THESIS TITLE

Effect of Tumble Turns on Swimming Performance in Level 3 Swimmers

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Declaration

I hereby declare that "Effect of Tumble Turns on Swimming Performance in Level 3 Swimmers" is my own work, that it has not been submitted before for any other degree in any other university, and that the sources I have used have been indicated and acknowledged as complete references.

Gareth Smithdorf

November 2018

Signed

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TABLE OF CONTENTS

APPENDICES

List of Tables

List of Acronyms, Abbreviations, Units of Measurement, Statistical Units and Miscellaneous Notation

List of Acronyms

FINA	=	The Federation Internationale de Natation Amateur
RTT	=	Round Trip Time
SSA	=	Swimming South Africa
UWC	=	University of the Western Cape
WCT	=	Wall Contact Time
WP	=	Western Province

Units of Measurement

cm	=	centimetres
°	=	degrees
m	=	metre
min	=	minutes
sec	=	seconds

List of Statistical Units

B	=	beta coefficient
F	=	variance
R	=	correlation coefficient
SD	=	standard deviation
X	=	mean

ABSTRACT

Swimming, as a sport, is constantly developing, both through the resources employed in training and assessment, and through the technological development of the fundamental aspects of swimming. In the freestyle events, swimmers spend between 38% and 50% of their competition time executing turns in short pool competitions over distances that vary from 50 m to 1500 m. The importance of the turn has been noted and analyzed for several decades, where it was found that the final turn velocity was second only to mid-pool swimming velocity for determining a medal finish in the men's race. Due to the impact that the tumble turn has on swimming performance, the present study investigated the importance of the tuck index, foot-plant index and wall-contact time (WCT) on swimming performance. Therefore, the aim of this study was to determine the effect of the tuck index, foot-plant index, and WCT on the round trip time (RTT) in the tumble turn performance in level 3 swimmers in the freestyle swimming stroke. A quantitative cross-sectional and descriptive design was used in this study. A convenient sample of ten (10) swimmers were tested, five male and five female, all being level 3 swimmers affiliated to the high performance team of Swimming South Africa (SSA). Video analyses of the turns were recorded. Each subject performed thirty (30) trials, each consisting of a 50 m freestyle swim with flip turns at race pace. Descriptive statistics and multiple stepwise regression analyses were used to analyse the data. A p-value of below 0.05 indicated statistical significance. The mean tuck index was 0.57 ± 0.14°. The mean foot-plant index was 0.45 ± 0.10 cm. The mean WCT was 74.31 ± 11.57 %. The mean RTT was 2.47 ± 0.40 s. A significant negative correlation was found between tuck index and RTT ($r = -0.41$; $p < 0.05$). No significant relationship was found between foot-plant and WCT. Further regression analysis showed that the tuck index was a significant predictor of RTT ($F = 21.745$, $p < 0.001$). Following the freestyle tumble turn, the flutter kick technique remained the superior method of exiting the wall, based on the 5 m RTT. Therefore, the introduction of optimal turning practice for age-group swimmers is likely to result in significant reductions in turning times and should be noted by coaches and swimmers alike.

Keywords: swimming, tumble turn, freestyle, front crawl, performance, sport

CHAPTER ONE: STATEMENT OF THE PROBLEM

1.1 Introduction

Improving athletic performance is one of the main goals of sport biomechanics, in general, and of swimming research, in particular. This goal is more difficult to obtain, as the elite swimming level increases, thus the chances for improvement are relatively limited. However, upon closely examining key swimming aspects, such as turning, underwater gliding and stroke resumption, as well as how the relevant swimmers timing might be optimised for improving their overall swimmer performance, these factors may provide valuable information to the coach. These conditions were observed by Lyttle et al. (1999), who stated that "little changes in the performance of the turning action [of a swimmer] can produce substantial improvements in the final event time". The goal of deepening one's knowledge about the particular swimming phase can be achieved, if an accurate method is used to describe the kinematics of the above-mentioned swimming phases (Vannozi et al., 2010). The total turn time in freestyle swimming is approximately 8 sec (Rejman & Borowska, 2008). Swimming, as a sport, is constantly developing, both through the resources employed in training and assessment, and through the technological development of its fundamental aspects (Araujo et al., 2010; Mason & Cossor, 2001).

