPES: (PROCEEDINGS PAPER OR BOOK CHAPTER OR NOTE OR MEETING ABSTRACT)

#4 (#1 AND #2) OR (#1 AND #3) OR (#1 AND #2 AND #3)

ScienceDirect

#1 (firefighter*:ab,ti OR firefighters*:ab,ti OR fire and rescue personnel*:ab,ti OR firefight*:ab,ti OR fire firefighter*:ab,ti OR firemen*:ab,ti)

http://etd.uwc.ac.za/

#2 AND (cardiovascular*:ab,ti OR ‘cardiovascular abnormalities’:ab,ti” OR ‘HRV’:ab,ti OR ‘heart rate variability’:ab,ti OR ‘heart rate interval’:ab,ti OR ‘aging’:ab,ti OR ‘RR variability’:ab,ti OR ‘cycle length variability’:ab,ti OR ‘heart period variability’:ab,ti OR ‘autonomic function’:ab,ti OR ‘vagal control’:ab,ti OR ‘lipid profile’:ab,ti OR ‘cholesterol’:ab,ti OR ‘diabetes’:ab,ti AND ‘mellitus’:ab,ti OR ‘blood glucose’:ab,ti OR ‘age’:ab,ti OR ‘obesity’:ab,ti OR ‘age’:ab,ti OR ‘aging’:ab,ti OR ‘age-group’:ab,ti OR ‘obesity’:ab,ti OR ‘central obesity’:ab,ti OR ‘waist circumference’:ab,ti OR ‘hypertension’:ab,ti OR ‘high blood pressure’:ab,ti OR ‘blood pressure’:ab,ti OR ‘metabolic syndrome’:ab,ti OR ‘hyperglycaemia’:ab,ti OR ‘cardiometabolic’:ab,ti OR ‘metabolic syndrome’:ab,ti OR ‘MetSyn’:ab,ti)

#3 (physical fitness*:ab,ti OR ‘exercise’:ab,ti OR ‘physical exertion’:ab,ti OR ‘muscular strength’:ab,ti OR ‘muscular endurance’:ab,ti OR ‘aerobic fitness’:ab,ti OR ‘cardiorespiratory fitness’:ab,ti OR ‘cardiorespiratory capacity’:ab,ti: $\dot{V}O_2max$’:ab,ti: OR ‘aerobic fitness’:ab,ti: OR ‘power:ab,ti: OR ‘anaerobic power’:ab,ti: OR ‘aerobic capacity’:ab,ti: OR ‘anaerobic capacity’:ab,ti:)

#4 (#1 AND #2) OR (#1 AND #3) OR (#1 AND #2 AND #3)

EBSCOHost

#1 Subject Terms:(“Firefighter” OR "fire and rescue" OR “firefighters” OR “fire fighter” OR “firefight” OR “firemen”) Field:(All text)

#2 AND ("cardiovascular” OR “cardiovascular abnormalities” OR “HRV*” OR “heart rate variability*” OR "heart rate interval" OR “aging” OR “RR variability” OR “cycle length variability” OR “heart period variability” OR “autonomic function” OR “vagal control” OR “lipid profile” OR “cholesterol” OR “diabetes” AND “mellitus” OR “blood glucose” OR “age” OR “obesity” OR “central obesity” OR “waist circumference” OR “hypertension” OR “high blood pressure” OR “blood pressure” OR “metabolic syndrome” OR “hyperglycaemia” OR “cardiometabolic” OR “metabolic syndrome” OR “MetSyn”) Field:(All text)

#3 AND (“physical fitness” OR “exercise” OR “physical exertion” OR “muscular strength” OR “muscular endurance” OR “aerobic fitness*” OR “cardiorespiratory fitness*” OR “cardiorespiratory capacity*” OR “cardiorespiratory capacity” OR “$\dot{V}O_2max$” OR “aerobic fitness” OR “power” OR “anaerobic power” OR “aerobic capacity” OR “anaerobic capacity”) Field:(All text)

#4 (#1 AND #2) OR (#1 AND #3) OR (#1 AND #2 AND #3)

http://etd.uwc.ac.za/

Table 1. critical appraisal of cross-sectional studies (adapted from the appraisal tool for cross-sectional studies checklist).

	Espinoza et al.[68]	Atikah et al. [69]	Porto et al. [70]	Barry et al. [71]	Delisle et al. [72]	Houck et al. [73]	McAllister et al.[74]	Nogueira et al. [75]	Li et al. [76]	Donovan et al. [42]	Kiss et al. [77]	Baur et al.[78]	Baur et al. [79]	Strauss et al. [41]	Kirlin et al. [80]	Vicente et al. [81]	Durand et al. [35]	Baur et al. [82]	Perroni et al., [43]	Seyedmehdi et al. [40]	Cameron et al. [83]
Introduction																					
Were the aims and objectives clear?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Methods																					
Was the study's design in line with the stated goals or objectives?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Was the sample size appropriate?	×	×	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Was the target demographic adequately defined?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Was the sample frame taken from an appropriate population base to fairly reflect the target population or the reference population?	×	✓	×	×	×	×	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Was it likely that participants chosen through the selection procedure would represent the target population?	×	×	×	×	×	×	×	✓	✓	✓	✓	✓	✓	×	×	✓	✓	✓	✓	✓	✓
Were precautions taken to address and classify non-responders?	×	✓	✓	×	×	×	×	×	×	✓	×	×	×	✓	✓	×	✓	✓	✓	✓	✓
Were the risk factor and outcome variables assessed applicable to the study's objectives?	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Instrumental measurements of the risk factor and outcome variables were	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

accurate and reliably used in previous research?																					
Is it apparent how statistical significance was determined?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Were the procedures sufficiently explained to allow for their replication?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Results																					
Were the fundamental data sufficiently explained?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Is non-response bias an issue given the response rate?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Has data pertaining to non-responders been described?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Was there internal consistency in the results?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Were the findings for all the analyses mentioned in the procedures/methods presented?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Discussion																					
Were the results sufficient to support the authors' discussions and conclusions?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Were the study's limitations discussed?	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Other																					
Were there any conflicts of interest that could have influenced how the writers interpreted the data?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Did participants give their ethical permission or consent?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
FINAL SCORE	15	16	16	16	16	16	17	17	18	18	18	18	18	18	18	18	19	19	19	19	19

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Table 2. Critical Appraisal Skills Programme of cohort and case-controlled studies (adapted from the Critical Appraisal Skills Programme).

CASP – Cohort Study	Li et al. [84]	Punakallio et al. [85]	Cameron et al. [83]	**CASP – Case Controlled Study**	Vandersmissen et al. [86]
1. Was the study's topic well defined?	1	1	1	1. Was the study's topic clearly defined?	1
2. Was the cohort appropriately recruited?	1	1	1	2. Did the authors approach answering their research question in a suitable way?	1
3. Was the bias minimized by appropriately measuring the exposure?	1	1	1	3. Were the subjects appropriately recruited?	1
4. Was the results correctly measured to reduce bias?	1	1	1	4. Were the controls chosen in a proper manner?	1
5. (A) Have all significant confounding variables been recognized by the authors?	1	1	1	5. Was the bias minimized by appropriately measuring the exposure?	1
5. (B) Have the confounding variables been considered in the design and/or analysis?	1	1	1	6. (A) Were the groups treated identically aside from the experimental intervention?	1
6. (A) Was the participant follow-up thorough enough?	1	1	1	6. (B) Did the authors account for any potential confounding variables in their analysis or design?	1
6. (b) Was the length of the subjects' follow-up sufficient?	1	1	1	7. How significant was the treatment's impact?	NA
7. What were the findings of this research?	1	1	1	8. How accurate was the treatment effect estimate?	1
8. How accurate are the findings?	1	1	1	9. Do you accept the findings?	1
9. Do you accept the findings?	1	1	1	10. Can the local population have the results applied to them?	1
10. Can the local population have the results applied to them?	1	1	1	11. Do the findings of this study accord with other pieces of information?	1
11. Do the findings of this study accord with other pieces of information?	1	1	1		
12. What practical implications does this study have?	1	1	1		
FINAL SCORE	14	14	14	FINAL SCORE	11

Note: NA – indicates not applicable; ✓ – indicates yes.

http://etd.uwc.ac.za/

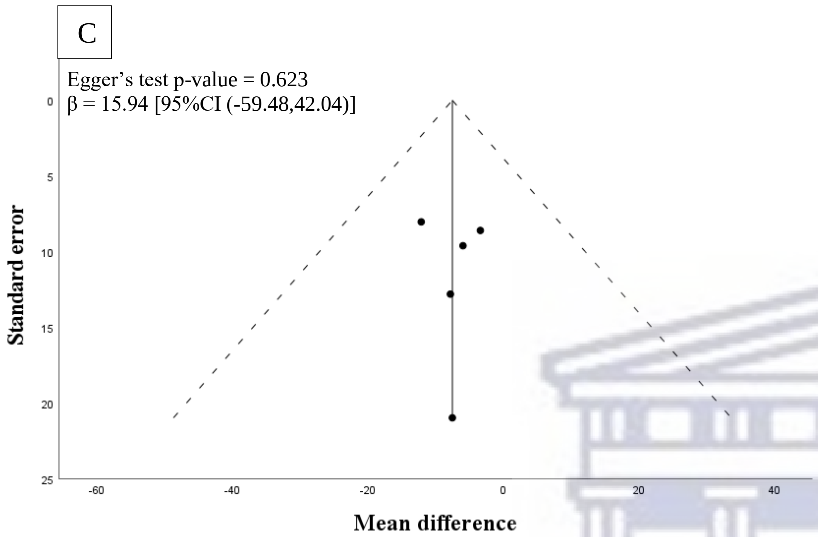


Figure 2C: Funnel plot for publication bias.

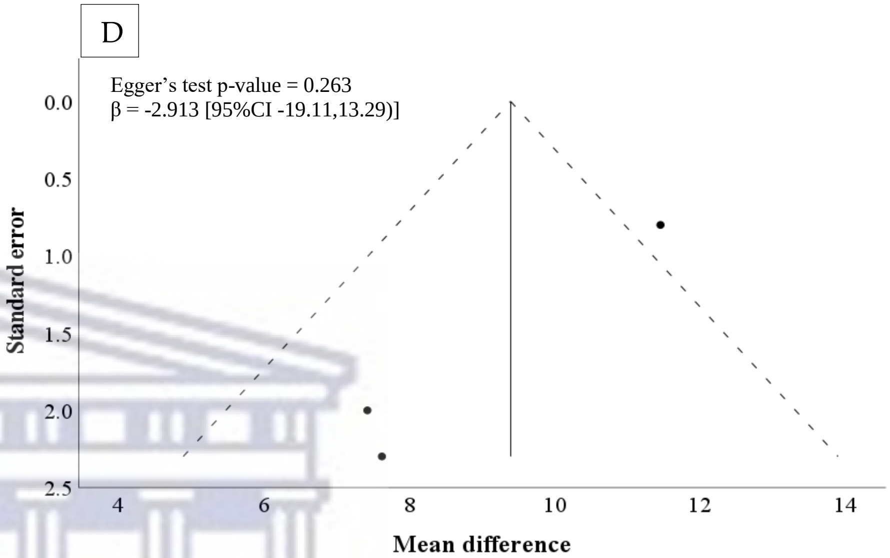


Figure 2D: Funnel plot for publication bias.

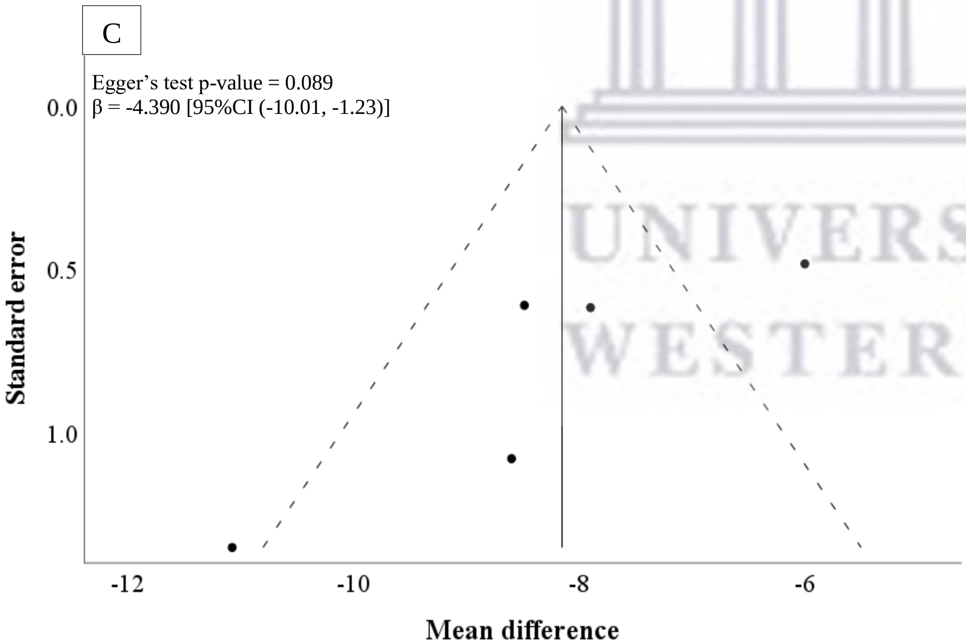


Figure 3C: Forest plot for publication bias.

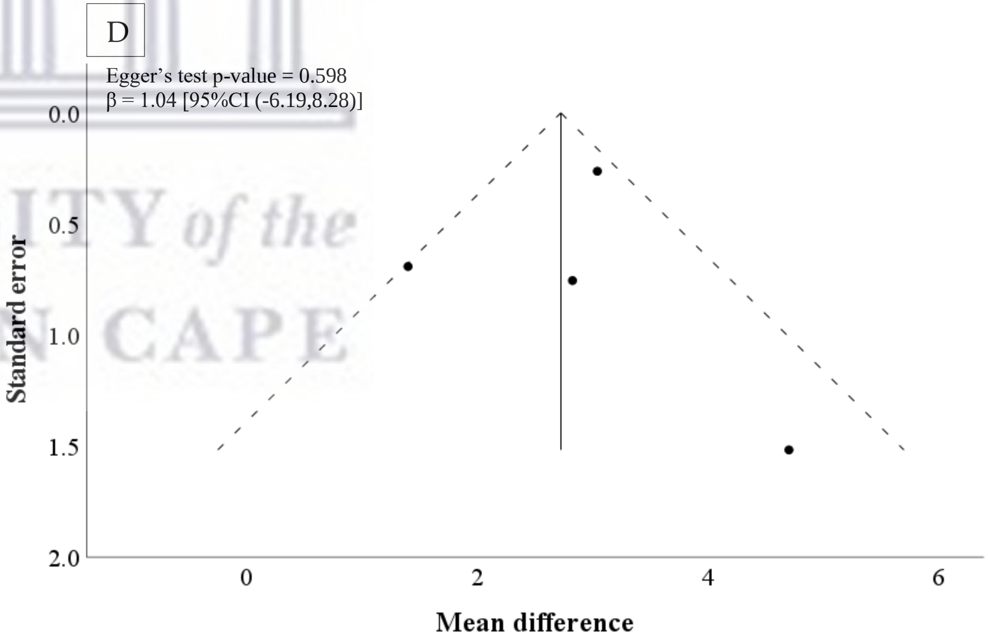


Figure 3D: Forest plot for publication bias.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

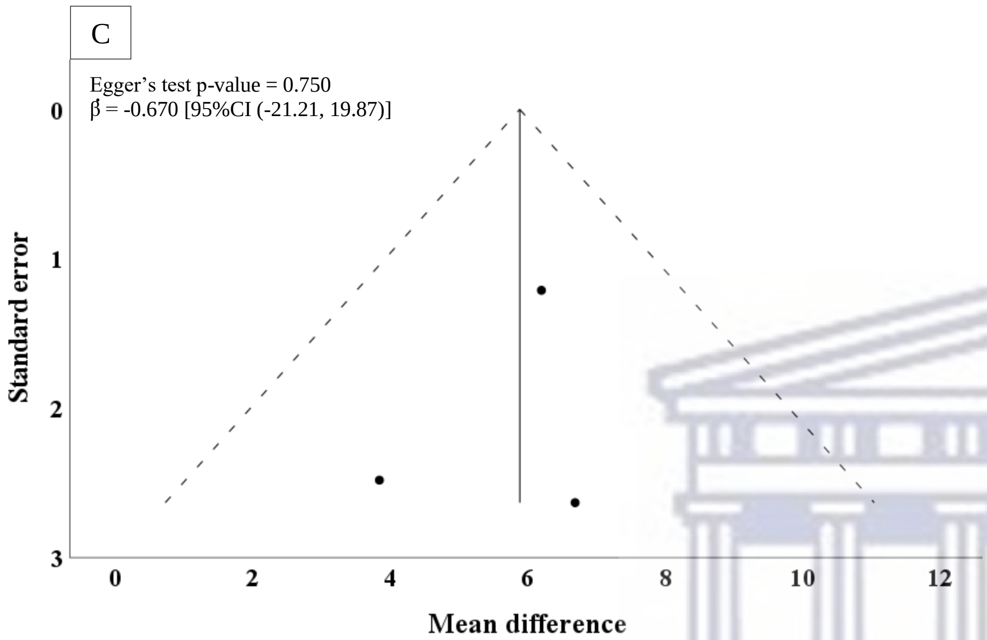


Figure 4C: Funnel Plot for publication bias.

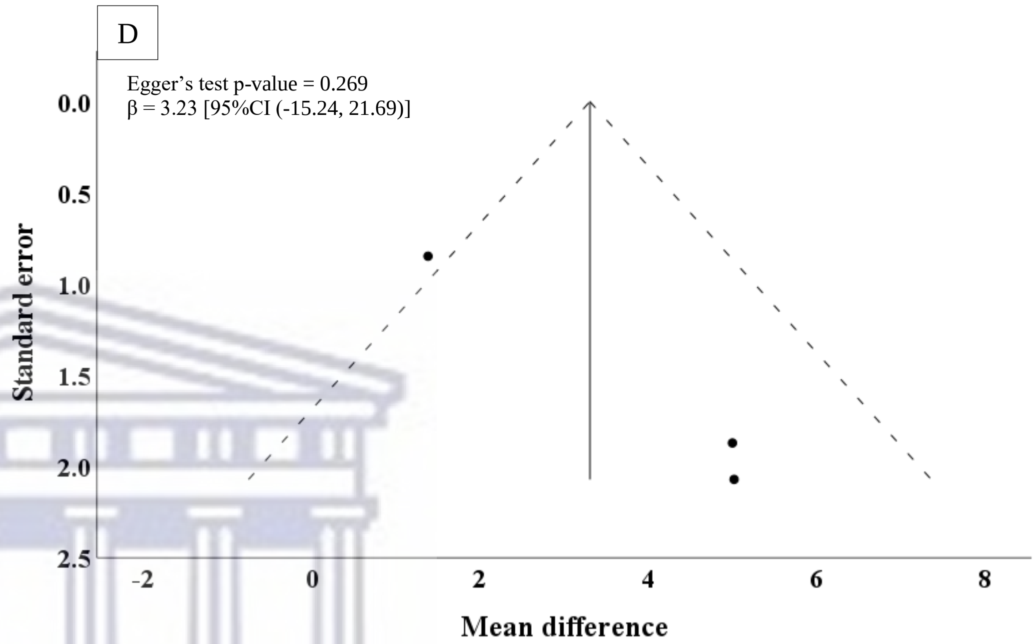


Figure 4D: Funnel plot for publication bias.

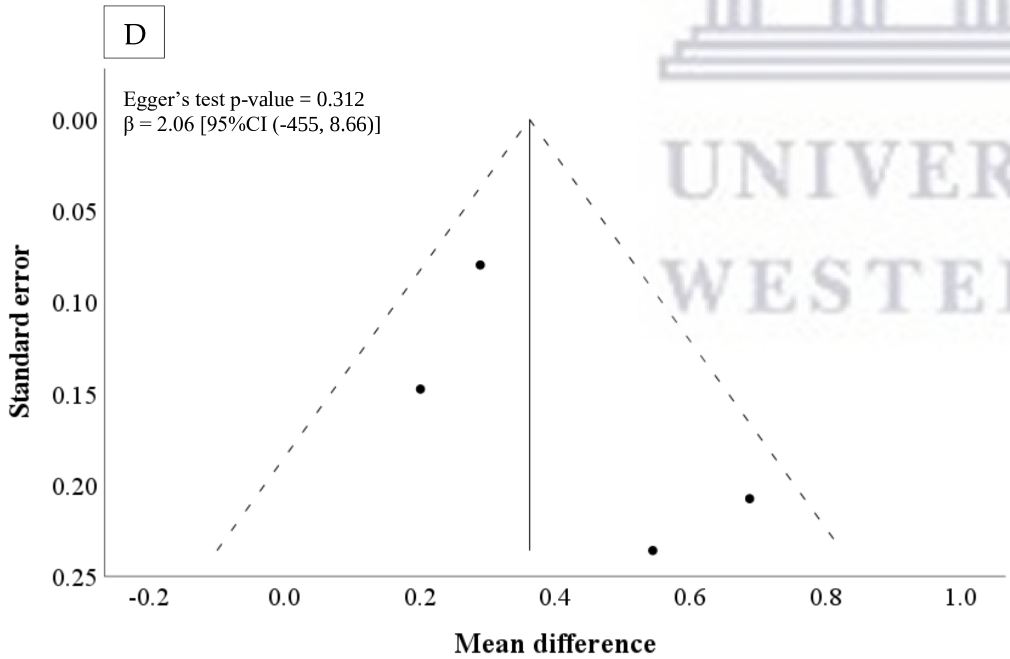


Figure 5D: Funnel plot for publication bias.