Swimming performance can be defined as the time taken to complete a race. It can be subdivided into starting, stroking and turning. Turns represent a paramount factor for determining the final performance in a swimming race (Pue et al., 2010). In the freestyle events, swimmers spend between 38% (Maglischo, 2003) and 50% (Sanches, 2000) of their competition time executing turns in short pool competitions over distances that vary from 50 m to 1500 m (Araujo et al., 2010). A successful swim turn results from a multitude of factors, and requires a complex series of moves to optimise the total turning performance (Pue et al., 2010). A race is made up of a number of key components, the free swim (where the athlete is stroking), starts, turns and finishes (Honda et al., 2010). Although the time a swimmer spends starting is less than in the free swim and turning phases, an effective start is, nevertheless, important for success (Honda et al., 2010; Miller, Hay, & Wilson, 1984). Among the mentioned swim phases, turning is one of the most critical to be analysed. In competitive swimming races, the improvement in swimming performance is related not only to the effect of stroking, but also to the execution of the start and the turn phase (Wada,Yamamoto, Jigami, Shimoyama, Wada, & Matsumoto, 2013).

The turn in freestyle swimming constitutes a major topic of discussion among researchers, and its importance in the race cannot be overstated (Araujo et al., 2010; Prins & Patz, 2006; Pereira et al., 2006; Maan˜on, Sanchez, Eiroa, Bran˜a, & Mon, 2003; Daniel, Klauck & Bieder, 2003; Little & Mason, 1997; Blanksby, Gathercole, & Marshall, 1996). Studies indicate that optimization of the turn technique can reduce swim times by at least 0.20 seconds per lap (Araujo et al., 2010; Maglischo, 2003). In aiming to achieve higher performances, swimmers should take full advantage of each component of the swimming race (Marinho et al., 2010). During the starts and turns, the gliding phase represents a critical determinant of the race component. Another interesting and less studied issue is related to the ideal depth to perform the underwater glide. Vennel et al. (2006) showed that to avoid significant wave drag, a swimmer with 0.25 m of chest depth must be deeper than 1.8 and 2.8 chest depths (which corresponds to water depths of 0.45 m and 0.70 m, respectively) below the surface for generating gliding velocities of 0.90 m/s and 2.0 m/s, respectively (Marinho et al., 2010). Lyttle et al. (1999) also showed that there was no significant wave-drag, when a typical adult swimmer was at least 0.60 m under the water surface. The underwater gliding motion during the start and turn phases are important for the total race time in modern swimming (Marinho et al., 2009).

Supplementing verbal feedback with visual feedback increases an athlete's ability to effectively make changes that positively influence performance (Slawson et al., 2010; Hume 2005; Tzetzis et al., 1999; Sanders, 1995). Feedback comes in two forms, intrinsic and extrinsic information about the technical performance. Intrinsic feedback comes from the swimmers nervous system receiving information from different receptors (Latash, 1998). Extrinsic feedback comes from a coach or camcorder giving the swimmer technical information about the performance. The extrinsic feedback (video imagery or coach) functions as a guide to learning, performing an associative function and acting as a motivator, according to Newell (1976). Technique learning is a complex process. Every swimmer has their own characteristics and tries to reproduce technical patterns to reach their highest performance. Having a better understanding of what is required, as well as the proposed modifications and the results thereof, will lead to an improvement in technique. Videography offers visual feedback about what the swimmer is doing. The velocity meter evaluates the increments in speed on the propulsive actions, as well as the decelerations caused by hydrodynamic resistance (Roig, 2010). The coach, by practically graphing the velocities from video images, will allow the swimmer to establish the direct relationship between, "What he/she feels" (sensations) with "What he/she does" (video images, execution) and "the result of what he/she does" (acceleration, deceleration, performance change) (Roig, 2010).

It is important for competitive swimmers to get the best out of every start and turn, as this may make a considerable difference in where they are placed in a race (Mason et al., 2012). Pereira et al. (2008) suggested that the ability to execute a quick and efficient turn is a vital requirement for success in swimming races (Araujo et al., 2010). Swimming turns are complex movements, being difficult to analyse without proper technology (Pereira et al., 2008). However, the proper analysis of this important phase of a swimming event is scarce, which is justified because of difficulties in analysis, and a lack of up-to-date technology (Pereira et al., 2008). It has been well-proven that the correct turn may help in improving the results of swimming performance (Rejman & Borowska, 2008). Assuming that the turns take approximately 36% of freestyle race time in a short course (Thayer and Hay, 1984), and 31% in a 50 m pool (Arellano et al., 1994), it has been proven that the reserve gained, due to correct turns, results in a clear difference in performance time (Rejman & Borowska, 2008). The time needed to cover a distance of 1500 m in a 50 m long pool (i.e., 29 turns), may be reduced by approximately 5.4 sec. (Rejman & Borowska, 2008; Chow et al., 1984).

1.2 Statement of the Problem

Swimming turns represent an important factor in determining the outcome of swimming races, with turning times correlating positively with the final event time (Chow et al., 1984). Swimming turns have been reported as comprising over one-third of the total race time in all events of 200 m and longer (Thayer & Hay, 1984). Hence, an improvement in turning technique could potentially improve event time and final position (Lyttle et al., 2000). Patz, 2005, states that the tuck index, foot-plant position, and the percentage of WCT in the active phase are kinetic factors, which have the potential to affect the turn outcome. Therefore, the purpose of this study was to determine the effect of the tuck index, foot-plant index and WCT on the tumble turn performance in level 3 swimmers for the freestyle swimming stroke.

1.3 Aim of the Study

It has been proven that the tumble turn plays an important role in a swimmers performance (Slawson et al., 2010). Therefore, the aim of this study was to determine the effect of the tuck index, foot-plant index and WCT on the RTT of the tumble turn performance in level 3 swimmers performing the freestyle swimming stroke.

1.4 Objectives of the Study

The objectives of this study were:

- To determine the optimal distance a swimmer's hips should be from the wall at foot-contact.
- To determine the optimal depth of foot-plant on the wall.
- To measure and determine the optimal percentage of WCT spent by the swimmer, when pushing-off from the wall.
- To determine the RTT of the tumble turn at race pace during freestyle swimming.

1.5 Study Hypotheses

It is hypothesized that, when executed correctly, the tumble turn with optimal tuck index, foot-plant depth and WCT will significantly improve the RTT and the swimmer's overall performance.

The execution of a tumble turn requires a swimmer to complete a series of complex movements to allow him/her to change direction. Turning technique is an important component in overall swimming performance, with turn times correlating positively with the final event times (Bahadoran et al., 2012).

1.6 Significance of the Study

The knowledge that will be generated by this study will assist in the development of the swimmers and coaches in various swimming clubs at all levels of performance. From a practical perspective, such research could be utilised by coaches for instructing swimmers about their turns, so as to facilitate effective technique in order to improve individual performance. The scientific investigation of tumble turns will attempt to assist future sport science researchers to broaden the science of swimming.

1.7 Delimitations of the Study

The delimitations of the study are divided into two categories, namely, the inclusion and exclusion criteria. The former relates to factors that determine whether participants would be included in the study, and the latter to factors that exclude participants from participating in the study.

1.7.1 Inclusion Criteria

The following inclusion criteria were applied in the study, namely:

- Subjects must be level 3 swimmers with the required qualifying times recorded on the national Swimming South Africa (SSA) database;

- Subjects must be aged from 12 to 18 years.