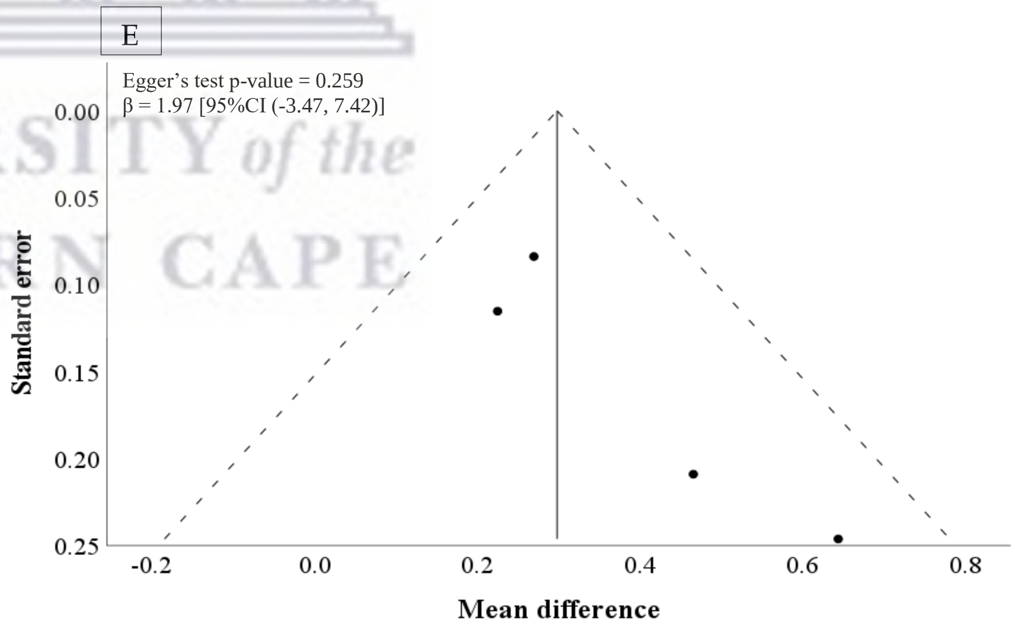


Figure 5E: Funnel plot for publication bias.

UNIVERSITY of the
WESTERN CAPE
http://etd.uwc.ac.za/

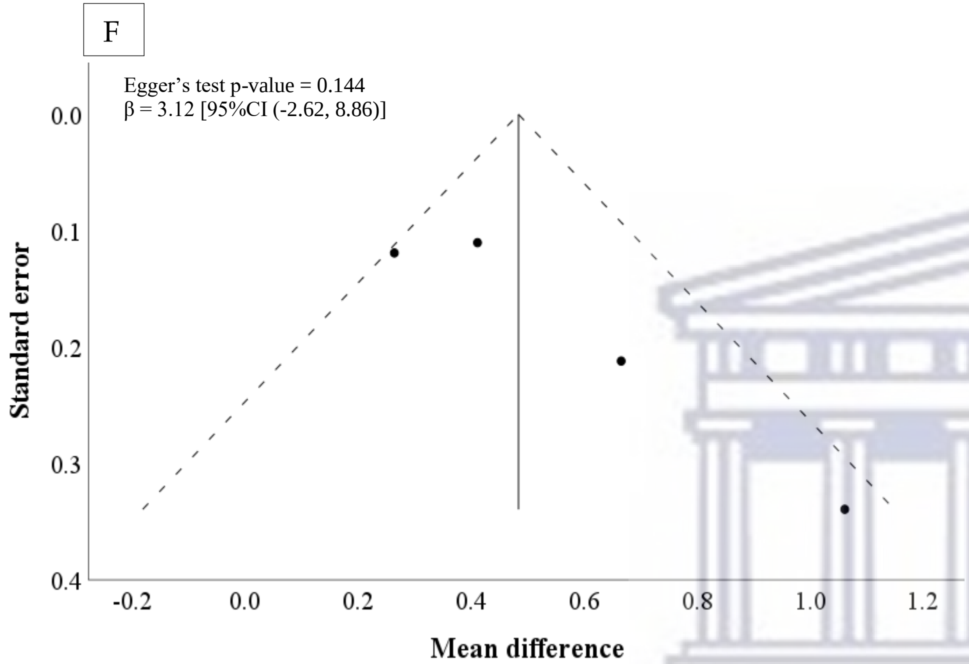


Figure 5F: Funnel plot for publication bias.

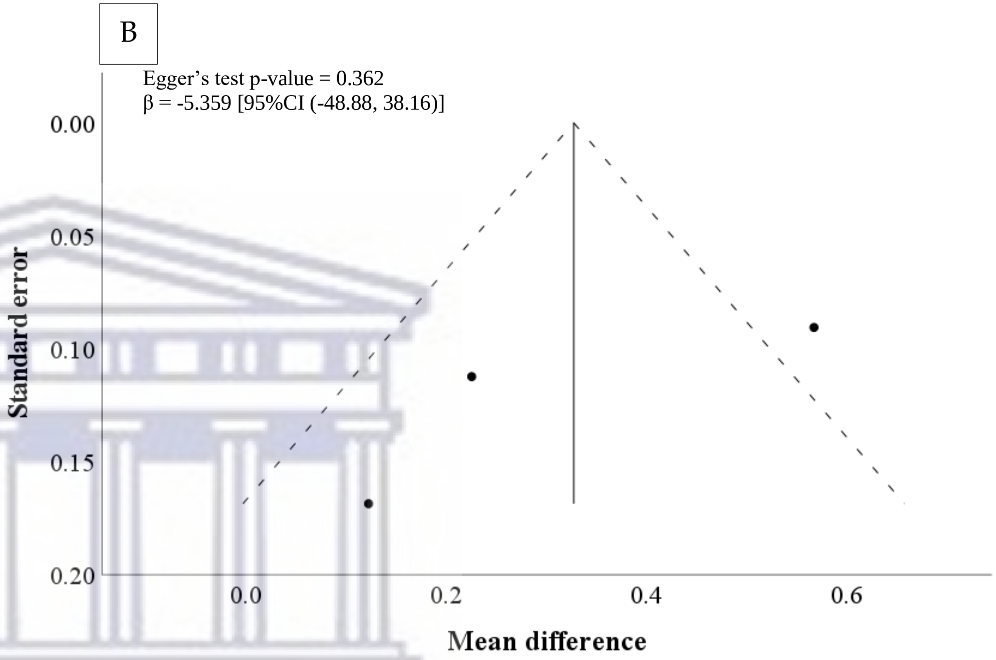


Figure 6B: Funnel plot for publication bias.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Appendix IX: Supplementary Table Original Research Article Six

Supplementary Table 1: Backward multiple linear regression models to explore the association between physical fitness and cardiovascular health in physical ability test performance.

Model	Variable	R^2	B	SE	β	VIF
Model: Physical fitness		0.490 §		125.96		
	$ab\dot{V}O_{2max}$		-102.85	34.08	-0.155	1.36
	Grip strength		-1.70	0.54	-.169	1.60
	Leg strength		-0.67	0.36	-.108	1.71
	Push-ups		-2.64	0.81	-0.207	2.07
	Sit-ups		-3.53	1.03	-0.207	1.89
	Lean body mass		-5.19	1.05	-0.286	1.73
	Intercept		1566.97	110.77		
Model: Cardiovascular health		0.301 §		149.17		
	Age		3.99	1.01	0.229	1.22
	Body mass index		-12.90	2.26	-0.321	2.56
	Body fat percentage		8.34	1.48	0.473	2.29
	Systolic blood pressure		3.10	0.83	-0.267	1.87
	Diastolic blood pressure		3.69	1.11	0.240	1.92
	Weekly MET minutes		-0.01	0.00	-0.238	1.04
	Intercept		590.02	93.29		
Model: Physical fitness and cardiovascular health		0.505 §		123.34		
	Weekly MET minutes		-0.01	0.00	-0.136	1.11
	Bodyfat percentage		4.80	0.95	0.256	1.35
	$ab\dot{V}O_{2max}$		-199.87	33.95	-0.304	1.41
	Grip strength		-2.40	0.54	-0.239	1.55
	Leg strength		-0.85	0.34	-0.140	1.68
	Sit-ups		-3.24	0.83	-0.190	1.25
	Intercept		1426.22	100.70		

Note: § − indicates statistical significance <0.001; B − unstandardized beta coefficient; SE – standard error; β − standardized beta coefficient; R^2 − R squared; VIF − variation inflation factor.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

APPENDIX X: BOOK CHAPTER

Use of Mobile Technology in Assessing Occupational Stress in Firefighters

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

Chapter 8
Use of Mobile Technology in Assessing Occupational Performance and Stress in Firefighters

Jaron Ras
University of the Western Cape, South Africa

Lloyd Leach
University of the Western Cape, South Africa

ABSTRACT

Firefighters are required to maintain all aspects of their health and wellness in order to sustain their fitness for duty. Heart rate variability (HRV) has been used as a reliable tool when assessing the stressors placed on firefighters, be it physical, emotional, or psychological. This review determined the usefulness of using HRV as a tool to determine the physical, physiological, and psychological health of firefighters at a more regular and frequent scale. HRV is a versatile technology with a plethora of uses, particularly in monitoring the cardiovascular strain as a result of firefighting and recovery post-fire suppression. In addition, the literature showed that HRV could be used to successfully monitor physical fitness, physiological stress, psychological stress, decision making, risk taking behavior and recovery in firefighters. The use of mobile technology measuring HRV may be used to successfully assess firefighter occupational performance. In future research, longitudinal studies investigating HRV use in firefighters are warranted.

INTRODUCTION AND BACKGROUND

All over the world, firefighting is a hazardous occupation that involves firefighters risking their lives in life-threatening situations, where they are exposed to severe temperatures, hazardous chemicals and fumes (Shin, Lee, Yang, Lee, & Chung, 2016; Smith, Barr, & Kales, 2013). This chapter reports on how mobile technology is used to assess and track firefighters' fitness for duty. New media can be crucial to

DOI: 10.4018/978-1-6684-3996-8.ch008

Copyright © 2022, IGI Global. Copying or distributing in print or electronic forms without written permission of IGI Global is prohibited.

http://etd.uwc.ac.za/

aid self-monitoring and could help with setting fitness exercise behavioral goals. Tracking and monitor- ing fitness exercise activity done through the use of portable and wearable devices like smart watches, fitness straps, as well as portable ECGs can all aid to monitor heart rate variability, but also help with exercise goal setting and fitness goal attainment (Bugajska, Zużewicz, Szmauz-Dybko, & Konarska, 2007; Chandel, Sharma, Kaur, Singh, & Kumar, 2021; Henriksen et al., 2018). This chapter reports on the applicability of these devices in determining firefighters at risk of poor physical fitness, cardiovascular disease, and psychological stress as they prepare for work in severe circumstances.

The dangerous conditions in which firefighters find themselves during emergency situations necessitate that firefighters' wear protective clothing and rescue equipment that is heavy and insulated, putting tremendous strain on the cardiovascular system (Smith, DeBlois, Kales, & Horn, 2016). Apart from extinguishing fires, firefighters also have additional strenuous work duties such as rescuing people in dangerous situations, performing emergency medical services, while working irregular hours and performing administrative tasks (Feairheller, 2015; Shin et al., 2016). These types of strenuous working conditions cause high levels of physical and mental stress, predisposing these individuals to higher risk of cardiovascular disease or sudden cardiac events (S. S. Al-Zaiti & Carey, 2015; Feairheller, 2015; Shin et al., 2016). Firefighters are required to maintain all aspects of their health and wellness in order to sustain their fitness for duty. Hence, underscoring the value of incorporating wearable and mobile devices to aid tracking and goal setting in this regard.

Firefighters who are not fit for duty are predisposed to significant morbidity and mortality, both on and off duty (Farioli et al., 2014; Smith et al., 2013, 2019; Smith, DeBlois, et al., 2016). In addition, firefighters are required to make life and death decisions while on duty, and their judgement may be negatively affected by undue physical and psychological stress (Clifford, Jung, Hoerrnann, Billinqhurst, & Lindeman, 2019; Jeklin et al., 2021; Prell et al., 2020). Cardiovascular measures, such as resting heart rate (RHR) and heart rate variability (HRV) are reported as significant predictors of cardiovascular diseases, specifically high blood pressure, hyperglycemia, diagnosis of diabetes within 12 years, and early mortality in firefighters (Wulsin, Horn, Perry, Massaro, & D'Agostino, 2015). An alarmingly high number of firefighters were found to have abnormal HRV readings, which identifies those at risk of cardiovascular disease (CVD) or sudden cardiac death (SCD) (S. Al-Zaiti, Rittenberger, Reis, & Hostler, 2015; Jeklin et al., 2021; Prell et al., 2020; Yook, 2019). The usefulness in monitoring of HRV and other psychophysiological measures with mobile technology highlight the need to better leverage new media portable technological devices that can aid in the monitoring of physiological data that can deliver associative data in this regard.

This review will, therefore, determine the usefulness of using HRV as a tool to determine the physical, physiological, and psychological health of firefighters at a more regular and frequent scale. By using HRV as a screening tool to assist in the early identification of at-risk firefighters, risk can be mitigated on an individual level. Subsequently, the institutional support of mobile and wearable technologies can assist in advocating for the early screening of firefighters and the implementation of appropriate health interventions as well as fitness goals.

Heart Rate Variability Definition, Application, and Measures

Heart rate variability is the variation in the time interval between consecutive heartbeats in milliseconds (Billman, Huikuri, Sacha, & Trimmel, 2015; Shin et al., 2016). It has been shown that heart rate variability is directly related to autonomic functioning (Shaffer & Ginsberg, 2017). Increased sympathetic

http://etd.uwc.ac.za/

activity causes a direct decrease in HRV, and increased parasympathetic activity, results in an increase in HRV(Shaffer & Ginsberg, 2017). The increased sympathetic activity increases the heart rate (HR) and decreases the variation in the beat-to-beat interval, whereas the opposite occurs when the parasympathetic nervous system is stimulated and cause more variation as the heart rate drops and the beat-to-beat intervals (Shaffer & Ginsberg, 2017). The beat-to-beat intervals, though subtle, provide important insights into autonomic and cardiovascular functioning. These types of measures are referred to as time domain measures and defined as the numbers obtained from statistical analysis of the intervals between heart beats and are observed during monitoring periods that may range from ±2 minutes to 24 hours (Malik et al., 1996; Shaffer, Ginsberg, & Shaffer, 2017). The most common measures include the standard deviation of normal-to-normal sinus intervals (SDNN) which is influenced by both the sympathetic and parasympathetic nervous system activity and considered the "gold standard" in HRV analysis (Malik et al., 1996; Shaffer et al., 2017). The root mean square of successive differences between normal heartbeats (RMSSD) and reflects the beat-to-beat variance in HR and is the primary time-domain measure used to estimate the vagally mediated changes in HRV; and lastly, the average interval between normal beats (AVNN) (Malik et al., 1996; Shaffer & Ginsberg, 2017). Frequency domain analysis is an analysis technique that indicates how much of a signal lies within one or more frequency bands (ranges) (Almeida-Santos et al., 2016; Malik et al., 1996; Shaffer & Ginsberg, 2017). In the case of HRV, research has found that certain frequency bands correlate directly with specific physiological phenomena (Acharya, Joseph, Kannathal, Lim, & Suri, 2006; Oka, Sawaguchi, Kuriyama, & Ito, 2021; Sessa et al., 2018; Shaffer et al., 2017). Frequency domains are divided into High Frequency power (HF), which is represented by a frequency activity range of 0.15 - 0.40 Hz range and Low Frequency power (LF), represented by a frequency activity in the 0.04 - 0.15 Hz range (Acharya et al., 2006; Malik et al., 1996; Shaffer & Ginsberg, 2017). The LF band has been associated with baroreceptor activity, and HF bands are related to HR variations related to the respiratory cycle (Shaffer & Ginsberg, 2017). Another measure is the LF/HF Ratio, which represents the ratio of Low Frequency to High Frequency and is considered indicative of sympathetic to parasympathetic autonomic balance, where a low frequency dominated ratio indicates parasympathetic dominance, and a high frequency dominated ratio indicates sympathetic dominance (Acharya et al., 2006; Almeida-Santos et al., 2016; Malik et al., 1996; Shaffer & Ginsberg, 2017). High frequency dominance would indicate a high stress state, which is often seen in emergency personnel, such as firefighters (Jeklin et al., 2021; Prell et al., 2020; Shin et al., 2016; Tomes, Schram, & Orr, 2020). Although there are many interpretations of time domain and frequency domain in HRV, we have elected to only explain the most frequently used domains in research regarding firefighters. All other HRV measures are variations on the standard time and frequency domains.

MAIN FOCUS OF THE CHAPTER

Heart Rate Variability in Firefighters

The advances in technology measuring HRV has become increasingly simpler and cost effective (Liao, Al-Zaiti, & Carey, 2014; Shin et al., 2016). Previously, HRV would need to be measured using an ECG, however, with today's technological advances and shrinking of mobile devices to a wearable size, HRV has become somewhat of a ubiquitous mobile technology, being used in many smart watches, chest straps, and portable ECG monitors (Morresi, Casaccia, Sorcinelli, Arnesano, & Revel, 2020; Plews et

http://etd.uwc.ac.za/

al., 2017). This allows HRV and the autonomic functioning of the heart to be monitored on the move in everyday life cost effectively and conveniently.

Heart Rate Variability is determined by the parasympathetic and sympathetic autonomic balance. Physiologically, the parasympathetic nervous system is known as the "rest and digest" system and is indicative of the body being in a relaxed and calm state (Acharya et al., 2006; Malik et al., 1996; Shaffer et al., 2017). Alternatively, the sympathetic nervous system is known as the "fight or flight" system and is indicative of the human body being in a state of stress (Billman et al., 2015; Tomes et al., 2020; Vyas & Mcgregor, 2018). Increased stress, poor physical fitness and poor cardiovascular health cause an increase in sympathetic stimulation, decreasing the time interval between beats, which corresponds to a decrease in HRV (Acharya et al., 2006; Almeida-Santos et al., 2016; Schuster, Fischer, Thayer, Mauss, & Jarczok, 2016; Shaffer et al., 2017; Shin et al., 2016). Improved physical fitness, good cardiovascular health, and low stress levels increase the parasympathetic dominance, which corresponds to an increase in the beat-to-beat time interval, and subsequently, an increase in HRV (Acharya et al., 2006; Malik et al., 1996; Tomes et al., 2020; Yook, 2019). Monitoring HRV can be used to determine those individu- als at risk for cardiovascular conditions, those with poor physical fitness, or those that have increased stress levels.

In firefighters, HRV has been used as a reliable tool when assessing the overall stressors placed on firefighters, be they physical, physiological, emotional, or psychological (Jeklin et al., 2021; Qiu et al., 2017; Schuster et al., 2016; Shin et al., 2016). Current research indicated that a relationship exists between HRV, cardiovascular health, mental health, and the physical fitness of firefighters, which may prove valuable in assessing underlying conditions present in firefighters (S. S. Al-Zaiti & Carey, 2015; Feairheller, 2015; Shin et al., 2016). A relationship that can further be strengthened in research and practice by utilizing mobile technology to collect data from mobile phones and wearable devices on a large scale, and more importantly, on an individual firefighter level. In addition, an alarmingly high number of firefighters were reported to have abnormal HRV readings (S. S. Al-Zaiti & Carey, 2015; Carlén, Nylander, Åström Aneq, & Gustafsson, 2019; Pillutla, Li, Ahmadi, & Budoff, 2012; Soteriades, Targino, et al., 2011). Having annual or routine physical check-ups using health screenings, in conjunction with HRV, can identify those who might be at risk of CVD or SCD and those who can benefit from preventive cardiovascular services. Moreover, the use of HRV may allow for the convenient monitoring of those firefighters at risk for cardiovascular disease, psychological burnout, and injury (Jeklin et al., 2021; Liao et al., 2014; Prell et al., 2020; Shin et al., 2016; Tomes et al., 2020; Yook, 2019).

Developments in the Use of Heart Rate Variability in Firefighters

The use of HRV and other technology in the monitoring of firefighters have progressed rather slowly, when considering that the first reported study of measuring heart rates to alarm tones in firefighters was conducted in 1981 by Kuorinka & Korhonen, 1981. In their study, due to the incipiency of heart rate sensing technology, an ECG was required to monitor simple heart rate measures. The relatively low number of studies using technology in firefighters, and other emergency occupations, may, in part, be due to the relative scarcity of researchers interested in this specific research field. Without constant research driving these new ideologies, the potential for use in firefighters and other emergency person- nel are merely theoretical and without any practical applications using hard scientific evidence goes, mostly, unaccepted. Although progressing gradually, the advancement of technology has allowed for more convenient monitoring of heart rates in firefighters in the early 2000's, which has ignited research

http://etd.uwc.ac.za/

interest in the application of technology in firefighters, particularly as a means to detect autonomic abnormalities and occupational stress in firefighters (Chuang, Chung, Shu, & Chen, 2007; Malik et al., 1996; Togo & Takahashi, 2009). Over time, research involving the multifaceted use of HRV in the general population investigating the relationship between HRV and physiological and psychological variables slowly trickled over to firefighter research. The use of HRV has now become a focal point in the endeavours to reduce the high cardiovascular related mortality, injury related early retirement and mental illness, often seen in this population (Jeklin et al., 2021; Meina et al., 2020; Prell et al., 2020; Shin et al., 2016; Yook, 2019). Researchers started applying the use of portable heart rate monitoring systems in the early-to-mid-2010s as a means to monitor heart rate responses, recovery, workload, and stress in firefighters (D M Baur, Leiba, Christophi, & Kales, 2012; Dorothee M. Baur, Christophi, Cook, & Kales, 2012; Dorothee M Baur, Christophi, Tsismenakis, Cook, & Kales, 2011; Yu et al., 2015). The incipiency of the HR technology, at the time, meant that standard heart rate was the preferred measure to assess firefighters physiological and psychological responses to emergencies. However, due to the current advancements, HRV monitoring has become readily available to the general population, and with modern HRV analysis advancements, the analysis of time-domains and frequency domains have become rather manageable.