1.7.2 Exclusion Criteria

The following exclusion criteria were applied in the study, namely:

- Subjects must not be injured or ill when participating in the study;
- Subjects not obtaining parental consent and/or giving individual written assent for participating in the study, as well as being video-recorded.

1.8 Definitions of Terms

Foot contact: The distance from the ankle to the surface of the water, when executing the tumble turn (Patz, 2005).

Round-trip time: The time taken from a fixed distance from the wall (e.g., 5 or 7.5 m) and ends when the swimmer enters a forward somersault manouvre and places the feet on the wall for propulsion into the glide phase (Patz, 2005).

Swimming South Africa Level 3 Swimmer: This is someone who swims within a particular qualifying time for 100 m freestyle between 1 min: 02 sec – 1 min: 19 sec that is recorded on the national Swimming South Africa (SSA) database.

Tuck index: The distance from the wall at foot-contact divided by the trochanteric height, when executing the tumble turn (Patz, 2005).

Wall-contact time: The time that is initiated by the feet making contact with the pool wall and is finished at toe-off, when executing the tumble turn (Lyttle, 2000).

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This review of the literature examines the turning technique of the freestyle swimming stroke, the different ways of measuring turning performance, and the importance of turns in swimming events. Particular attention will focus on the literature related to the mechanics of the tumble turn, since these aspects of the tumble turn, namely, foot depth, tuck index and WCT are the focus of this study. The review will focus mainly on the front crawl flip turn, but relevant literature regarding turns in other strokes will also be included in the literature.

Swimming turns are an integral part of a swimmer's performance (Beckett, 1985; Newble, 1982) and often determine who will win an event (Chow et al., 1984; Thayer & Hay, 1984; Adler, 1979; Ward, 1976; Carpinter, 1968). Despite a lack of documented research into swimming turns (Blanksby, Gathercole et al., 1996; Hay, 1988), greater attention has been focussed on this aspect of swimming performance (Blanksby et al., 2004; Daniel et al., 2002; Lyttle et al., 1999; Blanksby et al., 1998; Lyttle & Mason, 1997; Blanksby, Gathercole et al., 1996; Blanksby, Hodgkinson et al., 1996 Hodgkinson & Blanksby, 1995).

Underwater force plates and videography have been two developments that have facilitated greater interest in the investigation of swimming turns (Blanksby, Hodgkinson et al., 1996; Takahashi, Yoshida et al., 1983; Nicol & Kruger, 1979). Recent investigations in swimming turns have used 5 m RTT as the criterion turn performance measurement (Blanksby et al., 2004; Blanksby et al., 1998; Blanksby, Gathercole et al., 1996; Blanksby, Hodgkinson et al., 1996). This distance is considered to adequately represent the three main phases of a turn, namely, the approach, the tumble turn and wall-contact, and the exit from the turn. Key elements of the traditional tumble turn technique that decrease turn times have been identified as more extended lower limbs (greater tuck index), decreased wall-contact times, high peak forces on the wall and an optimised push-off glide (Blanksby, Gathercole et al., 1996). These authors also emphasised the need to maintain a streamlined position for an appropriate length of time in order to optimally utilise the speed off the wall and ensure a smooth transition from the glide to the commencement of stroking.

Although several studies on swimming have shown that race performance is strongly determined by the mid-pool, free swimming performance, however, portions of the swimming events that are often excluded from scrutiny are the start, turns and finish (Vantorre et al., 2014; Arellano et al., 2010; Prins & Patz, 2006; Patz, 2005; Chatard et al., 2003; Thompson, Haljand, & Maclaren, 2000; Mason, 1999; Thayer & Hay, 1984). The importance of the turn has been noted and analyzed for several decades (Bahadoran et al., 2012; Le sage et al., 2010; Slawson et al., 2009; Patz, 2005; Chatard et al., 2003; Thompson, Haljand, & Maclaren, 2000; Mason, 1999; Thayer & Hay, 1984). Patz (2005) found that the final turn velocity was second only to the mid-pool swimming velocity for determining a medal finish in the men's race, and that both stroke length and frequency were significantly related to swimming performance.

2.2 Freestyle Turn

Any swimming race requiring the competitor to swim further than the pool length necessitates a change in direction. This act of changing direction in the water is known as a turn. Specific turn techniques exist for all the competitive strokes and medley stroke changes. The turn techniques currently used are not only considered generally the most efficient, but must comply with the rules of the stroke as set by FINA (The Federation Internationale de Natation Amateur), the international governing body of swimming. According to FINA, "Freestyle means that in an event so designated, the swimmer may swim any style, except that in individual medley or medley relay events, freestyle means any style other than backstroke, breaststroke or butterfly" (FINA, 2002-2005, p.118). The variations seen between stroke definitions and rules are also seen in the rules governing the turns for each stroke. Generally, the nature of the stroke is incorporated into the turn. For example, breaststroke requires the hands to mirror each other while swimming. Not surprisingly, the breaststroke turn and finish require both hands to touch the wall simultaneously and symmetrically. Freestyle has no specific stroke rules, hence the action of turning during freestyle simply requires some part of the swimmer touching the wall upon completion of each length and at the finish (FINA, 2002-2005, p.118). The FINA rules for freestyle swimming also state that some part of the swimmer must break the surface of the water throughout the race, except it shall be permissible for the swimmer to be completely submerged during the turn and for a distance of not more than 15m after the start and for each turn. By that point, the head must have broken the surface (FINA, 2002-2005, p.118). Therefore, the unrestricted nature of freestyle swimming allows for variation in turn techniques to exist and be developed.

2.3 Freestyle Turn Technique

While the most common freestyle turn technique used today is the tumble turn, this was not always the case (Patz, 2005). This turn technique, known as the 'open turn', started with a rotation around the longitudinal axis of the body after the push off (Webster et al., 2011). Execution of a tumble turn requires a swimmer to complete a series of complex movements to allow them to change direction. Descriptions of the tumble turn technique and performance are found to vary slightly within the literature (Bahadoran et al., 2012). Costill, Maglischo and Richardson (1992) described the process of performing a flip/tumble turn using five separate movement phases. These phases were used for the purpose of explaining the tumble turn manoeuvre within this review. Note also, that the following explanation is a description only, with no attempt made to illustrate optimal turn performance at this time. The five turn phases are the approach, the turn, the push-off, the glide, and the pull-out. The approach to the turn refers to the final strokes and preparing the body for the turn manoeuvre. Maintaining maximal swim velocity is considered an important component of the approach to the turn (Bahadoran et al., 2012; Costill et al., 1992).

According to Costill et al. (1992), the turn phase incorporates the somersault (change of direction) movement. To achieve this, the swimmer keeps the opposite arm in the water at the hip, when beginning the final arm stroke. Forward rotation of the body is initiated by flexion of the head and a simultaneous small dolphin kick, during the final arm stroke. The legs are drawn to the chest by flexing the hips and knees. This movement causes a decrease in the moment of inertia around the axis of rotation, allowing the swimmer to somersault more easily. It is desirable for the arms to be in an extended position on completion of the flip in preparation for good streamlining, during the push-off. The swimmer should also execute a slight twist by turning the head to the side, during the second half of the somersault. This allows the feet to be planted on the wall with the toes facing out-and-up in the same direction as the swimmers' body.

The push-off phase involves foot contact with the wall, leg extension and exit from the wall. Costill et al. (1992) suggest that the swimmer rotates towards a prone position, while extending the legs powerfully. The push-off should be made horizontally, and is completed by using the legs to rotate the body into a prone position, after wall-contact is lost.

The glide phase involves the swimmer maintaining a streamlined position until race-swimming velocity is approached. Several kicks may be employed at this time, after which the swimmer is ready to pull the head up through the surface using the first arm stroke.