Firefighters are often burdened by immense mental and physiological stress and the imposition of these new technologies may introduce an additional burden that many firefighters will not accept, especially if fire departments attempt to enforce this on a large scale (Bucala & Sweet, 2019; Carey, Al-Zaiti, Dean, Sessanna, & Finnell, 2011; Dobson et al., 2013; Jahnke, Poston, Jitnarin, & Haddock, 2012). Studies have shown that the majority of firefighters think of themselves as "tough guys" (Bonnell et al., 2017; Bucala & Sweet, 2019; Dobson et al., 2013). Firefighters with this mindset may ridicule the idea of having sensors or monitoring systems in place to ensure they avoid injuring or overexerting themselves. Although this mindset appears to be very biased toward the older, more experienced firefighters, the younger generation, as with general society, may be more accepting of the use of technology, especially in the workplace (Bonnell et al., 2017; Bucala & Sweet, 2019; Dobson et al., 2013). The younger demographic population of firefighters should be targeted for the initial and long-term application of this technology use, which could drive the acceptance of technology forward in firefighters.

Use of Mobile Technology in Firefighters

In firefighter research, many different portable HRV monitoring systems have been used while firefighters are on duty to complete simulation protocols or to discern the physiological burden placed upon the cardiovascular system by firefighting (Biéchy et al., 2021; Marcel-Millet, Groslambert, Gimenez, Grosprêtre, & Ravier, 2021; Marciniak, Wahl, & Ebersole, 2021; Robertson et al., 2017; Schlicht et al., 2018). The most restricting HRV monitor appears to be the VitalJacket®. This portable HRV monitoring system fits over the torso as a conventional shirt and can be worn up to 72 hours continuously, and is noted to be unobstructive in performing everyday tasks (S Rodrigues, Dias, Paiva, & Cunha, 2018; Susana Rodrigues, Dias, Paiva, & Cunha, 2018; Susana Rodrigues, Paiva, Dias, & Cunha, 2018). Although the VitalJacket is a useful portable technology, the long-term use of these in firefighters may prove problematic, and inconvenient, due to the device needing cleaning after each use (Susana Rodrigues, Dias, et al., 2018; Susana Rodrigues, Paiva, Dias, & Cunha, 2018; Susana Rodrigues, Paiva, Dias, Pimentel, et al., 2018). In addition, the VitalJacket® may increase heat production and perspiration during intense firefighter related duties (Susana Rodrigues, Dias, et al., 2018; Susana Rodrigues, Paiva, Dias, & Cunha, 2018).

http://etd.uwc.ac.za/

Figure 1. VitalJacket®. © 2022, Biodevices, Biomedical Engineering Systems, S.A., Used with permission

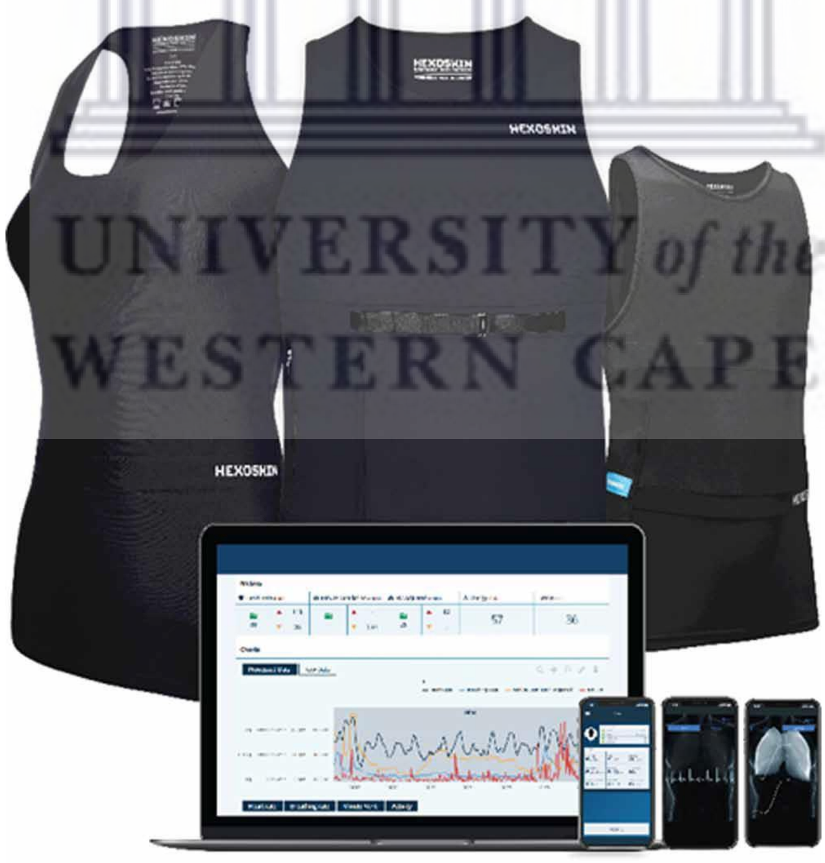
The Bodyguard® Firstbeat is another HRV product that has been used in firefighting research (Figure 2).

Figure 2. Bodyguard Firstbeat. © 2022, Firstbeat Technologies Oy, Used with permission

http://etd.uwc.ac.za/

The Bodyguard® Firstbeat, although very accurate, uses electrodes to monitor HRV. This technology becomes problematic when attempting to monitor electrocardiographic signals over a prolonged period, especially when individuals are engaged in vigorous activities, such as firefighting. This technology may be beneficial for platoon officers, station commanders, or divisional heads that are not often engaged in vigorous activities. Many of these older firefighters have underlying health concerns and implementing a live monitoring system of these high-risk firefighters may prove quite important in preventing duty related deaths (Gendron, Lajoie, Laurencelle, & Trudeau, 2018; Ras & Leach, 2021; Savall et al., 2020). The Hexoskin® t-shirt (Figure 3), similar to the VitalJacket® provides its wearers with a fully wearable "shirt" that is used to monitor HRV. The wearable shirt technology overcomes the burden of using electrodes which frequently become unattached. Unlike the VitalJacket®, the Hexoskin® does not use disposable electrodes to monitor HRV, rather using sensors that are manufactured into the shirt itself. This overcomes the issue of artefacts in the data, somewhat, due to the reliability of the electrodes remaining in the correct position and not becoming unattached while wearing the Hexoskin® t-shirt. The Hexoskin® shirt is not intrusive, however, may cause increase perspiration and, overtime, uncomfortability. For long term use, this equipment does not seem to be the most feasible option, but very useful for research purposes.

Figure 3. Hexoskin® t-shirt © 2022, Carre Technologies inc (Hexoskin)© Used with permission



UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

The Holter Monitor (Figure 4) have been the most commonly used portable ECG tool to measure HRV in firefighters. As with the VitalJacket® and Bodyguard® Firstbeat, the Holter monitor uses ECG electrodes. Most studies using the Holter monitor used resting measures, and electrodes falling off were not an issue. However, when the Holter monitor is used to measure firefighting activities, the electrodes would often become unstuck, and corrupt the HRV readings. This becomes problematic when one would like to use the Holter as a long term HRV monitoring system. For resting measures, the Holter would represent the gold standard in portable technologies, however, once firefighters initiate movement, become considerably more unreliable.

Figure 4. Holter monitor ©2022, ShutterStock, License purchased

Polar has been producing mobile devices which are reliable and accurate in measuring HRV for an extended period of time already (Figure 5) (Caminal et al., 2018; Donovan, 2009; Plews et al., 2017; Wallén, Hasson, Theorell, Canlon, & Osika, 2012). The Polar V800 watch has been used extensively in research, as a non-invasive technology to monitor HRV (Caminal et al., 2018). On its own, the watch cannot measure HRV, and requires it to be linked to a chest strap, such as the Polar H7 monitor, to monitor HRV. Data corruption or loss of signal can occur if the monitors are placed incorrectly or become unattached. All Polar devices link up to a downloadable application to record and analyze HRV. The convenience and unobtrusiveness of using the watch smartwatch makes it a viable option. The Equivital™ EQ-02 Life Monitor sensor belts are an amalgamation of a conventional HR strap and a fully wearable

http://etd.uwc.ac.za/

shirt (Figure 6). This may form the most comfortable method which may be used to monitor firefighters while on active dut (Hinde, White, & Armstrong, 2021) y. The Equivital™ EQ-02

Figure 5. Polar V800 wristwatch © 2022, Copyright Polar Electro Oy, Used with permission

Figure 6. Equivital™ EQ-02 Life Monitor sensor belts © 2022, Equivital™, Used with permission

UNIVERSITY of the WESTERN CAPE

http://etd.uwc.ac.za/

Life Monitor has been used in sport and military research previously and has been designed to produce accurate readings even in the most intense sporting or emergency situations (Cullen et al., 2015; Heesch & Slivka, 2015; Hinde et al., 2021; Levels, de Koning, Foster, & Daanen, 2012). However, firefighters often experience slips, trips and falls (Frost, Beach, Crosby, & McGill, 2015), which may pose a significant damage risk for these monitors, especially when firefighters are in emergency reduce situations, such as when evacuating civilians from burning buildings.

Although the large ECG equipment have been used often in research, smaller portable devices have become particularly popular in research involving HRV analysis (Choi, Ko, & Kojaku, 2017; Shin et al., 2016; Wallén et al., 2012). The Polar® RS800CX monitor is one such technology which have been frequently used in combination with the Polar Polar H7 chest strap (Figure 7).

Figure 7. Polar RS800CX © 2022, Copyright Polar Electro Oy, Used with permission

In terms of convenience, the wristwatches seem to be the best option to use in firefighters. However, the issue comes in when the watches need to be combined with the H7 chest straps. Although most ECG devices do use multiple devices to monitor HRV continuously, having to use the wristwatch and chest strap together may become cumbersome to firefighters. This may be attributed to firefighters having to ensure both devices are connected and functioning properly when needed during their shifts.

As previously mentioned, the Polar® H7 (Figure 8) HR monitor is the device which retrieves the HRV data when using the Polar smartwatches.

http://etd.uwc.ac.za/

Figure 8. Polar H7 heart rate monitor © 2022, Copyright Polar Electro Oy, Used with permission

Due to the progression of the chest strap HRV monitoring technology, research have slowly moved away from using the smartwatches in combination with the chest straps (Hernández-Vicente et al., 2021; Hernando, Roca, Sancho, Alesanco, & Bailón, 2018; Plews et al., 2017). The chest straps, rather, are connected to a smart phone application developed by Polar® which monitors HRV in real time. This allows HRV to be analyzed while firefighters are on duty, if the device is in range of the smartphones Bluetooth range. Although very useful, using this mobile device on duty may be problematic if a smart phone would need to be on the firefighters person. Another issue may be long term comfort using these monitors while on duty.

Figure 9. BioHarness3 HRV monitor, Awaiting permission from company to use image

The BioHarness3® (Figure 9) HRV monitor has all the positive atttibutes of the Polar® heart rate monitors and makes up for the negatives by providing its users the ability to store HRV data that can be accessed at a later time. In terms of firefighting, the BioHarness3® appear to be the best option to use in firefighters while on active duty.

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/

The development of wearable ECG wristwatches has progressed quite significantly over the past few years (Chandel et al., 2021; Henriksen et al., 2018; Isakadze & Martin, 2020; Morresi et al., 2020; Zimerman, Sheridan, Cooke, & Jena, 2020). These smartwatches may provide the best option available to use in all emergency occupations (Chandel et al., 2021; Henriksen et al., 2018; Hinde et al., 2021; Tomes et al., 2020). If provided to each firefighter, these can provide easy long term cardiovascular and physical activity monitoring in firefighters. Regularly checking these smartwatches or retrieving data is convenient, as these watches connect to downloadable applications for easy analyzes (Henriksen et al., 2018; Isakadze & Martin, 2020; Morresi et al., 2020; Spaccarotella et al., 2020). Due to the watches being located on the firefighter wrists, damage may occur relatively easily. More research should be conducted using these ECG smartwatches on firefighters while on duty to monitor their feasibility.

Physical Fitness, Stress, and Heart Rate Variability in Firefighters

Firefighting, an often laborious and dangerous occupation, places many firefighters in harm's way due to the accompanying heat stress, dehydration, and physical exertion. The combination of these factors may cause acute sympathetic activation in firefighters (Larsen, Snow, & Aisbett, 2015; Pluntke, Gerke, Sridhar, Weiss, & Michel, 2019; Schlicht et al., 2018; Shin et al., 2016). However, as recommended by many researchers, policy makers, and fire departments, regular physical activity provides a cardio-protective effect, such as bradycardia, and improved cardiovascular fitness. Therefore, the reduction of cardiovascular strain results in autonomic adaptations leaning toward parasympathetic dominance (Marcel-Millet, Ravier, Esco, & Groslambert, 2020; Porto et al., 2019; Yook, 2019). Specifically, the augmented stimulation of the vagal nerve subsequently prolongs the beat-to-beat interval and ultimately decreases HRV (D M Baur et al., 2012; Lavie et al., 2015; Smith, DeBlois, et al., 2016). Consequently, fitter firefighters will have a lower HRV, thus, allows HRV to be used as a more convenient screening tool to estimate cardiovascular fitness and health in firefighters.

Porto et al. (2019) conducted a study investigating the relationship between cardiorespiratory fitness and HRV in firefighters. In the study, firefighters HRV was measured using a Polar© heart rate monitor in a resting supine and orthostatic position. The study found that HRV was significantly related to higher cardiorespiratory fitness, in both the supine and orthostatic positions in firefighters. Most firefighting departments use a cardiorespiratory capacity higher than 12.5 METs as the baseline cardiorespiratory fitness standard for firefighters to be deemed fit for duty. As seen in Figure 9, PNN50 and rMSSD was significantly higher in fitter firefighters and low and high frequency ratio was singingly more dominated by low frequency compared to higher frequency. Firefighters' cardiovascular fitness may be assessed using HRV as a preventative measure to determine the functioning of the cardiovascular system (Porto et al., 2019). The study by Porto et al. serves as a promising base to implement resting HRV testing as a simple measuring tool for fitness in firefighters, as non-invasive, time-sensitive measures throughout the year when firefighters are not required to undergo fitness testing.

A study by Marcel-Millet et al. (2020) investigated the relationship between firefighters' fitness and parasympathetic reactivation, using a Hexoskin® t-shirt. The study reported that physical fitness did not influence cardiac parasympathetic reactivation. The study noted that the Log transformed root mean square of successive differences (LnRMSSD) showed high accuracy compared to the criterion the researchers used, indicating the usefulness of a wearable HRV t-shirt in firefighters. Although the study did not find a significant relationship between physical fitness and HRV, it demonstrates the usefulness in monitoring parasympathetic modulation while firefighters are on duty (Marcel-Millet et al., 2020).

http://etd.uwc.ac.za/

Figure 10 explains the relationship between heart rate variability in relation to performance and time demand, measured using the multi-dimensional NASA-Task Load Index (NASA-TLX). The study noted that specific HRV measures, such as LF/HF ratio, LF, and pNN50 was significantly predicted by performance on the tasks. In addition, time demand of the tasks could predict changes in HRV, specifically related to detrended fluctuation analysis (DFA1), pNN50 and rMSSD. These results may be useful in predicting the physiological strain on firefighters based on the task demand. This may provide an added benefit of physical fitness training in reducing these physical stressors using HRV.

Figure 10. Difference between HRV measures according to physical fitness in orthostatic position

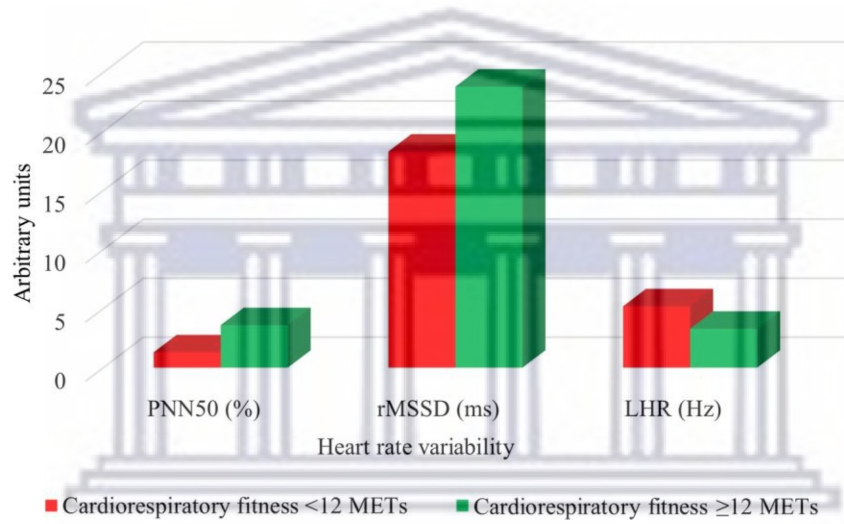
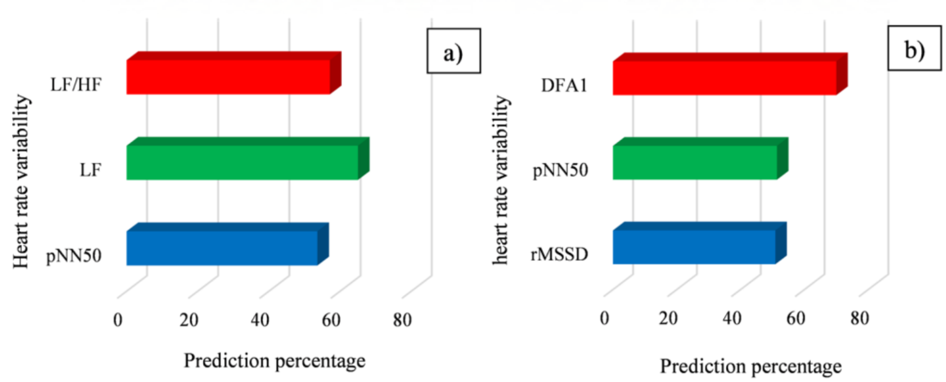


Figure 11. Relationship between heart rate variability and physical load: a) – heart rate variability and performance; b) – heart rate variability and time demand



http://etd.uwc.ac.za/

Cilhoroz et al. (2021) conducted a study investigating the blood pressure and HRV responses in five firefighters exposed to sudden vigorous exertion who had hypertension. The researchers used a Polar® V800TM HR monitor and Polar® H7 chest strap to measure the firefighters' baseline HRV. The HRV data was exported onto the Polar Flow software (Version 2.3; Polar ElectroOy, Kempele, Finland) for further analysis. The results of the study showed that there was a significant trend of increased blood pressure and LF/HF ratio in firefighters after completion of the graded exercise stress test. The study noted that HRV and ambulatory blood pressure are significantly affected by vigorous intensity, which lasts throughout the 19-hour monitoring period. In the study, as blood pressure increased, HRV decreased, specifically the LF/HF ratio, which is consistent with previous research, (Almeida-Santos et al., 2016; Schuster et al., 2016; Shin et al., 2016; Wulsin et al., 2015), as this designates alterations in baroreceptor reflexes and increased stress on the body. Routinely monitoring HRV throughout firefighter shifts may provide valuable information regarding the physiological stressors' firefighters may experience through the shift. Lyytikäinen, Toivonen, Hynynen, Lindholm, & Kyröläinen et al. (2017) investigated how aerobic fitness is associated with recovery, using the measurement of heart rate variability in firefighters over a 24-hour shift. The researchers recorded HRV using a portable Bodyguard, Firstbeat Technologies HR monitor. Stress and recovery were measured using salivary cortisol. The study reported that SDNN was lowest while firefighters were on shift and decreased during off-duty recovery. A similar decrease was seen in the baseline LF/HF ratio of off-duty firefighters. This indicates that while firefighters are on-duty, their stress levels are increased, causing a decrease in HRV and a general sympathetic dominance. Surprisingly, the researchers did not find a significant association between good cardiorespiratory fitness and HRV, however, there was a general trend toward increased RMSSD and SDNN with firefighters that had higher aerobic fitness levels (Lyytikäinen et al., 2017). Cortisol levels increased throughout the firefighters' work shift, which coincides with the decreased HRV measures, and remained elevated until the last day of recovery before the next shift (Lyytikäinen et al., 2017). The use of HRV and cortisol levels provide additional objective measures of monitoring HRV and stress in firefighters. Moreover, the combination of hormone monitoring along with physiological monitoring may provide additional benefits in ensuring long term health and fitness in firefighters, however, this approach may prove to be costly and considered implausible by fire departments.

An earlier study conducted by Marcel-Millet et al. (2018) investigated the relationship between para-sympathetic reactivation, monitored with the Hexoskin® t-shirt, during rescue interventions while wearing a breathing apparatus. The Hexoskin® t-shirt successfully and accurately monitored the firefighters' physiological responses during the simulation protocols and reported that firefighters that wore the SCBA experienced more physiological stress and important post-exercise vagal perturbation. More specifically, the increased physiological stress of the SCBA gear increased the post-exercise vagal perturbations in firefighters (Marcel-Millet et al., 2018). The study highlights the versatility of using HRV to monitor the physiological stressors during specific firefighter duties, which may have a prolonged negative effect of the cardiovascular system, post-event. This provides useful information in the applicability of using HRV to monitor firefighters' physiological recovery after an extended time post the emergency event. In addition, this may discern firefighters that require stress relief interventions, or those who may benefit from exercise training to better cope with the stressors of the job.

http://etd.uwc.ac.za/

Heart Rate Variability and Reflection of Respiration

Heart Rate Variability have been used as a measure to relate to respiratory reflexes, which is a relatively new method of applying HRV. Reflection of Respiration (RIR) is an objective index illustrating cardio-respiratory load. This was described by Malik et al. (1996) that described respiratory reflexes at rest or during low-load activities are present primarily in the high-frequency (HF) band (0.15–0.40 Hz), which relates to parasympathetic activity. However, the effect of respiratory reflex in the continuation of high load activity are present in the very-high-frequency (VHF) band (0.4–1.0 Hz) rather than in the HF band and are indicative of sympathetic activity (Ito, Oka, & Kuriyama, 2020). The use of the RIR index, provides visualization of the cardiorespiratory state of firefighters without using a metabolic monitoring device, such as a mask and a gas analyzer (Ito et al., 2020; Oka et al., 2021). The use of the RIR index to determine other biological parameters, such as blood lactate, has been researched and determined to be appropriate. The reflection of respiration has reliably been shown to indicate the shift from an aerobic to an anaerobic dominated state under high load intensity, which often occur in firefighters, due to the vigorous nature of many of the emergency situations they are faced with (Ito et al., 2020; Oka et al., 2021). Ito et al. (2020) investigated the relationship between RIR and firefighters' activity using a Holter monitor while firefighters performed a simulation protocol. The researchers reported that the combined use of HR and RIR provided invaluable insight into the physiological stressors firefighters faced, and significantly related to the intensity of the load placed on them. In addition, HRV and RIR measurements were related to the blood lactic acid levels and the activity level of the firefighters while performing the simulated tasks (Ito et al., 2020). The use of HR and RIR, in concurrence, may reduce the incidence of overexertion in firefighters and support the improvement in their occupational safety. As many firefighters do suffer from suboptimal lung function (Navarro et al., 2019; Slattery, Johnston, Paquet, Bennett, & Crockett, 2018), the use of HRV may also prove useful in measuring the firefighters' lung function while using SCBA and other breathing apparatuses.