The first arm stroke designates the beginning of the final turn phase, the pull-out. This arm stroke should be half completed when the head breaks through the water surface, after which normal swimming can be resumed. The freestyle turn description above is derived from one of many that can be obtained from the literature or coaching manuals (Per-Ludvik et al., 2010). Similarly, freestyle turns can be described and explained from a mechanical perspective (Silveira et al., 2011).

While early studies on swimming turns consisted primarily of time-based assessment (Beckett, 1985; Chow et al., 1984; Ward, 1976; Scharf & King, 1964; Fox et al., 1963; King & Irwin, 1957), more recent investigations have incorporated wall kinetics by using force platforms to examine turn performance (Blanksby et al., 2004; Daniel et al., 2002; ; Lyttle et al., 1999; Blanksby et al., 1998; Lyttle & Mason, 1997; Blanksby, Gathercole et al., 1996; Blanksby, Hodgkinson et al., 1996; Hodgkinson & Blanksby, 1995; Gathercole, 1994; Hodgkinson, 1994; Takahashi, Yoshida et al., 1983; Nicol & Kruger, 1979). Measurement of wall kinetics during turning has enabled both a comparison of turn techniques (Nicol & Kruger, 1979) and an elucidation of critical aspects of optimal wall contact during turning (Blanksby et al., 2004; Lyttle et al., 1999;   Blanksby et al., 1998; Blanksby, Gathercole et al., 1996). The current literature presents kinetic investigations into turns for all the competitive swimming strokes, ranging from untrained to trained swimmers, in all age groups, ranging from beginners to elite swimmers. Swim turns are currently categorised as one of two types, namely, a pivot turn that is preceded by a double-hand touch, as evidenced in breaststroke and butterfly, or a somersault (tumble) turn, as seen in freestyle and backstroke (Lyttle, 1999).

With respect to turn kinetics, Lyttle and Mason (1997) noted marked differences in the force profiles of the butterfly and freestyle turns. In addition, Blanksby et al. (1998) reported mean wall (foot)-contact times during breaststroke turns to be lower (0.39 s) than that found for freestyle tumble turns (0.58 s) by age-group swimmers (Gathercole, 1995). Due to the varied turn techniques and kinetics in breaststroke and butterfly relative to freestyle, kinetic studies investigating these turn types are beyond the scope of this thesis and, therefore, will not be explored in this review.

The first study to measure wall push-off kinetics during swim turns was conducted by Nicol and Kruger (1979). They attempted to achieve greater accuracy when analysing freestyle turns by using a time measuring device and a waterproofed two-dimensional (2-D) force platform. Five trained university-level swimmers (four females and one male) performed three trials with each of the following techniques: push-off with glide only; freestyle flip turn; open freestyle turn; and a flip turn with glide only. Mean velocity was calculated from time measurements between the 6 m and 3 m marks, before reaching the wall. In and out times of the swimmer, at measured intervals from the wall, were recorded, together with the horizontal impulse, during push-off. Conversion of kinetic energy from the forward movement, thus allowing the body to rotate, had no effect on maintaining swimming velocity in and out of the tumble turn (Nicol & Kruger, 1979). Conversely, the need for the leading arm to touch the wall, prior to rotation and push-off, decreased the forward swimming velocity in the open turn. As a result, the length of the glide, after push-off, and the time taken to perform the open turn were increased, because of the inability to incorporate little or no forward swimming velocity into the out-going velocity of the turn. No significant differences between the impulses, relative to the push-off and flip turn phases, were reported. Despite this, a 15% decrease in the length of the glide, following the flip turn, was observed. Nicol and Kruger (1979) cited greater resistance just after push-off, caused by incomplete body rotation after the flip turn, as the likely cause of the decreased glide length. Another explanation may be the increased resistive hydrodynamic flow, caused by the swimmer's approach, when travelling in the opposite direction to the push-off. The conclusion made by Nicol and Kruger (1979) was that the flip turn is an advantageous turn technique compared to the open turn.