In a study by Oka et al. (2021) the researchers investigated the applicability of using HRV analysis to improve firefighter occupational safety, using a threshold for firefighters to stop their activity immediately and recover. The researchers used the RIR as a means to determine the physiological stress of the firefighting activities. The study found that RIR parameters predicted increased perceived physiological stress and may provide valuable insight into the recovery of firefighters after strenuous emergency duties. The use of HRV to determine RIR shows additional usefulness and versatility in measuring and/or determining physiological stress that firefighters routinely face. Higher RIR may indicate the onset of anaerobiosis, which is indicative of high physiological strain (Oka et al., 2021; Vlasenko, 2020). Earlier onset of anaerobiosis will cause the earlier onset of fatigue, severely limiting occupational performance.

Physiological Demands and Energy Expenditure

Robertson et al. (2017) investigated the use of HRV technologies to assess the physiological demands and nutritional practices of Canadian Fire Rangers during fire deployments over a 16-hour wake period. To monitor HRV, the researchers used a BioHarness3 HRV monitor, an iPod Touch to monitor food logs, and an ActiSleep monitor to track the sleeping patterns of firefighters. The study divided fires into three classes, initial attack (most stressful and intense, short duration), project fire (prolonged, moderately- intensity) and fire base (firefighters are not on fire deployment). The results indicated that initial attack fires resulted in the highest physiological stress, and time spent in physiological recovery was lowest in

http://etd.uwc.ac.za/

this group. This provided information on the reduced parasympathetic reactivation between short and intense firefighting events and moderate-intensity prolonged firefighting events. In addition, HRV could estimate energy expenditure, which can be used by fire services to monitor the energy requirements of firefighters to ensure peak performance on duty, especially vigorous-intensity emergency duties (Robertson et al., 2017). The use of the portable monitors to track physical demands of emergency duties, and the energy expenditure of that duty, may provide additional benefits for efficient recovery in firefighters and ensure adequate nutrient intake post emergency. This may be especially useful in observing overall workload throughout the shift week.

Recovery and Heart Rate Variability

Recovery is an often-overlooked aspect in firefighters' ability to cope with the stressors of the job. Due to the strenuous nature of firefighting many firefighters routinely exceed 90% of the age predicted HR maximum (Johnson et al., 2020; Nazari, MacDermid, Sinden, & Overend, 2018; Smith, DeBlois, et al., 2016; Smith, Haller, Benedict, & Moore-merrell, 2015). Along with the vigorous nature of their occupation, firefighters contend with hazardous chemicals and fumes, extreme temperatures, and traumatic incidents (Smith et al., 2013; Smith, DeBlois, et al., 2016; Soteriades, Smith, Tsismenakis, Baur, & Kales, 2011). This places significant physical and psychological strain on firefighters throughout a shift. Monitoring firefighters that are experiencing exorbitant amounts of physical and psychological stress may provide useful information in ensuring adequate recovery.

Ebersole, Cornell, Flees, Shemelya, & Noel (2020) investigated the contribution of the autonomic nervous system to recovery in a sample of 37 male firefighters. The researchers used a Polar V800 watch and H7 monitor to collect heart rate and R-R interval data in firefighters. The HRV standard software (version 3.0; Kubios, Kuopio, Finland) was used to analyze the HRV data, specifically the RMSSD. The study reported that recovery was related to the intensity of the activity performed by the firefighters and HRV, where HRV was reduced after maximal physical exertion. Recovery was significantly lower after the 10-minute recovery period after maximal effort activities. These results may aid in prescribing adequate recovery after monitoring heart rate responses and HRV during strenuous emergency situations. Monitoring HRV will allow for adequate autonomic recovery after maximal effort activities, such as fire suppression. Biéchy et al. (2021) used HRV as a tool to measure the benefit to cardiovascular recovery using deep breathing and mental imagery in firefighters after physical stress was induced using the cooper run test. The study found that HRV could be used to accurately monitor recovery, and that deep beathing and mental imagery assisted recovery. The study highlighted the versatility of using HRV in determining the usefulness in using various recovery measures in firefighters.

Schlicht et al. (2018) investigated the effect of wrist cooling on recovery in firefighters, using HRV (Polar H7 heart rate monitor) as the recovery indicator. Although the study did not find a significance using HRV as an indicator of recovery, it did share a similar result of non-significance with rating of fatigue. This may allude to fatigue and HRV being closely related in relation to high temperature exposures. The study suggests that HRV may also be used as a long-term monitoring system, post fire suppression, to monitor firefighters' physiological recovery. However, more research needs to be conducted on this.

http://etd.uwc.ac.za/

Heat Stress and Heart Rate Variability

Heat stress is an external stress which places significant stress unto firefighters (Larsen et al., 2015; Vincent et al., 2017). Although different monitors can be used to assess heat strain on firefighters, there are specific measures of HRV that can be used to measure changes in baroceptor activity, which would suggest that HRV would provide insight into vascular activity in firefighters while performing firefighter suppression duties (Larsen et al., 2015; Malik et al., 1996; Vincent et al., 2017). Therefore, HRV provides information on vascular responses firefighters may be experiencing in these strenuous situations. Andersen et al. (2017) assessed whether firefighting activities were associated with cardiovascular effects in young trainee firefighters exposed to live fires and particulate matter (PM) while wearing appropriate Personal Protective Equipment (PPE). Cardiovascular effects were measured using reactive hyperemia index (RHI) and HRV, using the portable EndoPAT2000. The study did not find any significance between the microvascular function and HRV during any fire extinguish protocols. However, fire extinction was associated with a decrease in RHI and HRV. Specifically, a decrease in time domain HRV measures (SDNN, pNN50 and RMSSD), and associated with reduced HF power, increased LF power and increased LF/HF ratio toward sympathetic dominance. The fire exposure also increased the firefighters body temperature; however, this may be due to the increased workload, rather than heat-induced. This decrease in HRV may be related, in particular, to the increased physical exertion and physical stress associated with fire suppression in firefighters. The close relationship between HRV, particularly the LF/HF ratio, may provide valuable insight into vascular function of firefighters during fire suppression, especially when under heat stress. As established, the frequency domains are closely related to physiological phenomenon, particularly baroreceptor function (Acharya et al., 2006; Shaffer & Ginsberg, 2017).

Specific HRV measures may be applied to firefighters fulfilling different duties who may experience different physiological or psychological stressors. This may provide valuable feedback when firefighters are performing fire suppression for extended periods of time and the risk of heat exhaustion is increased.

Psychological Stress and Heart Rate Variability

As previously discussed, firefighting is a psychologically demanding occupation where firefighters are routinely exposed to life threatening situations. This requires firefighters to make spontaneous life or death decisions, perform emergency recusation, and are regularly the first responders on site to attend to vehicle collisions and other traumatic events. Research has indicated that these high stress situations are related to the development and progression of cardiovascular conditions (Carpenter et al., 2015; Gaughan et al., 2014; Smith, DeBlois, et al., 2016). These stressors that cause increased psychological load may cause increased sympathetic activation, as firefighters are in a constant state of anxiety or fear. Eventually, these stressors cause long term psychological conditions such as post-traumatic stress disorders, depression, and mental burnout (Liao et al., 2014; Shin et al., 2016; Yook, 2019). The increased sympathetic stimulation manifests as a decrease in HRV and may indicate firefighters that are experiencing severe psychological load and may need professional therapy to remain psychologically fit for active duty.

Pluntke et al. (2019) investigated the relationship between physical and psychological stress in seven firefighters using HRV. In the study, the researchers used a Polar H7 heart rate monitor and the Elite-HRV app to visually monitor, in real-time, the data streaming. The study reported that HRV was very accurate and reliable in identifying stress inducing factors and would be particularly useful in high stress

http://etd.uwc.ac.za/

occupations such as fire suppression, and particularly useful in detecting physical and mental stress. The researchers developed a model to accurately detect and classify physical and mental stress using HRV analysis in real-time. This was developed using a low cost unintrusive technology that did not hinder firefighter activity/mobility during the simulation course (Pluntke et al., 2019). However, another study conducted on similar variables contradicted these results, where the study reported that occupational stress was not significantly related to HRV in firefighters (Yook, 2019).

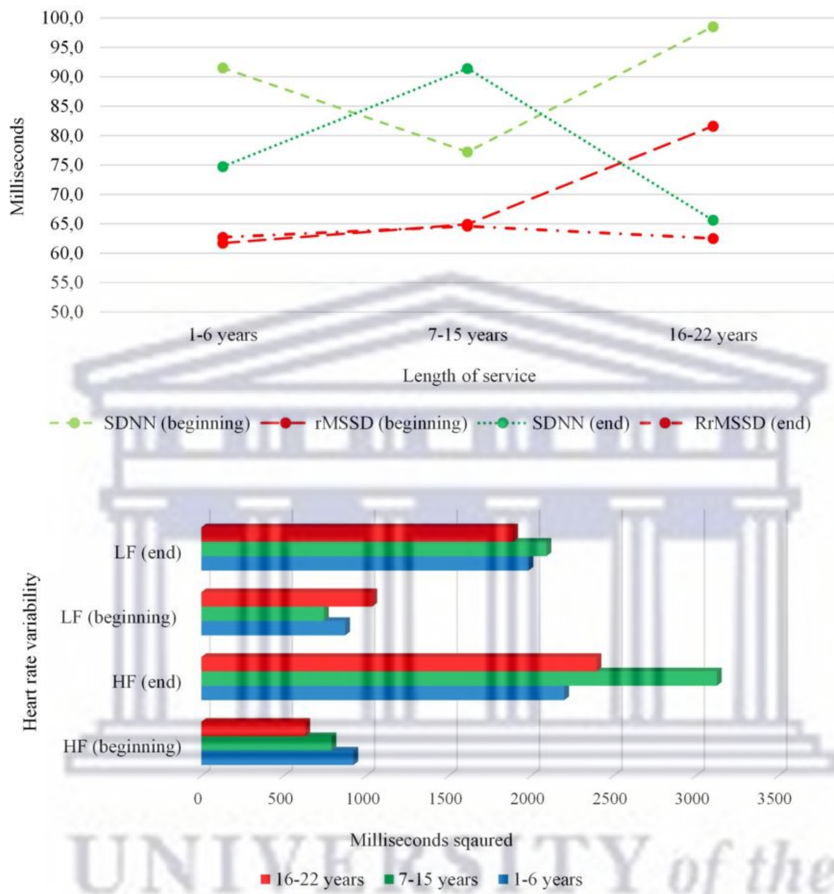
Age may be a compounding factor in this, nonetheless, firefighters with more years of experience have higher prevalence's of cardiovascular health risks, mental illnesses, and poor work ability (Airila, Hakanen, Punakallio, Lusa, & Luukkonen, 2012; Bucala & Sweet, 2019; Firoozeh, Saremi, Kavousi, & Maleki, 2017; Negm et al., 2017; Ras, Mosie, Strauss, & Leach, 2021; Saremi, fallah, Laal, Noorizade, & Rahimi, 2019). Vlasenko (2020) investigated the relationship between complex visual-motor reactions, HRV and length of service in firefighters exposed to varying workloads. The researchers used the Kredo diagnostic complex to monitor HRV. The study noted that HRV parameters were significantly different at the beginning of the work shift compared to the end of the shift. At the end of the shift, an increase in vagal effects was noted in all the service length groups. However, firefighters with 7-18 years of service experienced the most significant alterations in HRV measures (Figure 10). This suggested that all firefighters are at risk for altered HRV, regardless of age or experience levels. Firefighters may benefit from HRV monitoring that are routinely exposed to high workloads, are aged (40 years and older) and have spent an extended period as firefighters. Coincidentally, these are the demographic characteristics of firefighters that most often have underlying cardiovascular and musculoskeletal health concerns (Frost et al., 2015; Ras & Leach, 2021; Smith et al., 2013, 2019; Smith, DeBlois, et al., 2016; Soteriades, Smith, et al., 2011).

Marcel-Millet et al. (2021) investigated the psychophysiological responses of firefighters to day and night shifts using HRV. The researchers used the Hexoskin® suit to monitor HRV while performing an intermittent fitness test. Thereafter, firefighters completed the same simulated rescue intervention under three different conditions; firstly, during the day, in the morning, with a sound alarm signal (DaySA); secondly, during the night with a sound alarm signal (NightSA); and thirdly, during the night with a vibrating alarm signal (NightVA). The study by Marcel-Millet et al. (2021) reported all the HRV indices were lower in the NightSA condition in comparison to the DaySA condition. Heart rate reactivity was lower in the DaySA condition in comparison to the NightSA condition and was also lower in the NightVA condition in comparison to the NightSA condition. Additionally, they found that firefighters had a higher stress response to alarm signals during night-time simulation performance, compared to during the day. Parasympathetic reactivation after the simulation was more impaired in the night in comparison to the day. From the results of the study, night shift or 24-hour shifts may pose increased stress on firefighters and firefighters may benefit from these extended working periods or shift work. The study indicated that during night-time the risk for impaired autonomic control may be significantly increased. Night- time monitoring of HRV may prove useful to discern firefighters who are stressed, fatigued or sleepy or sluggish, which may negatively impact performance.

Susana Rodrigues, Paiva, Dias, & Cunha (2018), investigated HRV during a conventional shift week. Heart rate variability was measured using a VitalJacket® and data was collected onto a smartphone us- ing a software application designed for the VitalJacket®. The study used the AVNN heart beats and the LF/HF ratio. The results showed that fires were the most common emergency, however, accidents were the more stressful situation, causing abnormalities in HRV. Fire services often divide the core duties of firefighters, where many firefighters would attend to accident scenes the majority of their monthly

http://etd.uwc.ac.za/

Figure 12. Heart rate variability and length of service



UNIVERSITY of the
WESTERN CAPE

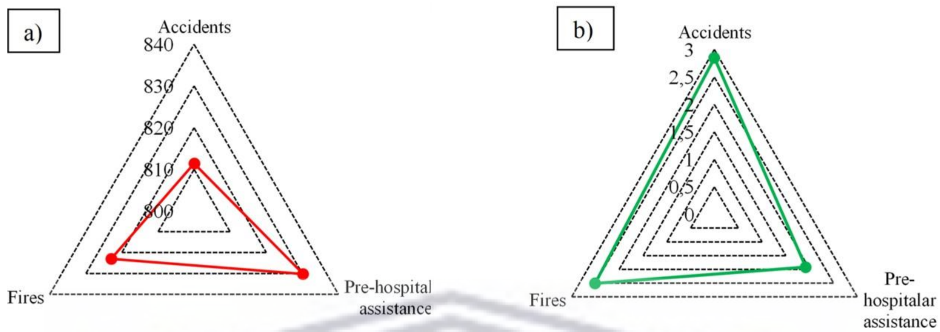
shifts (Rodrigues, et al. 2018). This would cause significant psychological strain and may account for the high prevalence of mental illness in firefighters. The use of HRV to monitor workloads in firefighters, especially during pre and post shift provides valuable information in monitoring the physiological strain firefighters experience during that particular shift. This may allow firefighters to start using flexible shifts, where firefighters that were physically overloaded on a particular shift may benefit from having a longer break between subsequent shifts.

Cognitive Performance and Heart Rate Variability

Cognitive performance is essential for acceptable occupational performance and decision making. Mental fatigue or reduced cognitive performance may prove detrimental for firefighter decision making, particularly when placed in stressful situations. Susana Rodrigues, Paiva, Dias, Pimentel, et al. (2018) investigated the applicability of using HRV to monitor the influence of stress on cognitive performance in firefighters using the VitalJacket® connected to a smartphone application. They used the Trier Social

http://etd.uwc.ac.za/

Figure 13. The difference in heart rate variability between emergency duties. a) represents AVNN in milliseconds and b) represents LF/HF ratio

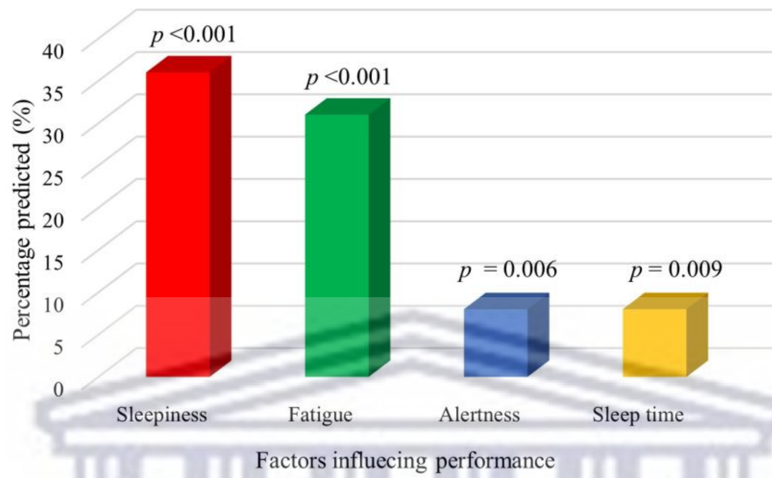


Stress Test and the 2-Choice Reaction Time Task to assess the relationship between stress, cognitive performance, and HRV. The results indicated that stress induced tasks resulted in a decrease in HRV (AVNN, SDNN and LF/HF) and was related to a decrease in cognitive performance in firefighters. Heart rate variability may provide a valuable intermediate measure to discern firefighters at risk for stress induced cognitive impairment while on duty. Another study by Susana Rodrigues, Dias, et al. (2018) investigated the relationship between stress on a typical work shift and HRV in firefighters. Similar to the previous study, the authors used the VitalJacket® to record HRV data. The researchers used AVNN, SDNN RMSSD, pNN50 and LF/HF to retrieve HRV data. The study reported that stress was significantly related to all HRV indices, and that stress significantly increased throughout firefighters shifts. Often, firefighters work double shifts, and following the general trend of the study by Rodrigues et al. would indicate that the double shifts would cause significant psychophysiological stress in firefighters (Chappel, Aisbett, Vincent, & Ridgers, 2016; Jang, Jeong, Ahn, & Choi, 2020).

Similarly, Jeklin et al. (2021) investigated the relationship between HRV and indices of fatigue, total sleep time, and reaction time in ten firefighters. The researchers used a Polar H7 heart rate monitor and a smartphone application (Elite HRV®) to monitor HRV. The computer software program Kubios HRV 2.2 was used to analyze the HRV data. Reaction time was measured using three tasks, i.e., simple reaction time (SRT), choice reaction time (CRT), and discrimination reaction time (DRT), and administered using E-prime software Version 3.0 on an ASUS tablet. Sleep was objectively measured using a triaxial actigraph/accelerometer, and levels of fatigue, alertness, and sleepiness were measured subjectively us- ing visual analogue scales (VAS). The study reported that there was no significant relationship between reaction time and HRV, however, HRV had a significant association between sleepiness, feelings of fatigue alertness and total sleep time. The study noted that HRV was a significant predictor of sleepiness (36%), fatigue (31%), alertness (8%) and sleep time (8%). No significant association was found between HRV and cognitive performance. Previous studies on HRV and reaction time indicated that reduced HRV decreased reaction time. However, in the study by Jeklin et al., there were no such relationships present. This may be due to the small sample size, and large-scale studies may provide different results.

http://etd.uwc.ac.za/

Figure 14. Prediction of factors influencing performance in firefighters



Risk Taking Behavior and Heart Rate Variability

Risk taking behavior is an important facet of firefighters that are routinely exposed to dangerous situations. Firefighters are at a higher risk for injury, or worse, in the instance that poor decisions were made while in these dangerous or life threatening situations Prell et al. (2020) investigated the relationship between HRV, risk taking behavior and resilience in firefighters. The Polar RS800CX (Polar Electro Oy, Kempele, Finland) heart rate monitor was used to record HRV, and to assess risk taking, resilience, and subjective stress, the risk-taking scale, the Resilience Scale and the multi-dimensional NASA-Task Load Index (NASA-TLX) were used, respectively. The study found that increased stress negatively affected heart rate variability, and that risk taking behavior increased as HRV decreased, indicating sympathetic dominance, and resilience was positively associated with an increase in HRV. These results indicated that firefighters that are under more stress, and have a low HRV, are more likely to make poor decisions on duty, which may cause harm to themselves or civilians. Although having a high HRV may indicate good cardiovascular and physical health, it also indicates good mental resilience in firefighters (Prell et al., 2020). In Figure 13a, LF/HF ratio had the highest prediction value of risk-taking behavior. This is expected as a ratio toward high frequency dominance indicates firefighters are more stressed and can account for the increased risky behavior in emergency situations. Healthier psychological coping mechanisms during stressful situations, and better decision making may reduce serious injuries in firefighters, as well as increase the work efficiency of firefighters. Monitoring HRV on duty, prior and during emergency situations, become increasingly important when ensuring good decision making by firefighters, especially when lives may be at risk.

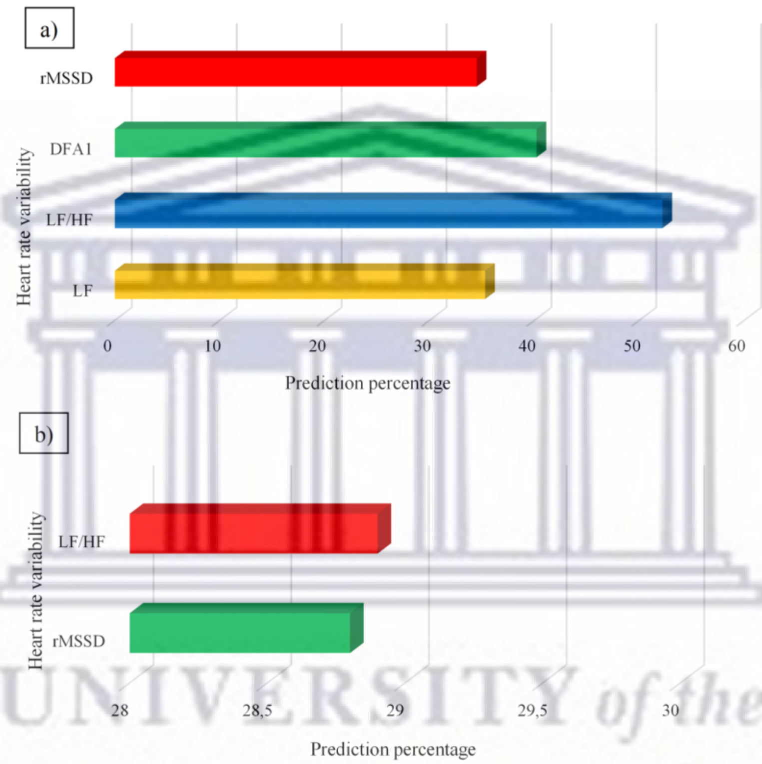
Resilience and Heart Rate Variability

Firefighters are routinely exposed to traumatic events on duty which negatively affect their mental health. The ability of firefighters to cope with these traumatic events is known as resilience. Firefighters with higher resilience have better coping mechanisms, assisting in reducing the incidence of post-traumatic

http://etd.uwc.ac.za/

stress disorders, depression, and mental burnout. If firefighters develop their resilience, their HRV will be higher, and as a result, their decision making may improve in high-risk situations while on duty. Although resilience is a very important aspect of long-term mental health in firefighters, the ability of firefighters to adapt mentally to varying stress inducing situations may prove invaluable.

Figure 15. Predicting risk-taking behavior using heart rate variability



Schwerdtfeger & Dick (2019) investigated the psychophysiological concomitants of resilience, particularly related to HRV in every-day life in firefighters, who are routinely exposed to stressful work environments. The researchers measured psychological and contextual variables in daily life using the smartphone application movisensXS (movisens, Karlsruhe, Germany), resilience was assessed using the resilience scale, RS-25, and HRV was measured using a portable ECG that recorded continuously throughout a 24-hour work shift. Heart rate variability was analyzed using RMSSD, SDNN, LF and HF. The study notes that stressful incidents predicted reductions in both RMSSD and HF-HRV. Firefighters that had higher levels of resilience had lower negative emotions during varying stressful situations. Stressful situations were also related to reduced RMSSD, indicating that firefighters experienced vagal withdrawal and autonomic dysregulation during stressful situations (Schwerdtfeger & Dick, 2019). Firefighters that had the ability to rapidly withdraw vagal effect was a positive and protective adaptive response to the stressors placed upon them, possibly protecting their physical health in strenuous and stressful situations (Schwerdtfeger & Dick, 2019). A study reported that HRV was significantly associated with resilience

http://etd.uwc.ac.za/

in firefighters, particularly LF/HF ratio and rMSSD (Prell et al., 2020)(Figure 13b). Although having a high HRV may indicate good cardiovascular and physical health, it also indicates good mental resilience in firefighters, to allow better coping during stressful situations, and better decision making. Monitoring HRV on duty, prior and during emergency situations become increasingly important when ensuring good decision making by firefighters when in life threatening emergency situations.

Although resilience is an important aspect in firefighters coping strategies to the strenuous conditions that they routinely face, measuring this stress while firefighters are on-duty may be an important in determining those firefighters with high perceived stress based on their movements and HRV measures while on duty. Meina et al. (2020) examined the relationship between HRV and accelerometery to determine the perceived stress levels during a 24-hour work shift in 43 firefighters. The researchers used a researcher generated questionnaire, specifically designed to assess firefighters perceived stress and HRV was monitored using Equivital™ EQ-02 Life Monitor sensor belts and calculated using time domain measures, such as SDNN and rMSSD among others. The study reported that HRV was significantly related to perceived stress and motion in firefighters. The higher movements while on shift were generally related to lower HRV.

The use of HRV in firefighters, while on duty, provides a valuable psychological screening tool, where stressed induced mental fatigue may be pre-emptively noticed, and safety precautions made. In addition, the use of HRV may be used as a real time psychological and physiological monitoring system in firefighters to discriminate symptoms of chronic and acute stress in firefighters (Meina et al., 2020). Firefighters with low HRV may be at higher risk for risky behavior in emergency situations, have increased fatigue and sleepiness and reduced reaction time (Hom et al., 2016; Jeklin et al., 2021; Meina et al., 2020; Prell et al., 2020; Schwerdtfeger & Dick, 2019; Vincent et al., 2017). Future research should be conducted on establishing clear guidelines and cut-off values to indicate mental fitness for duty using this new developing technology.

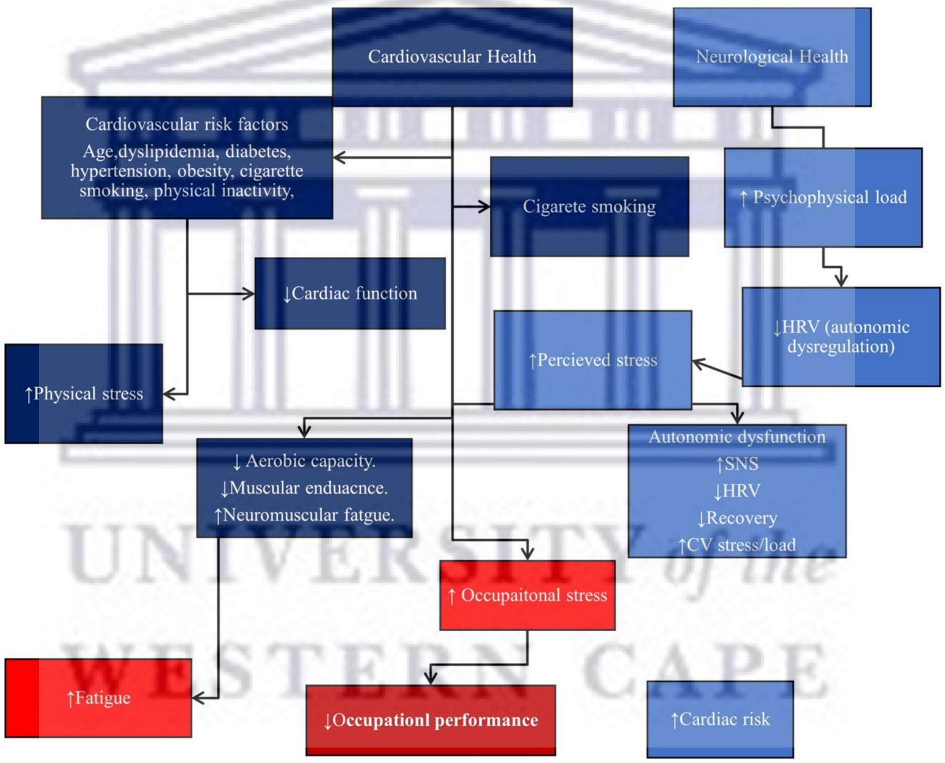
Theoretical Underpinnings Explaining the Relationship Between Coronary Artery Disease Risk Factors and Heart Rate Variability in Firefighters

Figure 16 highlights the relationship between cardiovascular, psychological health and HRV in firefighters, and is based on the previous literature discussed in the chapter. Individually, all the factors that negatively affect cardiovascular health and also affect HRV in firefighters (Mehta, 2015; Schuster et al., 2016; Sessa et al., 2018; Tomes et al., 2020). This is due to the increased physiological stress with increased number of risk factors, and the increased inflammatory responses associated with these risk factors. The combination of deteriorating cardiovascular health and reduced HRV may indicate firefighters that are not ready for active duty and may have high risk cardiovascular abnormalities present (S. Al-Zaiti et al., 2015; S. S. Al-Zaiti & Carey, 2015; Soteriades, Targino, et al., 2011). The increased cardiovascular strain and sympathetic nervous system stimulation significantly reduces cardiorespiratory capacity and muscular endurance, potentially leading to premature fatigue while on duty. Needless to say, this poses a significant risk for firefighters themselves, but also the civilians they have sworn to protect. The psychological stress and its relation to physiological health is often overlooked in relation to its influence on fatigue, occupational performance, and cardiac risk in firefighters. In the diagram, we can see the effect that increased psychological load has on HRV, which stimulates the body's fight or flight response, and increasing SNS activation. The increasing SNS stimulation, and reduced HRV, augments the cardiovascular load for the duration of fire suppression and other emergency duties and, in turn,

http://etd.uwc.ac.za/

adversely effects their cardiovascular recovery post fire suppression (S. Al-Zaiti et al., 2015; Ebersole et al., 2020; Lyytikäinen et al., 2017; Qiu et al., 2017). The subtle physiological changes, although small, significantly increase firefighters' risk for cardiac events while on duty. Heart rate variability may also be used as a means to monitor chronic fatigue and psychophysiological burnout in firefighters. Chronic fatigue and psychophysiological stress would manifest as low HRV in the absence of any pathological conditions present. The use of HRV to monitor fatigue and psychophysiological stress may be most appropriate in middle-aged firefighters, where chronic fatigue and burnout seem to be most prominent (Vaulerin, d'Arripe-Longueville, Emile, & Colson, 2016).

Figure 16. Flow diagram illustrating the possible relationship between CAD and HRV in firefighters



Physiological Factors Affecting Heart Rate Variability and Occupational Performance

As previously mentioned, physical fitness is an important factor that affects HRV in firefighters, either positively or negatively. Improved physical fitness will reduce the cardiovascular and physical stress experienced by firefighters during vigorous intensity activities (Marcel-Millet et al., 2020; Porto et al., 2019; Yook, 2019). Heat stress is an external factor that augments the physiological load experienced by firefighters, causing a decrease in HRV that remains depressed for an extended period of time post activ- ity (Schlicht et al., 2018; Smith, Horn, Woods, Ploutz-Snyder, & Fernhall, 2016; Vincent et al., 2017). It was reported that increased physical fitness was related to better thermal regulation when exposed to heat stress (Havenith & van Middendorp, 1990). The improved physical fitness may reduce the negative heat

http://etd.uwc.ac.za/

stress that firefighters experience. This is related to improved vascular functioning and improved thermo-regulatory abilities (Larsen et al., 2015; Schlicht et al., 2018; Vincent et al., 2017). Physical activity led to increased heat production as a by-product of energy metabolism (Havenith & van Middendorp, 1990; Larsen et al., 2015). For any given load, fitter firefighters will cope much better and have lower energy requirements, resulting in lower heat production compared to unfit firefighters. The lower internal heat produced by fitter firefighters will lessen the physiological strain during fire suppression duties. To the same extent, heat stress experienced by unfit firefighters will be augmented by the increased metabolic heat production in combination with the external heat stress (Havenith & van Middendorp, 1990; Larsen et al., 2015). Physical fitness also has a direct relationship to recovery in firefighters. Fitter firefighters' recovery is faster after all stressors that are placed upon them (Ebersole et al., 2020; Lyytikäinen et al., 2017). Improved recovery enhanced vagal reactivation, autonomic regulation, and thermoregulatory recovery post fire suppression (Marcel-Millet et al., 2020, 2018). Improved recovery after emergency duties may well allow better performance on concurrent strenuous emergency situations. With the use of HRV, heat stress, physical health and recovery can easily be monitored while firefighters are on duty. Resting HRV will be much higher in fitter firefighters, lower in unfit firefighters, and could be used as an early screening system for those firefighters, specifically. The physiological stress of heat on firefight- ers may be monitored while firefighters are inundated by fire suppression duties, and recovery post fire suppression, can be monitored when firefighters have completed their duties. Poorer recovery, increased HRV depression due to heat stress and reduced physical fitness manifesting as depressed HRV can be used as an early warning system to indicate firefighters at risk for injury while on duty.

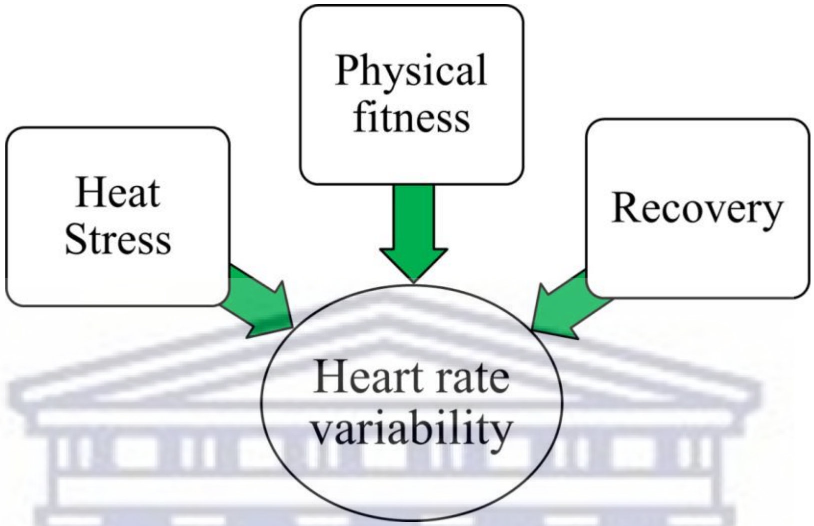
Depressed HRV is related to reduced decision-making ability in firefighters (Clifford et al., 2019; Prell et al., 2020; Schwerdtfeger & Dick, 2019). In addition, when HRV was depressed, firefighters would have riskier behavior on duty (Prell et al., 2020). This could be partially due to the increased fatigue caused by reduced HRV as a result of the increased cardiovascular strain (Marcel-Millet et al., 2020; Pluntke et al., 2019; Shin et al., 2016). Moreover, increased fatigue has been shown to reduce decision making ability (Dennison, Mullineaux, Yates, & Abel, 2012; Jeklin et al., 2021; Prell et al., 2020). Not only does higher fatigue cause poorer decision-making abilities in firefighters, but may also cause reduced physical performance while engaging in vigorous intensity duties. Premature fatigue is particularly detrimental to performance of their duties and may increase the damage to property and risk of injury and loss of life of civilians. Due to increased fatigue, performance of their duties may be significantly and negatively affected (Dennison et al., 2012; Nazari et al., 2018). Depressed HRV may adversely affect muscular force production and cardiorespiratory capacity, reducing occupational performance on duty (Dennison et al., 2012; Porto et al., 2019; Schmit & DeBeliso, 2019; Siddall, Stevenson, Turner, & Bilzon, 2018). The increased time taken to execute their duties may significantly increase the spread of fires and dam- age to property, and the risk of severe injury or death of citizens. From the literature, monitoring HRV may assist in reducing the possibility of firefighters at risk for increased risk-taking behavior, fatigue, and suboptimal occupational performance.

SOLUTIONS AND RECOMMENDATIONS

Though HRV is a relatively new technology, it has many applications and the research interest and prac-ticality of its use in firefighters has grown substantially. It is recommended that health policy makers and the health care industry advance the case for and adopt the use of HRV technology, such as ECG

http://etd.uwc.ac.za/

Figure 17. Physiological factor impacting heart rate variability and occupational performance in firefighters



smartwatches and chest straps to regularly monitor the cardiovascular health in firefighters that may be at high cardiovascular, physical, and psychological risk. Initially, those firefighters at the highest risk of suboptimal occupational performance should be monitored, and thereafter, the mobile technology should be made more freely available to all firefighters. Because of the advancements of technology and the relatively low cost of monitoring HRV in firefighters, should, in theory, be easily implemented, particularly in the younger firefighter generation. In addition, this will assist in the early detection of firefighters at risk for suboptimal occupational performance, reducing the likelihood of damage to property and civilian casualties. Moreover, this will assist in lowering the long-term costs associated with injuries, missed workdays, and medical treatment associated with the occupation, and in the long term, reduce the incidence of early retirement and on-duty fatalities in firefighters.

FUTURE RESEARCH AND INNOVATION

Future research should investigate on a longitudinal level, the use of HRV to screen the cardiovascular health of firefighters, as a means to predict physical fitness and musculoskeletal health in firefighters, as a relatively cost-effective assessment tool in firefighters. In addition, research should investigate the applicability of using this technological tool in firefighter psychophysiological stress monitoring and fitness for duty. More research should be conducted on non-invasive applications on using these mobile devices on and with firefighters, which is comfortable and does not infringe on work performance. A study conducted by (Dąbrowska, Bartkowiak, & Kotas, 2021) investigated the use of a warning system installed into smart protective clothing developed for firefighters. Although the results are promising, the research is still in its infancy, and future research should investigate the applicability of implementing mobile and wearable technology, which monitors firefighters' vital signs, in real time, which would, in theory, reduce duty related fatalities.

http://etd.uwc.ac.za/

Strengths and Practical Applications of Mobile Technology in Firefighters

This chapter illustrates the usefulness of technology in firefighters, especially for monitoring physical and psychological load. The chapter has highlighted the possibility in monitoring increased cardiovascular load in emergency situations in firefighters. In addition, the chapter has highlighted the use of mobile technology in monitoring the physical fitness levels and the psychological load in firefighters, which negatively affect their physical health, decision making ability and likelihood of risky behavior while on duty. In addition, the progressive nature of technology and research have highlighted future uses of technology in firefighters, specifically for monitoring pulmonary function, energy consumption and recovery. In a practical sense, this allows firefighters to be monitored continuously while in emergency situations, and to use HRV as an early warning system for those firefighters at increased risk for cardiovascular or psychological health concerns. Although using technology in firefighters is still in its incipiency, it provides the basis of developing an advanced monitoring system in firefighters to ensure firefighters continue to be fit and are ready for active duty.

CONCLUSION

Firefighters adopting to the use of technology has been a slow progression in the literature. Partly due to firefighters' attitudes toward not having aids to assist with their physiological monitoring on duty and the reluctance of older firefighters to adopt newer technology. Heart rate variability is a versatile technology with a plethora of uses, particularly in monitoring the cardiovascular strain as a result of firefighting and recovery post-fire suppression. In addition, HRV may be used as a monitoring system for firefighters that are categorized as high risk. Future research should focus on conducting longitudinal studies investigating the applicability of using this new technology on firefighters while on duty, both from a practical and a financial standpoint. Technology use in high-risk emergency occupations is the future and use of these technologies to ensure career health and wellness are inevitable.

UNIVERSITY of the WESTERN CAPE

REFERENCES

Acharya, U. R., Joseph, K. P., Kannathal, N., Lim, C. M., & Suri, J. S. (2006). Heart rate variability: A review. *Medical & Biological Engineering & Computing*, *44*(12), 1031–1051. doi:10.100711517-006-0119-0 PMID:17111118

Airila, A., Hakanen, J., Punakallio, A., Lusa, S., & Luukkonen, R. (2012). Is work engagement related to work ability beyond working conditions and lifestyle factors? *International Archives of Occupational and Environmental Health*, *85*(8), 915–925. doi:10.100700420-012-0732-1 PMID:22270385

Al-Zaiti, S., Rittenberger, J. C., Reis, S. E., & Hostler, D. (2015). Electrocardiographic Responses during Fire Suppression and Recovery among Experienced Firefighters. *Journal of Occupational and Environmental Medicine*, *57*(9), 938–942. doi:10.1097/JOM.0000000000000507 PMID:26340281

http://etd.uwc.ac.za/

Al-Zaiti, S. S., & Carey, M. G. (2015). The prevalence of clinical and electrocardiographic risk factors of cardiovascular death among on-duty professional firefighters. *The Journal of Cardiovascular Nursing*, *30*(5), 440–446. doi:10.1097/JCN.0000000000000165 PMID:24874885

Almeida-Santos, M. A., Barreto-Filho, J. A., Oliveira, J. L. M., Reis, F. P., da Cunha Oliveira, C. C., & Sousa, A. C. S. (2016). Aging, heart rate variability and patterns of autonomic regulation of the heart. *Archives of Gerontology and Geriatrics*, *63*, 1–8. doi:10.1016/j.archger.2015.11.011 PMID:26791165

Andersen, M. H. G., Saber, A. T., Pedersen, P. B., Loft, S., Hansen, Å. M., Koponen, I. K., Møller, P. (2017). Cardiovascular health effects following exposure of human volunteers during fire extinction exercises. *Environmental Health: A Global Access Science Source*, *16*(1), 1–9. doi:10.1186/s12940-017-0303-8

Baur, D. M., Christophi, C. A., Tsismenakis, A. J., Cook, E. F., & Kales, S. N. (2011). *Cardiorespiratory Fitness Predicts Cardiovascular Risk Profiles in Career Firefighters*. *53*(10), 1155–1160. doi:10.1097/JOM.0b013e31822c9e47

Baur, D. M., Christophi, C. A., Cook, E. F., & Kales, S. N. (2012). Age-related decline in cardiorespiratory fitness among career firefighters: Modification by physical activity and adiposity. *Journal of Obesity*, *2012*, 1–6. Advance online publication. doi:10.1155/2012/710903 PMID:22666557

Baur, D M, Leiba, A., Christophi, C. A., & Kales, S. N. (2012). Low fitness is associated with exercise abnormalities among asymptomatic firefighters. Occupational Medicine. doi:10.1093/occmed/kqs112

Biéchy, J. P., Charissou, C., Gobert, S., Verdier, J. C., Castel-Lacanal, E., Amarantini, D., & Fautrelle, L. (2021). The combination of deep breathing and mental imagery promotes cardiovascular recovery in firefighters. *Ergonomics*, *64*(10), 1231–1242. doi:10.1080/00140139.2021.1916606 PMID:33899680

Billman, G. E., Huikuri, H., Sacha, J., & Trimmel, K. (2015). An introduction to heart rate variability: Methodological considerations and clinical applications. *Frontiers in Physiology*, *6*(February), 2013–2015. doi:10.3389/fphys.2015.00055 PMID:25762937

Bonnell, E., Huggins, C., Huggins, C., McCaffrey, T., Palermo, C., & Bonham, M. (2017). Influences on Dietary Choices during Day versus Night Shift in Shift Workers: A Mixed Methods Study. *Nutrients*, *9*(3), 193. doi:10.3390/nu9030193 PMID:28245625

Bucala, M., & Sweet, E. (2019). Obesity in the fire service: An inside look at the perceptions of firefighters towards obesity and other health issues. Research Square., doi:10.21203/rs.2.15518/v1

Bugajska, J., Zużewicz, K., Szmauz-Dybko, M., & Konarska, M. (2007). Cardiovascular stress, energy expenditure and subjective perceived ratings of fire fighters during typical fire suppression and rescue tasks. *International Journal of Occupational Safety and Ergonomics*, *13*(3), 323–331. doi:10.1080/10803548.2007.11076730 PMID:17888240

Caminal, P., Sola, F., Gomis, P., Guasch, E., Perera, A., Soriano, N., & Mont, L. (2018). Validity of the Polar V800 monitor for measuring heart rate variability in mountain running route conditions. *European Journal of Applied Physiology*, *118*(3), 669–677. doi:10.100700421-018-3808-0 PMID:29356949

http://etd.uwc.ac.za/

Carey, M. G., Al-Zaiti, S. S., Dean, G. E., Sessanna, L., & Finnell, D. S. (2011). Sleep problems, depression, substance use, social bonding, and quality of life in professional firefighters. *Journal of Occupational and Environmental Medicine*, *53*(8), 928–933. doi:10.1097/JOM.0b013e318225898f PMID:21785370

Carlén, A., Nylander, E., Åström Aneq, M., & Gustafsson, M. (2019). ST/HR variables in firefighter exercise ECG – relation to ischemic heart disease. *Physiological Reports*, *7*(2), 1–10. doi:10.14814/phy2.13968 PMID:30688031

Carpenter, G. S. J., Carpenter, T. P., Kimbrel, N. A., Flynn, E. J., Pennington, M. L., Cammarata, C., Zimering, R. T., Kamholz, B. W., & Gulliver, S. B. (2015). Social support, stress, and suicidal ideation in professional firefighters. *American Journal of Health Behavior*, *39*(2), 191–196. doi:10.5993/AJHB.39.2.5 PMID:25564831

Chandel, R. S., Sharma, S., Kaur, S., Singh, S., & Kumar, R. (2021). Smart watches: A review of evolution in bio-medical sector. *Materials Today: Proceedings*.

Chappel, S. E., Aisbett, B., Vincent, G. E., & Ridgers, N. D. (2016). Firefighters' Physical Activity across Multiple Shifts of Planned Burn Work. *International Journal of Environmental Research and Public Health*, *13*(10), 973. Advance online publication. doi:10.3390/ijerph13100973 PMID:27706057

Choi, B., Ko, S., & Kojaku, S. (2017). Resting heart rate, heart rate reserve, and metabolic syndrome in professional firefighters: A cross-sectional study. *American Journal of Industrial Medicine*, *60*(10), 900–910. doi:10.1002/ajim.22752 PMID:28869309

Chuang, C., Chung, W., Shu, C., & Chen, M. (2007). Pain Assessment in Musculoskeletal Pain Patients by Heart Rate Variability. Journal of Musculoskeletal Pain. doi:10.1300/J094v15n04

Cilhoroz, B., Zaleski, A., Taylor, B., Fernhall, B., Chen, M., Thompson, P., & Pescatello, L. (2021). The ambulatory blood pressure and heart rate variability responses following sudden vigorous physical exertion among firefighters with hypertension [Hipertansiyonlu itfaiyeciler arasında ani yu¨ ksek şiddetli fiziksel efor sonrası ambulatuvar kan basıncı]. *Turkish Journal of Sports Medicine*, *56*(3), 98–105. doi:10.47447/tjsm.0492

Clifford, R. M. S., Jung, S., Hoerrnann, S., Billinqhurst, M., & Lindeman, R. W. (2019). Creating a stressful decision making environment for aerial firefighter training in virtual reality. *26th IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2019 - Proceedings*, 181–189. 10.1109/VR.2019.8797889

Cullen, S., O'Loughlin, G., McGoldrick, A., Smyth, B., May, G., & Warrington, G. D. (2015). Physiological Demands of Flat Horse Racing Jockeys. *Journal of Strength and Conditioning Research*, *29*(11), 3060–3066. doi:10.1519/JSC.0000000000000977 PMID:25932980

Dąbrowska, A., Bartkowiak, G., & Kotas, R. (2021). Evaluation of Functionality of Warning System in Smart Protective Clothing for Firefighters. *Sensors (Basel)*, *21*(5), 1767. Advance online publication. doi:10.339021051767 PMID:33806399

Dennison, K. J., Mullineaux, D. R., Yates, J. W., & Abel, M. G. (2012). The Effect of Fatigue and Training Status on Firefighter Performance. *Journal of Strength and Conditioning Research*, *26*(4), 1101–1109. doi:10.1519/JSC.0b013e31822dd027 PMID:22446677

http://etd.uwc.ac.za/

Dobson, M., Choi, B., Schnall, P. L., Wigger, E., Garcia-Rivas, J., Israel, L., & Baker, D. B. (2013). Exploring Occupational and Health Behavioral Causes of Firefighter Obesity: A Qualitative Study. *American Journal of Industrial Medicine*, *56*(7), 776–790. doi:10.1002/ajim.22151 PMID:23335437

Donovan, G. (2009).. . *Validity and Reliability of Short-Term Heart-Rate Variability from the Polar*, *S810*(January). Advance online publication. doi:10.1249/MSS.0b013e318184a4b1

Ebersole, K. T., Cornell, D. J., Flees, R. J., Shemelya, C. M., & Noel, S. E. (2020). Contribution of the Autonomic Nervous System to Recovery in Firefighters. *Journal of Athletic Training*, *55*(9), 1001–1008. doi:10.4085/1062-6050-0426.19 PMID:32841323

Farioli, A., Yang, J., Teehan, D., Baur, D. M., Smith, D. L., & Kales, S. N. (2014). Duty-related risk of sudden cardiac death among young US firefighters. *Occupational Medicine*, *64*(6), 428–435. doi:10.1093/occmed/kqu102 PMID:25104277

Feairheller, D. L. (2015). Blood pressure and heart rate responses in volunteer firefighters while wearing personal protective equipment. *Blood Pressure Monitoring*, *20*(4), 194–198. doi:10.1097/MBP.0000000000000120 PMID:25856421

Firoozeh, M., Saremi, M., Kavousi, A., & Maleki, A. (2017). Demographic and occupational determinants of the work ability of firemen. *Journal of Occupational Health*, *59*(1), 81–87. doi:10.1539/joh.15-0296-FS PMID:27916763

Frost, D. M., Beach, T. A. C., Crosby, I., & McGill, S. M. (2015). Firefighter injuries are not just a fireground problem. *Work (Reading, Mass.)*, *52*(4), 835–842. doi:10.3233/WOR-152111 PMID:26409354

Gaughan, D. M., Siegel, P. D., Hughes, M. D., Chang, C. Y., Law, B. F., Campbell, C. R., Richards, J. C., Kales, S. F., Chertok, M., Kobzik, L., Nguyen, P., O'Donnell, C. R., Kiefer, M., Wagner, G. R., & Christiani, D. C. (2014). Arterial stiffness, oxidative stress, and smoke exposure in wildland firefighters. *American Journal of Industrial Medicine*, *57*(7), 748–756. doi:10.1002/ajim.22331 PMID:24909863

Gendron, P., Lajoie, C., Laurencelle, L., & Trudeau, F. (2018). Cardiovascular Disease Risk Factors in Québec Male Firefighters. *Journal of Occupational and Environmental Medicine*, *60*(6), e300–e306. doi:10.1097/JOM.0000000000001309 PMID:29461386

Havenith, G.,& van Middendorp, H.(1990). The relative influence of physical fitness, acclimatization state, anthropometric measures and gender on individual reactions to heat stress. *European Journal of Applied Physiology and Occupational Physiology*, *61*(5), 419–427. doi:10.1007/BF00236062 PMID:2079061

Heesch, M. W. S., & Slivka, D. R. (2015). Running Performance, Pace Strategy, and Thermoregulation Differ Between a Treadmill and Indoor Track. *Journal of Strength and Conditioning Research*, *29*(2), 330–335. doi:10.1519/JSC.0000000000000662 PMID:25162647

Henriksen, A., Haugen Mikalsen, M., Woldaregay, A. Z., Muzny, M., Hartvigsen, G., Hopstock, L. A., & Grimsgaard, S. (2018). Using Fitness Trackers and Smartwatches to Measure Physical Activity in Research: Analysis of Consumer Wrist-Worn Wearables. *Journal of Medical Internet Research*, *20*(3), e110. doi:10.2196/jmir.9157 PMID:29567635

http://etd.uwc.ac.za/

Hernández-Vicente, A., Hernando, D., Marín-Puyalto, J., Vicente-Rodríguez, G., Garatachea, N., Pueyo, E., & Bailón, R. (2021). Validity of the Polar H7 Heart Rate Sensor for Heart Rate Variability Analysis during Exercise in Different Age, Body Composition and Fitness Level Groups. *Sensors (Basel)*, *21*(3), 902. Advance online publication. doi:10.339021030902 PMID:33572800

Hernando, D., Roca, S., Sancho, J., Alesanco, Á., & Bailón, R. (2018). Validation of the Apple Watch for Heart Rate Variability Measurements during Relax and Mental Stress in Healthy Subjects. *Sensors (Basel)*, *18*(8), 2619. Advance online publication. doi:10.339018082619 PMID:30103376

Hinde, K., White, G., & Armstrong, N. (2021). Wearable Devices Suitable for Monitoring Twenty Four Hour Heart Rate Variability in Military Populations. *Sensors (Basel)*, *21*(4), 1061. Advance online publication. doi:10.339021041061 PMID:33557190

Hom, M. A., Stanley, I. H., Rogers, M. L., Tzoneva, M., Bernert, R. A., & Joiner, T. E. (2016). The association between sleep disturbances and depression among firefighters: Emotion dysregulation as an explanatory factor. *Journal of Clinical Sleep Medicine*, *12*(2), 235–245. doi:10.5664/jcsm.5492 PMID:26350604

Isakadze, N., & Martin, S. S. (2020). How useful is the smartwatch ECG? *Trends in Cardiovascular Medicine*, *30*(7), 442–448. doi:10.1016/j.tcm.2019.10.010 PMID:31706789

Ito, Y., Oka, Y., & Kuriyama, Y. (2020). Applicability of the Reflection Index of Respiration Based on Heart Rate Variability Analysis to Firefighting Activity. *Fire Science & Technology*, *39*(1), 1–15. doi:10.3210/fst.39.1

Jahnke, S. A., Poston, W. S. C., Jitnarin, N., & Haddock, C. K. (2012). Health Concerns of the U.S. Fire Service: Perspectives from the Firehouse. *American Journal of Health Promotion*, *27*(2), 111–118. doi:10.4278/ajhp.110311-QUAL-109 PMID:23113781

Jang, T. W., Jeong, K. S., Ahn, Y. S., & Choi, K. S. (2020). The relationship between the pattern of shift work and sleep disturbances in Korean firefighters. *International Archives of Occupational and Environmental Health*, *93*(3), 391–398. doi:10.100700420-019-01496-3 PMID:31768636

Jeklin, A. T., Perrotta, A. S., Davies, H. W., Bredin, S. S. D., Paul, D. A., & Warburton, D. E. R. (2021). The association between heart rate variability, reaction time, and indicators of workplace fatigue in wildland firefighters. *International Archives of Occupational and Environmental Health*, *94*(5), 823–831. Advance online publication. doi:10.100700420-020-01641-3 PMID:33426591

Johnson, Q. R., Goatcher, J. D., Diehl, C., Lockie, R. G., Orr, R. M., Alvar, B., ... Dawes, J. J. (2020). Heart rate responses during simulated fire ground scenarios among full-time firefighters. *International Journal of Exercise Science*, *13*(2), 374–382. PMID:32148623

Kuorinka, I., & Korhonen, O. (1981). Firefighters' reaction to alarm, an ECG and heart rate study. *Journal of Occupational Medicine. Official Publication of the Industrial Medical Association*, *23*(11), 762–766. doi:10.1097/00043764-198111000-00010 PMID:7320775

Larsen, B., Snow, R., & Aisbett, B. (2015). Effect of heat on firefighters' work performance and physiology. *Journal of Thermal Biology*, *53*, 1–8. doi:10.1016/j.jtherbio.2015.07.008 PMID:26590449

http://etd.uwc.ac.za/

Lavie, C. J., Arena, R., Swift, D. L., Johannsen, N. M., Sui, X., Lee, D. C., Earnest, C. P., Church, T. S., O'Keefe, J. H., Milani, R. V., & Blair, S. N. (2015). Exercise and the cardiovascular system: Clinical science and cardiovascular outcomes. *Circulation Research*, *117*(2), 207–219. doi:10.1161/CIRCRESAHA.117.305205 PMID:26139859

Levels, K., de Koning, J. J., Foster, C., & Daanen, H. A. M. (2012). The effect of skin temperature on performance during a 7.5-km cycling time trial. *European Journal of Applied Physiology*, *112*(9), 3387–3395. doi:10.100700421-012-2316-x PMID:22270485

Liao, L.-M., Al-Zaiti, S. S., & Carey, M. G. (2014). Depression and heart rate variability in firefighters. *SAGE Open Medicine*, *2*. doi:10.1177/2050312114545530 PMID:26770735

Lyytikäinen, K., Toivonen, L., Hynynen, E., Lindholm, H., & Kyröläinen, H. (2017). Recovery of rescuers from a 24-h shift and its association with aerobic fitness. *International Journal of Occupational Medicine and Environmental Health*, *30*(3), 433–444. doi:10.13075/ijomeh.1896.00720 PMID:28481376

Malik, M., Bigger, J. T., Camm, A. J., Kleiger, R. E., Malliani, A., Moss, A. J., & Schwartz, P. J. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal*, *17*(3), 354–381. doi:10.1093/oxfordjournals.eurheartj.a014868 PMID:8737210

Marcel-Millet, P., Groslambert, A., Gimenez, P., Grosprêtre, S., & Ravier, G. (2021). Psychophysiological responses of firefighters to day and night rescue interventions. *Applied Ergonomics*, *95*(April), 103457. Advance online publication. doi:10.1016/j.apergo.2021.103457 PMID:33984583

Marcel-Millet, P., Ravier, G., Esco, M. R., & Groslambert, A. (2020). Does firefighters' physical fitness influence their cardiac parasympathetic reactivation? Analysis with post-exercise heart rate variability and ultra-short-term measures. *International Journal of Occupational Safety and Ergonomics*, 1–9. doi:10.1080/10803548.2020.1738689 PMID:32586212

Marcel-Millet, P., Ravier, G., Grospretre, S., Gimenez, P., Freidig, S., & Groslambert, A. (2018). Physiological responses and parasympathetic reactivation in rescue interventions: The effect of the breathing apparatus. *Scandinavian Journal of Medicine & Science in Sports*, *28*(12), 2710–2722. doi:10.1111ms.13291 PMID:30171784

Marciniak, R. A., Wahl, C. A., & Ebersole, K. T. (2021). Autonomic Nervous System Response to Far-Infrared Sauna Exposure in Firefighters. *Annals of Work Exposures and Health*. Advance online publication. doi:10.1093/annweh/wxab088 PMID:34632485

Mehta, R. K. (2015). Impacts of obesity and stress on neuromuscular fatigue development and associated heart rate variability. *International Journal of Obesity*, *39*(2), 208–213. doi:10.1038/ijo.2014.127 PMID:25042859

Meina, M., Ratajczak, E., Sadowska, M., Rykaczewski, K., Dreszer, J., Bałaj, B., Biedugnis, S., Węgrzyński, W., & Krasuski, A. (2020). Heart rate variability and accelerometry as classification tools for monitoring perceived stress levels—A pilot study on firefighters. *Sensors (Switzerland)*, *20*(10), 1–21. doi:10.339020102834 PMID:32429383

http://etd.uwc.ac.za/

Morresi, N., Casaccia, S., Sorcinelli, M., Arnesano, M., & Revel, G. M. (2020). Analysing performances of heart rate variability measurement through a smartwatch. *2020 IEEE International Symposium on Medical Measurements and Applications (MeMeA)*, 1–6. 10.1109/MeMeA49120.2020.9137211

Navarro, K. M., Kleinman, M. T., Mackay, C. E., Reinhardt, T. E., Balmes, J. R., Broyles, G. A., Ott- mar, R. D., Naher, L. P., & Domitrovich, J. W. (2019). Wildland firefighter smoke exposure and risk of lung cancer and cardiovascular disease mortality. *Environmental Research*, *173*(March), 462–468. doi:10.1016/j.envres.2019.03.060 PMID:30981117

Nazari, G., MacDermid, J. C., Sinden, K. E., & Overend, T. J. (2018). The Relationship between Physical Fitness and Simulated Firefighting Task Performance. *Rehabilitation Research and Practice*, *2018*(2007), 1–7. doi:10.1155/2018/3234176

Negm, A., MacDermid, J., Sinden, K., D'Amico, R., Lomotan, M., & MacIntyre, N. J. (2017). Prevalence and distribution of musculoskeletal disorders in firefighters are influenced by age and length of service. *Journal of Military*, *Veteran and Family Health*, *3*(2), 33–41. doi:10.3138/jmvfh.2017-0002

Oka, Y., Sawaguchi, Y., Kuriyama, Y., & Ito, Y. (2021). Proposal for alert threshold for "stop activity" to improve firefighters' occupational safety based on heart rate variability analysis. *Safety Science*, *144*, 105449. doi:10.1016/j.ssci.2021.105449

Pillutla, P., Li, D., Ahmadi, N., & Budoff, M. J. (2012). Comparison of Coronary Calcium in Firefighters With Abnormal Stress Test Findings and in Asymptomatic Nonfirefighters With Abnormal Stress Test Findings. *The American Journal of Cardiology*. doi:10.1016/j.amjcard.2011.09.044

Plews, D. J., Scott, B., Altini, M., Wood, M., Kilding, A. E., & Laursen, P. B. (2017). Comparison of Heart-Rate-Variability Recording With Smartphone Photoplethysmography, Polar H7 Chest Strap, and Electrocardiography. *International Journal of Sports Physiology and Performance*, *12*(10), 1324–1328. doi:10.1123/ijspp.2016-0668 PMID:28290720

Pluntke, U., Gerke, S., Sridhar, A., Weiss, J., & Michel, B. (2019). Evaluation and Classification of Physical and Psychological Stress in Firefighters using Heart Rate Variability. *2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2207–2212. doi:10.1109/EMBC.2019.8856596

Porto, L. G. G., Schmidt, A. C. B., de Souza, J. M., Nogueira, R. M., Fontana, K. E., Molina, G. E., Korre, M., Smith, D. L., Junqueira, L. F., & Kales, S. N. (2019). Firefighters' basal cardiac autonomic function and its associations with cardiorespiratory fitness. *Work (Reading, Mass.)*, *62*(3), 485–495. doi:10.3233/WOR-192883 PMID:30909264

Prell, R., Opatz, O., Merati, G., Gesche, B., Gunga, H. C., & Maggioni, M. A. (2020). Heart Rate Variability, Risk-Taking Behavior and Resilience in Firefighters During a Simulated Extinguish-Fire Task. *Frontiers in Physiology*, *11*(July), 1–11. doi:10.3389/fphys.2020.00482 PMID:32754042

Qiu, S., Cai, X., Sun, Z., Li, L., Zuegel, M., Steinacker, J. M., & Schumann, U. (2017). *Heart Rate Recovery and Risk of Cardiovascular Events and All-Cause*. doi:10.1161/JAHA.117.005505

http://etd.uwc.ac.za/

Ras, J., & Leach, L. (2021). Prevalence of coronary artery disease risk factors in firefighters in the city of Cape Town fire and rescue service – A descriptive study. *Journal of Public Health Research*, *10*(1). doi:10.4081/jphr.2021.2000

Ras, J., Mosie, D., Strauss, M., & Leach, L. (2021). Knowledge and attitude toward health and CVD risk factors among firefighters in Cape Town, South Africa. *Journal of Public Health Research*. Advance online publication. doi:10.4081/jphr.2021.2307 PMID:34351095

Robertson, A. H., Larivière, C., Leduc, C. R., McGillis, Z., Eger, T., Godwin, A., Larivière, M., & Dorman, S. C. (2017). Novel tools in determining the physiological demands and nutritional practices of Ontario firerangers during fire deployments. *PLoS One*, *12*(1), 40–50. doi:10.1371/journal.pone.0169390 PMID:28107380

Rodrigues, S., Dias, D., Paiva, J. S., & Cunha, J. P. S. (2018). Psychophysiological Stress Assessment among On-Duty Firefighters. *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, *EMBS*, 4335–4338. doi:10.1109/EMBC.2018.8513250

Rodrigues, S., Dias, D., Paiva, J. S., & Cunha, J. P. S. (2018). Psychophysiological Stress Assessment Among On-Duty Firefighters. *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 4335–4338. doi:10.1109/EMBC.2018.8513250

Rodrigues, S., Paiva, J. S., Dias, D., & Cunha, J. P. S. (2018). Stress among on-duty firefighters: An ambulatory assessment study. *PeerJ*, *6*, e5967. doi:10.7717/peerj.5967 PMID:30581658

Rodrigues, S., Paiva, J. S., Dias, D., Pimentel, G., Kaiseler, M., & Cunha, J. P. S. (2018). Wearable Biomonitoring Platform for the Assessment of Stress and its Impact on Cognitive Performance of Firefighters: An Experimental Study. *Clinical Practice and Epidemiology in Mental Health*, *14*(1), 250–262. doi:10.2174/1745017901814010250 PMID:30972123

Saremi, M., Fallah, R., Laal, F., Noorizade, N., & Rahimi, E. (2019). Assessment of mental workload, work ability and musculoskeletal disorders of firefighters. Journal of Community Health Research. doi:10.18502/jchr.v8i3.1562

Savall, A., Charles, R., Bertholon, A., Gramont, B., Trombert, B., Barthélémy, J. C., & Roche, F. (2020). Volunteer and career French firefighters: Cardiovascular risk factors and cardiovascular risk assessment. *European Journal of Preventive Cardiology*, *27*(1), 107–109. doi:10.1177/2047487319827463 PMID:30722684

Schlicht, E., Caruso, R., Denby, K., Matias, A., Dudar, M., & Ives, S. J. (2018). Effects of Wrist Cooling on Recovery From Exercise-Induced Heat Stress With Firefighting Personal Protective Equipment. *Journal of Occupational and Environmental Medicine*, *60*(11), 1049–00. doi:10.1097/JOM.0000000000001436 PMID:30188495

Schmit, M., & DeBeliso, M. (2019). The Relationship between Firefighters' Physical Performance Aspects and Simulated Firefighting Demands. *Turkish Journal of Kinesiology*, *5*(2), 63–75. doi:10.31459/turkjkin.560623

http://etd.uwc.ac.za/

Schuster, A. K., Fischer, J. E., Thayer, J. F., Mauss, D., & Jarczok, M. N. (2016). Decreased heart rate variability correlates to increased cardiovascular risk. *International Journal of Cardiology*, *203*, 728–730. doi:10.1016/j.ijcard.2015.11.027 PMID:26587729

Schwerdtfeger, A. R., & Dick, K. (2019). Episodes of momentary resilience in daily life are associated with HRV reductions to stressful operations in firefighters: An ambulatory assessment approach using bayesian multilevel modeling. *The Journal of Positive Psychology*, *14*(5), 593–602. doi:10.1080/17439760.2018.1497689

Sessa, F., Anna, V., Messina, G., Cibelli, G., Monda, V., Marsala, G., Ruberto, M., Biondi, A., Cascio, O., Bertozzi, G., Pisanelli, D., Maglietta, F., Messina, A., Mollica, M. P., & Salerno, M. (2018). Heart rate variability as predictive factor for sudden cardiac death. *Aging (Albany NY)*, *10*(2), 166–177. doi:10.18632/aging.101386 PMID:29476045

Shaffer, F., & Ginsberg, J. P. (2017). An Overview of Heart Rate Variability Metrics and Norms. *Frontiers in Public Health*, *5*, 258. doi:10.3389/fpubh.2017.00258 PMID:29034226

Shaffer, F., Ginsberg, J. P., & Shaffer, F. (2017). An Overview of Heart Rate variability Metrics and Norms. Frontiers in Public Health. doi:10.3389/fpubh.2017.00258

Shin, J. H., Lee, J. Y., Yang, S. H., Lee, M. Y., & Chung, I. S. (2016). Factors related to heart rate variability among firefighters. *Annals of Occupational and Environmental Medicine*, *28*(1), 1–9. doi:10.118640557-016-0111-6 PMID:27298728

Siddall, A. G., Stevenson, R. D. M., Turner, P. J. F., & Bilzon, J. L. J. (2018). Physical and Physiological Performance Determinants of a Firefighting Simulation Test. *Journal of Occupational and Environmental Medicine*, *60*(7), 637–643. doi:10.1097/JOM.0000000000001313 PMID:29485491

Slattery, F., Johnston, K., Paquet, C., Bennett, H., & Crockett, A. (2018). The long-term rate of change in lung function in urban professional firefighters: A systematic review. *BMC Pulmonary Medicine*, *18*(1), 149. doi:10.118612890-018-0711-8 PMID:30189854

Smith, D. L., Barr, D. A., & Kales, S. N. (2013). Extreme sacrifice: Sudden cardiac death in the US Fire Service. *Extreme Physiology & Medicine*, *2*(1), 1–9. doi:10.1186/2046-7648-2-6 PMID:23849605

Smith, D. L., DeBlois, J. P., Kales, S. N., & Horn, G. P. (2016). Cardiovascular strain of firefighting and the risk of sudden cardiac events. *Exercise and Sport Sciences Reviews*, *44*(3), 90–97. doi:10.1249/JES.0000000000000081 PMID:27111479

Smith, D. L., Haller, J. M., Benedict, R., & Moore-merrell, L. (2015). *Cardiac Strain Associated with High-rise Firefighting*. doi:10.1080/15459624.2014.970272

Smith, D. L., Haller, J. M., Korre, M., Sampani, K., Porto, L. G. G., Fehling, P. C., Christophi, C. A., & Kales, S. N. (2019). The Relation of Emergency Duties to Cardiac Death Among US Firefighters. *The American Journal of Cardiology*, *123*(5), 736–741. doi:10.1016/j.amjcard.2018.11.049 PMID:30567633

Smith, D. L., Horn, G. P., Woods, J., Ploutz-Snyder, R., & Fernhall, B. (2016). Effect of Aspirin Supplementation on Hemostatic Responses in Firefighters Aged 40 to 60 Years. *The American Journal of Cardiology*, *118*(2), 275–280. doi:10.1016/j.amjcard.2016.04.032 PMID:27241836

http://etd.uwc.ac.za/

Soteriades, E. S., Smith, D. L., Tsismenakis, A. J., Baur, D. M., & Kales, S. N. (2011). (in Review). Cardiovascular disease in US firefighters: A systematic review. *Cardiology*, *19*(4), 202–215. doi:10.1097/CRD.0b013e318215c105 PMID:21646874

Soteriades, E. S., Targino, M. C., Talias, M. A., Hauser, R., Kawachi, I., Christiani, D. C., & Kales, S. N. (2011). Obesity and Risk of LVH and ECG Abnormalities in US Firefighters. *Journal of Occupational and Environmental Medicine*, *53*(8), 867–871. doi:10.1097/JOM.0b013e318221c6fe PMID:21775903

Spaccarotella, C. A. M., Polimeni, A., Migliarino, S., Principe, E., Curcio, A., Mongiardo, A., Sorrentino, S., De Rosa, S., & Indolfi, C. (2020). Multichannel Electrocardiograms Obtained by a Smartwatch for the Diagnosis of ST-Segment Changes. *JAMA Cardiology*, *5*(10), 1176–1180. doi:10.1001/jamacardio.2020.3994 PMID:32865545

Togo, F., & Takahashi, M. (2009). Heart rate variability in occupational health - A systematic review. *Industrial Health*, *47*(6), 589–602. doi:10.2486/indhealth.47.589 PMID:19996534

Tomes, C., Schram, B., & Orr, R. (2020). Relationships Between Heart Rate Variability, Occupational Performance, and Fitness for Tactical Personnel: A Systematic Review. *Frontiers in Public Health*, *8*(November), 583336. Advance online publication. doi:10.3389/fpubh.2020.583336 PMID:33240835

Vaulerin, J., d'Arripe-Longueville, F., Emile, M., & Colson, S. S. (2016). Physical exercise and burnout facets predict injuries in a population-based sample of French career firefighters. *Applied Ergonomics*, *54*, 131–135. doi:10.1016/j.apergo.2015.12.007 PMID:26851472

Vincent, G. E., Aisbett, B., Larsen, B., Ridgers, N. D., Snow, R., & Ferguson, S. A. (2017). The Impact of Heat Exposure and Sleep Restriction on Firefighters' Work Performance and Physiology during Simulated Wildfire Suppression. *International Journal of Environmental Research and Public Health*, *14*(2), 180. Advance online publication. doi:10.3390/ijerph14020180 PMID:28208688

Vlasenko, N. Yu. (2020). Peculiarities of Complex Visual–Motor Reaction and Heart Rate Variability Influenced by Working Load in Rescue Firefighters. *Human Physiology*, *46*(5), 522–530. doi:10.1134/S0362119720040143

Vyas, K., & Mcgregor, C. (2018). The use of heart rate for the assessment of firefighter resilience: A literature review. *2018 IEEE Life Sciences Conference*. *LSC*, *259–262*. Advance online publication. doi:10.1109/LSC.2018.8572095

Wallén, M. B., Hasson, D., Theorell, T., Canlon, B., & Osika, W. (2012). Possibilities and limitations of the polar RS800 in measuring heart rate variability at rest. *European Journal of Applied Physiology*, *112*(3), 1153–1165. doi:10.100700421-011-2079-9 PMID:21766225

Wulsin, L. R., Horn, P. S., Perry, J. L., Massaro, J. M., & D'Agostino, R. B. (2015). Autonomic imbalance as a predictor of metabolic risks, cardiovascular disease, diabetes, and mortality. *The Journal of Clinical Endocrinology and Metabolism*, *100*(6), 2443–2448. doi:10.1210/jc.2015-1748 PMID:26047073

Yook, Y. S. (2019). Firefighters' occupational stress and its correlations with cardiorespiratory fitness, arterial stiffness, heart rate variability, and sleep quality. *PLoS One*, *14*(12), 1–9. doi:10.1371/journal.pone.0226739 PMID:31869395

http://etd.uwc.ac.za/

Yu, C. C. W., Au, C. T., Lee, F. Y. F., So, R. C. H., Wong, J. P. S., Mak, G. Y. K., Chien, E. P., & Mc-Manus, A. M. (2015). Association between leisure time physical activity, cardiopulmonary fitness, cardiovascular risk factors, and cardiovascular workload at work in firefighters. *Safety and Health at Work*, *6*(3), 192–199. doi:10.1016/j.shaw.2015.02.004 PMID:26929827

Zimerman, A., Sheridan, B., Cooke, S., & Jena, A. B. (2020). Trends in New Diagnoses of Atrial Fibrillation after Release of an ECG-Capable Smartwatch. *Circulation*, *814–816*(8), 814–816. Advance online publication. doi:10.1161/CIRCULATIONAHA.119.045562 PMID:32833515

KEY TERMS AND DEFINITIONS

Cognitive Performance: Involves the mental ability to think critically, logically, make the correct inferences and respond swiftly and appropriately to any situation one faces.

Decision Making: The ability to make the correct decision or appropriate course of action among several alternative option, particularly while in uncertain situations, while under external pressure.

Heart Rate Variability: Is the variation in the time between each heartbeat, measures in milliseconds (ms).

Occupational Performance: Is the ability to perceive, desire, recall, plan and carry out roles, routines, tasks, and sub-tasks for the purpose of self-maintenance, productivity, leisure and rest in response to demands of the internal and/or external environment.

Physical Fitness: The ability to perform muscular work satisfactorily and include cardiovascular endurance, body composition, muscular strength, muscular endurance, and flexibility.

Physical Stress: A feeling of physical tension originating from a strenuous situation or task that places strain unto an individual's body as one attempts to overcome the strenuous challenge or physical demand.

Psychological Stress: A feeling of mental tension or strain originating from a strenuous, dangerous, or hazardous situation, between the person and the environment, that causes increased feelings of anxiety, worry, depression, anger, irritability, restlessness, and bad decision making.

Recovery: The ability of one's bodily processes to achieve a state of resting homeostasis swiftly and timeously after intense mental and physical exertion.

Resilience: The psychological ability to cope with a crisis mentally or emotionally and/or the ability to return to pre-crisis state promptly.

Risk Taking Behavior: When one consciously or non-consciously makes decision or takes action with a perceived uncertainty about its outcome, and/or about its possible benefits or costs for the physical, economic or psycho-social well-being of oneself or others.

http://etd.uwc.ac.za/

Appendix XI: Additional papers published under PhD canditure

Check for updates
pagepress
Journal of Public Health Research 2021; volume 10:2000

Article

Prevalence of coronary artery disease risk factors in firefighters in the city of Cape Town fire and rescue service – A descriptive study

Jaron Ras, Lloyd Leach

Department of Sport, Recreation and Exercise Science, Faculty of Community and Health Sciences, University of The Western Cape, Cape Town, South Africa

Abstract

Background: Over 45% of firefighter deaths are attributable to sudden cardiac death related to coronary artery disease (CAD), with many of these deaths attributed to comorbidities. The purpose of the study is to determine the prevalence of coronary artery disease (CAD) risk factors in firefighters in the City of Cape Town (CoCT).

Design and Methods: The study used a quantitative, cross-sectional and descriptive design. A total of 124 full-time firefighters were conveniently recruited between September and November 2019 from the City of Cape Town Fire and Rescue Service.

Results: The most prevalent CAD risk factors among firefighters were hypertension (33.1%), obesity (37.1%), cigarette smoking (39.5%) and dyslipidaemia (40.3%). A total of 41.9% of firefighters were categorized as low-risk, 54.8% as moderate-risk, and 3.2% as high-risk for CAD.

Conclusion: The majority of firefighters had at least one CAD risk factor, with older males having the highest prevalence of multiple CAD risk factors. Compared to other regions of the world, the (CoCT) firefighters have higher prevalence of dyslipidaemia and cigarette smoking. Preventative behavioural strategies and education on CAD should be promoted to mitigate the development of CAD.

Introduction

Over 45% of firefighter deaths are due to sudden cardiac death, with many of these deaths attributed to comorbidities.[1] Firefighting is a hazardous occupation that involves firefighters in life-threatening situations, where they are exposed to severe temperatures, tremendous cardiovascular workloads and hazardous chemicals and fumes.[1,2] These severe conditions necessitate that firefighters wear protective clothing and rescue equipment that is heavy and insulated, which puts tremendous strain on the cardiovascular system.[2,3] The majority of firefighters (67%-85%) have at least one coronary artery disease (CAD) risk factor.[1,4-6] Many firefighters have multiple CAD risk factors, thus, increasing the risk of premature morbidity and/or mortality, while on duty.[1,6,7] Previous studies found that an alarming number of firefighters were hypertensive (27%), dyslipidemic (33.3%), cigarette smokers (38%), physically inactive (49%) and obese (63%).[3,6,8-10] Viewed collectively, the hazardous conditions of firefighting, together with the excess weight of the firefighting equipment and the multiple CAD risk factors present in many firefighters, increase the likelihood of a sudden cardiac event.[1,5,6] Appropriate and timely screening of CAD risk factors will highlight the firefighters at risk, and provide data to aid in reducing firefighter casualties and the associated loss of life and property.[1,6]

Design and Methods

This study used a quantitative, cross-sectional and descriptive design. A total of 124 full-time firefighters, males and females, were conveniently recruited from the City of Cape Town Fire and Rescue Service. The demographic characteristics included were age, gender, marital status, family history of CAD, smoking and ethnicity using a researcher-generated questionnaire. The International Physical Activity Questionnaire (IPAQ) was used to measure physical activity. Ethnicity was self-reported by each participant, based upon the historical South African classification system, *i.e.*, Black, mixed ethnicity, White, Indian, and other. Ethnicity was included to encompass all demographic characteristics in the Cape Town metropolitan area. The study took place between September and November 2019. All subjects gave their informed consent for inclusion before they participated in the study. The study protocol was approved by the Ethics Committee of the Biomedical Research Ethics Committee (BMREC) at the University of the Western Cape (Ethics reference number: BM19/4/3). The study was also approved by the Chief Fire Officer of the City of Cape Town Fire and Rescue Service, as well as the Director of Policy and Strategy of the City of Cape Town. All the information obtained from the participants remained confidential. No personal information of the participants will be disclosed to the Fire Department that could compromise the confidentiality of the participants. All information regarding this research is stored securely in the SRES department, with access available to the researcher and supervisor only.

Significance for public health

This paper adds new knowledge on coronary artery disease (CAD) risk factors in firefighters, in the City of Cape Town Fire and Rescue Service. This study also provides valuable research into a scarcely studied research field. This article highlights the high prevalence of CAD risk factors present in firefighters and the general community of Cape Town, and the need for immediate corrective measures including behavioural modification to reduce these risk factors, and education on preventative measures. There is a high prevalence of CAD risk factors among firefighters, both male and female, in the Fire and Rescue Service in the City of Cape Town that likely contributes to premature morbidly and mortality in this population.

OPEN ACCESS

[Journal of Public Health Research 2021; 10:2000]

http://etd.uwc.ac.za/

Relationship Between Various Coronary Artery Disease Risk Factors in Firefighters

Jaron Ras, MSc and Lloyd Leach, PhD

Objective: To determine the correlation between the various coronary artery disease risk factors in firefighters. **Methods:** The study used a quantitative, cross-sectional, and correlational study design. A total of 124 full-time firefighters were conveniently recruited to participate. Research procedures were based on the ACSM guidelines. **Results:** Significances were found between age and body mass index (BMI) ($r = 0.42$, $P < 0.001$), age and waist circumference (WC) ($r = 0.52$, $P < 0.001$), BMI and WC ($r = 0.88$, $P < 0.001$), BMI and diastolic blood pressure (DBP) ($r = 0.48$, $P < 0.001$), between WC and DBP ($r = 0.48$, $P < 0.001$) and between gender and cigarette smoking ($\chi^2[1] = 5.66$, $P = 0.017$). **Conclusion:** There were significant strong relationships between BMI, SBP, DBP, dyslipidemia, and increasing age, especially in male firefighters. Reducing key risk factors should be emphasized.

Keywords: cardiovascular, cigarette smoking, coronary artery disease risk factors, dyslipidemia, firefighters, hypertension

Nearly 50% of firefighter fatalities are related to coronary artery disease (CAD) risk factors, with many of these CAD risk factors occurring in clusters.[1] Firefighting is a strenuous occupation, placing enormous workloads on the cardiovascular system. In performing their duties, firefighters are continually placed in life-threatening situations, where they are exposed to severe temperatures and hazardous chemicals and fumes.[1,2] Moreover, an alarmingly high percentage of firefighters have multiple CAD risk factors occurring simultaneously that increases the risk of premature morbidity and/or mortality, especially when on duty.[1,3–5] These risk factors have synergistic relationships where the increase in one risk factor leads to an increase in another.[4–6] Previous literature reported significant correlations between certain major risk factors of CAD, with a tendency of these risk factors to occur in clusters, specifically obesity, hypertension, cigarette smoking, and physical inactivity.[1,7–10] The clustering of CAD risk factors, and the catalytic effect of certain risk factors on the development of others, in combination with the severe cardiovascular workloads experienced by firefighters, as well as the exposure to extreme temperatures, and hazardous chemicals and fumes, significantly increases the likelihood of a sudden cardiac event among firefighters in the line-of-duty.[5,6,11,12] Moreover, it is suggested that risk factors increase as firefighters age, with more male firefighters at risk compared to females.[13–15] A previous study conducted in the City of Cape Town Fire and Rescue Service (CoCTFRS) reported a similar trend with age, gender, and ethnicity influencing the distribution of CAD risk factors in the population.[16] Therefore, the current study investigated the correlation between the various CAD risk factors in firefighters according to demographic characteristics, such as gender, age, and ethnicity in the CoCTFRS.

METHODS

This study used a quantitative, cross-sectional design. A total of 124 full-time firefighters, males and females, were conveniently recruited from the City of Cape Town Fire and Rescue Service (CCTFRS). The demographic characteristics and CAD risk factors of the participants were collected using a researcher-generated questionnaire, and included age, gender, ethnicity, a family history of CAD, and cigarette smoking. The International Physical Activity Questionnaire was used to measure physical activity.[17] The study protocol and ethical clearance were approved by the Biomedical Research Ethics Committee at the University of the Western Cape (Ethics reference number: BM19/4/3). Permission to conduct the study was obtained from the Chief Fire Officer of the CoCTFRS, as well as the Director of Policy and Strategy for the City of Cape Town. All subjects gave their informed consent for inclusion in the study. The study took place between September and November 2019.

Research Measures

Stature was measured using a portable stadiometer, standing barefoot on a level plastic plate with the heels together, and the heels, buttocks, and upper back aligned to the stadiometer rod, and the head in the Frankfort plane. Body mass was measured with the participant wearing minimal indoor clothing, and measured to the nearest 50 g using a precision electronic scale. Blood pressure (BP) was measured using a standard BP sphygmomanometer and stethoscope, with the appropriate cuff size. The standard auscultatory method of BP measurement was used.[18] Total cholesterol and non-fasting blood glucose were measured using the finger-prick method and analyzed with an AcuTrend® Plus GC meter. Waist circumference was measured at the point of the umbilicus,[18] between the lower costal border and top of the iliac crest, perpendicular to the long axis of the trunk. Hip circumference was taken at the level of the greatest posterior protuberance of the buttocks. Waist and hip circumferences were measured to the nearest 0.1 cm at the end of normal expiration.[19]

The cross-hand technique was used to measure all circumferences, using a steel tape measure.[18] The research instruments used for data collection were calibrated, prior to testing. A minimum test–retest reliability coefficient of 0.8 was required prior to the commencement of the study and only one tester was used for data collection in the study.[19]

Data Analysis

All data was captured by double-entry into a Microsoft Office Excel spreadsheet, and then cleaned of errors. Thereafter, it was

From the University of The Western Cape, Cape Town, Western Cape, South Africa (Mr Ras and Dr Leach).

This work is based on the research supported by wholly/in part by the National Research Foundation of South Africa (Grant Number: 117718).

The study protocol and ethical clearance was approved by the Biomedical Research Ethics Committee (BMREC) at the University of the Western Cape (Ethics reference: BM19/4/3). Permission to conduct the study was obtained from the Chief Fire Officer of City of Cape Town Fire and Rescue Service (CCTFRS), as well as the Director of Policy and Strategy for the City of Cape Town. All subjects gave their informed consent for inclusion in the study.

The authors report no conflicts of interest.

Clinical significance: There is a high correlation between certain CAD risk factors which act as catalyzers in the clustering of risk factors in firefighters that is likely linked to the premature morbidity and mortality in this demographic population. Emphasis should be placed on controlling or reducing these risk factors.

Address correspondence to: Jaron Ras, MSc, Department of Sport, Recreation and Exercise Science, University of The Western Cape, Robert Sobukwe Road, Bellville, Cape Town, 7530, South Africa (jaronras@gmail.com).

Copyright © 2021 American College of Occupational and Environmental Medicine

DOI: 10.1097/JOM.0000000000002256

Copyright © 2021 American College of Occupational and Environmental Medicine. Unauthorized reproduction of this article is prohibited

http://etd.uwc.ac.za/

Check for updates

RESEARCH ARTICLE

Predicting coronary artery disease risk in firefighters – a cross-sectional study [version 1; peer review: 1 approved with reservations]

Jaron Ras, Lloyd Leach

Department of Sport, Recreation and Exercise Science, University of The Western Cape, Cape Town, Western Cape, South Africa

v1 **First published:** 30 Jul 2021, **10**:701
https://doi.org/10.12688/f1000research.54219.1
Latest published: 30 Jul 2021, **10**:701
https://doi.org/10.12688/f1000research.54219.1

Abstract

Background: Firefighters are placed under severe cardiovascular load in performing active duty and, when carrying various coronary artery disease (CAD) risk factors, firefighters are predisposed to significant morbidity and mortality. Reducing the incidence of these risk factors is paramount. The purpose of this study is to determine the predictors of CAD risk.

Methods: This study used a quantitative, cross-sectional and correlational design. The researchers conveniently sampled 124 full-time firefighters from the City of Cape Town Fire and Rescue Service. A researcher-generated questionnaire was used to collect sociodemographic and CAD risk factors information, such as age, gender, ethnicity, family history of CAD, cigarette smoking and physical activity levels, and all research procedures were conducted according to the American College of Sports Medicine guidelines. Data collection took place between September and November 2019. Linear and logistic regression were used to determine the relationship between the various CAD risk factors and the predictors of CAD risk.

Results: Age was a significant predictor of hypertension ($p < 0.01$), dyslipidemia ($p < 0.01$), diabetes ($p < 0.01$), obesity ($p < 0.01$) and central obesity ($p < 0.01$). Gender was a significant predictor of obesity, central obesity and cigarette smoking ($p < 0.05$). Waist circumference was a significant predictor of hypertension ($p < 0.01$), dyslipidemia ($p < 0.01$) and diabetes ($p < 0.05$).

Conclusion: Age was a significant predictor of various modifiable CAD risk factors, including obesity, in both genders and all ethnicities. Attentive monitoring should be in place as firefighters age, along with behavioural modifications designed to reduce age-related increases in CAD risk factors.

Keywords
cardiovascular, CAD risk factors, age, obesity, firefighters

Open Peer Review

Approval Status ?

	1
version 1 30 Jul 2021	? view

1. **Francois Trudeau**, University of Quebec at Trois-Rivières, Trois-Rivières, Canada

Any reports and responses or comments on the article can be found at the end of the article.

http://etd.uwc.ac.za/

1874-9445/21

Send Orders for Reprints to reprints@benthamscience.net

360

The Open Public Health Journal

Content list available at: https://openpublichealthjournal.com

RESEARCH ARTICLE

Association Between Major Coronary Artery Disease Risk Factors in The City of Cape Town Firefighter and Rescue Service

Jaron Ras[1,*] and Lloyd Leach[1]

[1]Department of Sport, Recreation and Exercise Science, University of The Western Cape, Western Cape, Cape Town, South Africa

Abstract:

Background:

Many CAD risk factors occur concurrently, increasing the odds of the development of other risk factors, which is particularly seen in male and older firefighters.

Objective:

The purpose of this study was to determine the association and odds ratios between the various CAD risk factors in firefighters.

Methods:

This study used a quantitative, cross-sectional and correlational design. A total of 124 full-time firefighters, males and females, were conveniently recruited from the City of Cape Town Fire and Rescue Service. A researcher generated questionnaire was used to collect participant sociodemographic information, and all research procedures were conducted according to the ACSM guidelines. The study took place between September and November 2019.

Results:

There were significant associations between hypertension and age [$\chi^2(1) = 18.0$, $p < 0.001$, OR = 6.3 (95% CI: 2.6, 15.5)], hypertension and obesity [$\chi^2(1) = 7.9$, $p = 0.005$, OR = 3.0 (95% CI: 1.4, 6.6)], hypertension and diabetes [$\chi^2(1) = 5.1$, $p = 0.040$, OR = 4.0 (95% CI: 1.1, 14.8)], and hypertension and dyslipidaemia [$\chi^2(1) = 8.5$, $p = 0.004$, OR = 3.1 (95% CI: 1.4, 6.7)], family history and central obesity [$\chi^2(1) = 3.9$, $p = 0.04$, OR = 2.4 (95% CI: 0.9, 5.8)], and family history and central obesity [$\chi^2(1) = 3.9$, $p = 0.04$, OR = 2.4 (95% CI: 0.9, 5.8)].

Conclusion:

Increased age, central obesity, hypertension and dyslipidaemia increased the odds of developing other major CAD risk factors, which was predominantly apparent in male firefighters of mixed ethnicity. The City of Cape Town Fire and Rescue Service should emphasize the mitigation of these major CAD risk factors through education and behavioural modification, especially as male firefighters aged.

Keywords: Firefighters, Coronary artery disease risk factors, Cardiovascular, Dyslipidaemia, Cigarette smoking, Hypertension, Obesity.

Article History	Received: March 09, 2021	Revised: May 26, 2021	Accepted: June 06, 2021

1. INTRODUCTION

Firefighting is a strenuous occupation, placing enormous workloads on the cardiovascular system. In performing their duties, firefighters are continually placed in life-threatening situations, where they are exposed to severe temperatures, and hazardous chemicals and fumes [1, 2]. Furthermore, a disconcertingly high percentage of firefighters have several CAD risk factors occurring concurrently that exacerbates the risk, not only of developing additional risk factors, but also of premature morbidity and/or mortality, especially while on duty [2 - 5]. Approximately 45% of firefighter fatalities are related to Coronary Artery (CAD) Disease Risk factors, 42% of all firefighter deaths are due to sudden cardiac death, and 39% of all firefighter deaths in the United States are due to myocardial infarctions, with many of these CAD risk factors occurring concurrently [2, 6, 7]. Previous research indicates that these concurrent CAD risk factors occur more often in male compared to female firefighters, with increasing age being a

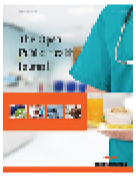
* Address correspondence to this author at Department of Sport, Recreation and Exercise Science, University of The Western Cape, Robert Sobukwe Road, Bellville, Cape Town, South Africa; Tel: 072 795 5518; E-mail: jaronras@gmail.com

DOI: 10.2174/1874944502114010360, 2021, *14*, 360-370

http://etd.uwc.ac.za/

1874-9445/22

Send Orders for Reprints to reprints@benthamscience.net



The Open Public Health Journal

Content list available at: https://openpublichealthjournal.com

RESEARCH ARTICLE

Alcohol Consumption, Physical Activity, and CAD Risk Factors in Firefighters

Jaron Ras[1,*] and Lloyd Leach[1]

[1]*Department of Sport, Recreation and Exercise Science, Faculty of Community and Health Sciences, University of The Western Cape, Cape Town 7530, South Africa*

Abstract:

Introduction:

Firefighting is a physically and psychologically stressful occupation, where firefighters often resort to alcohol use as a coping strategy. Firefighters are particularly vulnerable to alcohol misuse and alcohol disorders, negatively affecting their health, well-being and, possibly, work performance. Therefore, this study investigated the prevalence of alcohol consumption and its relationship with the participants' sociodemographic characteristics, weekly physical activity, and coronary artery disease (CAD) risk factors.

Methods:

This study used a quantitative, cross-sectional and descriptive design. A total of 124 full-time firefighters, males and females, were conveniently recruited from the City of Cape Town Fire and Rescue Service, South Africa, between September to November, 2020. Firefighters were then separated according to sex, age, ethnicity, and CAD risk factors. Mann-Whitney U and Kruskal-Wallis H were used to determine the statistical differences between groups, Kendall's Tau was used to assess the correlation between ordinal and continuous variables, and Chi-square to assess the association between categorical variables. A p-value of less than 0.05 was used to indicate statistical significance.

Results:

In the present study, 72.6% (n = 90) of firefighters reported consuming alcohol, of which 75.5% (n = 74) were male and 61.5% (n = 16) were female. Of this total, 40.0% (n = 44) reported that they consumed a variety of alcoholic beverages, 32.2% (n = 36) consumed beers mainly, 14.4% (n = 16) consumed spirits mainly, and 13.3% (n = 15) consumed wines mainly. In addition, 21.1% (n = 19) were categorised as moderate drinkers and 10% (n = 9) as heavy drinkers. The overall volume of alcohol consumption was significantly different between sexes and ethnicities ($p < 0.05$). In addition, the volume of alcohol consumption was significantly associated with sex, ethnicity, total low-intensity physical activity minutes, diastolic blood pressure, and hypertension ($p = 0.005$). Sex ($p = 0.021$) and ethnicity ($p = 0.042$) were significantly associated with alcohol type. The volume of alcohol consumption was a significant predictor of total low-intensity physical activity, as well as systolic ($p = 0.048$) and diastolic blood pressures ($p = 0.036$).

Conclusion:

The majority of firefighters consumed alcohol, preferred a variety of alcoholic beverages and were classified as light drinkers. Younger male firefighters consumed more alcohol than females and were more likely to be categorized as heavy drinkers. Alcohol consumption was significantly associated with sex, ethnicity, physical activity, and hypertension. Educational programs to mitigate alcohol consumption should be implemented as a preventative measure in the fire service, especially among young male firefighters.

Keywords: Firefighters, Alcohol consumption, Physical activity, CAD risk factors, Light drinkers, Heavy drinkers.

Article History	Received: April 13, 2022	Revised: August 21, 2022	Accepted: September 7, 2022

1. INTRODUCTION

Firefighting is a physically and psychologically stressful occupation, where firefighters are routinely exposed to hazardous environments, harmful chemicals and fumes. Firefighters are often the first responders to traffic collisions and are required to make life or death decisions and, sometimes, to perform emergency resuscitation [1 - 4]. Due to the hazards and stress related to the profession, firefighters are particularly vulnerable to alcohol abuse and alcohol-related disorders, which places an additional burden on an already high-risk occupational group [4 - 7].

Over fifty percent of firefighters reported excessive alcohol use and often indulged in periodic binge drinking [6]. Studies

* Address correspondence to this author at the Department of Sport, Recreation and Exercise Science, Faculty of Community and Health Sciences, University of the Western Cape, Cape Town, 7530, South Africa; E-mail: jaronras@gmail.com

DOI: 10.2174/18749445-v15-e221026-2022-73, 2022, *15*, e187494452210311

http://etd.uwc.ac.za/

Journal of Public Health Research 2022; volume 11:2307

Article

Knowledge of and attitudes toward health and cardiovascular disease risk factors among firefighters in Cape Town, South Africa

Jaron Ras, Duncan Mosie, Matthew Strauss, Lloyd Leach

Department of Sport, Recreation and Exercise Science, University of the Western Cape, Cape Town, South Africa

Abstract

Background: Firefighting is a hazardous occupation, and the firefighters' fitness for duty is affected by their knowledge of and attitudes toward their health and their relationship in the development of cardiovascular disease (CVD). The aim of this study was to assess knowledge and attitude toward health and CVD risk factors among firefighters in South Africa.

Design and Methods: The study used a cross-sectional research design. A sample of 110 firefighters, males and females, aged 18 to 65 years were conveniently sampled from the City of Cape Town Fire and Rescue Service. A researcher-generated self-administered questionnaire was completed online to obtain data from firefighters. A p-value of less than 0.05 indicated statistical significance.

Results: The results showed that 52.8% of firefighters had a poor knowledge of health, and 47.2% had a good knowledge of health, while 10% reported a negative attitude towards health and 90.0% had a positive attitude towards health. There was a significant difference between firefighters' knowledge of health and their attitudes toward health ($P<0.05$), particularly related to marital status, age, years of experience and in those with CVD risk factors ($P<0.05$). Significant correlations were found between knowledge of CVD and knowledge of health-risk behaviours ($P<0.05$).

Conclusion: Significant differences in health knowledge and attitudes toward health were present in married, aged and hypertensive firefighters. Overall health knowledge and health-risk behaviours were significant predictors of attitudes toward health.

Introduction

The emergency services provided by firefighters place high physiological demands on their bodies.[1] Firefighters are individuals who generally tend to live unhealthy lifestyles, which negatively impact their overall well-being.[2] Many firefighters do not possess sufficient knowledge on health, while many of them have developed poor attitudes toward their health, which places a tremendous burden on their fitness for duty.[3,4] There is a high prevalence of overweight and obesity among firefighters, which is indicative of a lack of appropriate knowledge or a poor attitude towards health.[3,4]

There are specific requirements that firefighters need to meet, such as being physically fit and healthy in order to perform their work safely and effectively.[2] However, current literature has indicated that many firefighters are not fit for duty, and this could be as a result of having either poor knowledge of health or poor attitudes toward health.[2,5-7]

The health of firefighters and their attitudes toward living a healthy lifestyle are vital to the community they serve.[8,9] With healthier and more adept firefighters, they will be able to attend to emergencies with greater vigour and speed, leading to less damage to property, possible prevention of loss of life, and less injuries to themselves while on duty.[10] With healthier firefighters, their families will not have to endure the potential loss of family members in the fire service, due to cardiovascular disease, which is largely preventable.[11-13]

When compared to other public safety personnel, firefighters reported the lowest health knowledge, the highest stigma, and the lowest willingness to seek professional help.[14,15] Even though professional services were made available to offer support, many firefighters opted to speak to close family members or friends rather than a healthcare professional.[14] The lack of assessing support by firefighters has resulted in an increase in their mental stress, with many showing signs of suicidal ideation.[15] The mental and physical health of firefighters are not seen as matters of extreme urgency globally, and there is little research in a South African context with regard to understanding and managing the health burdens of firefighters.

Firefighters have differing attitudes toward health, in which both positive and negative attitudes impact on their lifestyle choices.[6] Torre *et al.*[7] suggested that firefighters' attitudes toward their health, specifically toward their eating patterns, were poor. Furthermore, the barriers to healthy eating were a lack of motivation, a lack in prioritization of the diet, and/or a lack of time to prepare proper meals.[7] The study further stated that many firefighters had either heard or read about cardiovascular disease risk factors, such as obesity, diabetes and hypertension, but they still preferred to indulge in poor food choices.[7] Firefighters opt for unhealthier dietary choices, due to the perception that this behaviour does not negatively affect their health and work performance.[5] Some firefighters do have sound knowledge of good dietary practices but, due to peer pressure, opt for unhealthy food choices.[2] Even though many firefighters are at risk of cardiovascular disease, many are not well-informed about the importance of healthy lifestyles.[6] This study, therefore, aimed to assess knowledge and attitude toward

Significance for public health

This paper provides valuable information into the health knowledge and attitude toward health of firefighters in the City of Cape Town Fire and Rescue Service, particularly related to their knowledge on of cardiovascular disease (CVD) risk factors, knowledge of health-risk behaviours and attitudes toward diet and physical activity. This paper also provides information on the relationship between demographic information, such as age, years of experience, marital status and gender and health knowledge and their attitudes toward health. This paper provides new knowledge in understanding the reason for firefighters' high prevalence for CVD and CVD risk factors and the measures needed to reduce these risk factors, particularly related to increasing firefighters' attitudes toward health.

http://etd.uwc.ac.za/

Firefighters' Health Knowledge, Cardiovascular Disease Risk Factors, and Sociodemographic Characteristics as Predictors of Firefighters Attitudes Toward Health

Jaron Ras, MSc and Lloyd Leach, PhD

Objective: The aim of the study is to determine the predictors of firefighters' attitudes toward health based on firefighters' knowledge cardiovascular disease (CVD) risk factors and sociodemographic characteristics. **Methods:** The study used a web-based cross-sectional, descriptive, and correlational research design. Convenience sampling was used to recruit 110 firefighters, males, and females, aged 18 to 65 years. **Results:** Firefighters' health knowledge, age group 30 to 39 years, and having CVD risk factors present were significant predictors of firefighters' attitudes toward regular aerobic exercise ($P < 0.05$). Firefighters' health knowledge was a significant predictor of firefighters liking exercise to look physically fit, and health knowledge and the age group 20 to 29 and 30 to 39 years were significant predictors of firefighters liking exercise to be fit for firefighting ($P < 0.05$). **Conclusions:** Health knowledge, age group, years of experience, and having CVD risk factors present were significant predictors of firefighters' attitudes toward health.

Keywords: attitudes toward health, exercise, diet, firefighters, health knowledge, predicting

Firefighting is considered one of the most physically demanding occupations globally and one of the most demanding among the emergency services.[1] For this reason, firefighters are expected to be physically fit and healthy.[2,3] However, firefighters tend to live unhealthy lifestyles and may be attributed to their questionable health knowledge and attitudes and attitudes toward health.[4] Many firefighters have been reported to be physically inactive outside of their occupation and regularly opt for unhealthy foods, while on and off duty.[1,5,6] Physical inactivity and poor dietary choices negatively impact firefighters' overall health and well-being and, subsequently, reduces their work efficiency while on duty.[1–3,6–8] This is particularly concerning in the City of Cape Town Fire and Rescue Services (CoCTFRS) where it has been reported that firefighters had a poor attitude toward their health.[4] Moreover, South African firefighters are often overworked and under significant stress,[10,11] due to the high number of informal settlements and rural fires,[12,13] and often cause them to not have time to prepare healthier foods. Over time, this may perpetuate the overall negative attitudes toward their health.[4]

Many firefighters do not possess sufficient knowledge about healthy dietary practices and weight management.[8,14] In addition, many firefighters' attitudes toward their diet were reported to be poor, with many of them facing barriers when trying to eat healthy.[8,14] In South Africa, a similar result was reported, where 52.8% of firefighters had a poor knowledge of health and 10% reported having a poor attitude toward their health. In the literature, the barriers reported confronting firefighters included a lack of time to prepare proper meals, a lack of motivation to eat healthy, and a lack of priority concerning their diet.[15] However, in South Africa, there is insufficient literature available on the most significant factors related to the knowledge and attitudes toward health of firefighters.[4] With the high prevalence of CVD risk factors present in firefighters in the CoCTFRS,[16] more research regarding their attitudes is warranted. Previous studies reported that firefighters often opted for unhealthy food choices and convenient "fast foods" while on duty, due to time constraints related to cooking "healthy meals."[1,9] In addition, many firefighters often snacked on unhealthy foods while on duty, either to relieve boredom on "slow days" or to cope with stress from emergency call outs.[1,9] This, along with the periodic high levels of physical inactivity, invariably leads to many firefighters becoming obese and developing a negative attitude toward their health.[1,5,9]

When compared with other public safety personnel, various studies reported that firefighters had the lowest health knowledge and the highest social stigma, as well as the lowest willingness to seek professional advice.[17,18] Moreover, although many firefighters were at increased risk of CVD, they were not well informed or educated about the importance of establishing and maintaining healthy lifestyles.[9] Many firefighters have heard or read about CVD risk factors, yet they still opted to indulge in their preferred, but often undesirable, dietary practices, due to peer influence and, sometimes, even peer pressure.[15] This is seen in firefighters in the CoCTFRS, where they still opted for unhealthy food choices although they knew the negative health consequences.[4] In addition, studies have indicated that many of them felt ill equipped to manage the health burden of obesity and other CVD risk factors.[9,14] Consequently, the development of CVD risk factors is a common public health burden among many of them.[19,20] This is true in a South African context, where many firefighters have a high prevalence of lifestyle-related CVD risk factors, such as hypertension, dyslipidemia, and cigarette smoking.[16]

Optimizing firefighters' health and well-being, as well as their attitudes toward living healthy lifestyles, is of paramount importance, not only to firefighters themselves but also to their families and the communities they serve.[21,22] Healthier and physically proficient firefighters will be more capable when attending to emergencies, more attentive in reducing the potential damage to property, more efficient in preventing the loss of life, and more diligent in mitigating personal injury while on duty.[23] In the fire services, generally, firefighters' health knowledge and attitudes toward health are not seen as matters of priority and importance. This is demonstrated by the scarcity of research, especially in a South African context, on the health knowledge and attitudes of firefighters.[4] In addition, because of the poor attitude of firefighters in the CoCTRFS,[4] determining the predictors of their negative attitudes may contribute significantly to literature locally and in a global context. Therefore, the aim of this study is to determine the predictors of firefighters' attitudes toward health based on firefighters' knowledge, CVD risk factors, and sociodemographic characteristics.

From the Department of Sport, Recreation and Exercise Science, University of the Western Cape, Cape Town, South Africa.
Conflict of interest: None declared.
Sources of funding: None to disclose.
Ethical Considerations and Disclosures: Ethical approval for the study was obtained from the Humanities and Social Sciences Research Ethics Committee (HSSREC) at the University of the Western Cape (ethics reference: HS20/4/27). Permission to conduct the study was obtained from the chief fire officer of City of Cape Town Fire and Rescue Service (CCTFRS), as well as the Director of Policy and Strategy for the City of Cape Town. Information about the study was provided to the participants online, and consent was obtained online for voluntary participation in the study.
Address correspondence to: Jaron Ras, MSc, Department of Sport, Recreation and Exercise Science, University of the Western Cape, Robert Sobukwe Rd, Bellville, Cape Town 7535, South Africa (jaronras@gmail.com).
Copyright © 2022 American College of Occupational and Environmental Medicine
DOI: 10.1097/JOM.0000000000002679

Copyright © 2022 American College of Occupational and Environmental Medicine. Unauthorized reproduction of this article is prohibited.

http://etd.uwc.ac.za/

Appendix XII: Turninin Report

Plagiarism Report

ORIGINALITY REPORT

12%	11%	6%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.mdpi.com Internet Source	5%
2	Amanda L. Hunter, Anoop S.V. Shah, Jeremy P. Langrish, Jennifer B. Raftis et al. "Fire Simulation and Cardiovascular Health in Firefighters", Circulation, 2017 Publication	1%
3	hdl.handle.net Internet Source	1%
4	www.journaltocs.ac.uk Internet Source	1%
5	openpublichealthjournal.com Internet Source	<1%
6	Submitted to King's College Student Paper	<1%
7	ok-em.com Internet Source	<1%
8	docplayer.net Internet Source	<1%

UNIVERSITY of the
WESTERN CAPE

http://etd.uwc.ac.za/