Takahashi, Yoshida et al. (1983) investigated the relationship between the force generated against the wall during a turning motion, and the horizontal velocity of the swimmer after turning. Three highly trained and three recreational male swimmers of mean stature 171.0 cm and body mass 70.7 kg were asked to perform under two conditions, i.e., after a maximal push and glide from the wall, and after a flip (tumble) turn and glide from the wall, both of which were preceded by a 10 m freestyle swim approach. Three trials for each condition were performed, from which the turn force on the wall, the right knee joint angle and the horizontal swim velocity (maximal push and glide trials only) were measured. Takahashi, Yoshida et al. (1983) reported that during the tumble turn, the highly trained swimmers spent less time in contact with the wall and produced greater propulsive impulses and peak forces than the recreational swimmers. Despite substantial differences in the forces measured between the groups, secondary analysis of the raw data by Lyttle (1999) reported these differences to be statistically non-significant ($p > 0.05$). The tumble turn trials, containing greater impulse and peak forces, were accompanied with decreased WCT and greater maximum knee flexion. Wall exit velocity was not obtained from the tumble turn trials, due to measurement constraints. Therefore, the relationships between wall contact measures and exit velocity were not determined. The freestyle turn force profiles reported by Takahashi, Yoshida et al. (1983) differ from those reported in more recent research (Lyttle & Mason, 1997; Blanksby, Gathercole et al., 1996). Takahashi, Yoshida et al. (1983) showed a mean force-time curve, representing total wall-contact, to comprise a large initial peak that almost immediately decreased to zero. This impact spike was followed by a 0.08 s period of zero force, which was then followed by a tri-modal pattern of peaks that approximated two-thirds of the initial impact peak force. Force variations in the main push-off phase (tri-modal; 0.3 s) were subjectively attributed to the complicated motion of the turn (Takahashi, Yoshida et al., 1983). Various mechanical actions, such as initial foot-contact, sculling the hands, stretching the arms and rotating the trunk, were postulated as contributing factors.

The period of zero force observed by Takahashi, Yoshida et al. (1983) can only be attributed to a break in contact between the swimmer and the wall (force plate). The tri-modal force-time curves reported by Lyttle and Mason (1997) and Blanksby, Gathercole et al. (1996) indicate no break in wall-contact. Different turning techniques exhibited by current swimmers are a likely explanation for the differences observed in force-time curves between these investigations. A positive relationship was shown between the initial velocity of the swimmer's waist and the impulse generated against the wall, when calculated for all the swimmers (n = 6). Peak force, during push-off from the static start, occurred at an included knee joint angle of approximately 120º (60º of knee flexion). Similar ranges of knee angle (120 – 140º) have been reported to correspond with peak force during vertical jumping (Ae, 1982, as cited in Takahashi and Yoshida et al., 1983), and within a comparable range for knee extension (114 – 125º) that was found during maximal isokinetic contractions for dynamic peak torque (Thorstensson, Grimby, & Karlsson, 1976). The knee angle corresponding with peak force, during the tumble turn, was not reported. In summary, the findings of Takahashi, Yoshida et al. (1983) suggest that there were differences in the static start and tumble turn performance between trained (skilled) and untrained (less skilled) swimmers, which can be observed from wall kinetic and kinematic data. Furthermore, a greater impulse is applied to the wall during the static starts that resulted in greater wall exit velocity (Takahashi, Yoshida et al., 1983).

Blanksby, Hodgkinson et al. (1996) employed the use of a 2-D strain gauge force plate to measure the freestyle turn kinetics of 10 male and 9 female national level freestyle swimmers. Data was collected during 50 m freestyle sprint performances in a short course pool via two underwater video cameras and a wall-mounted force platform. Each subject performed three swim trials from which peak perpendicular force, total impulse, WCT and 50 m, 5 m and 2.5 m RTTs were recorded. Significant gender differences were observed in 11 of the 14 variables measured, which resulted in the male and female swimmers performances being considered separately. The results revealed significant ($p < 0.05$) negative correlations between the peak forces and both the 5 m and 2.5 m force-time curves, from the maximal push and glide trials, which indicated that the force increased in two increments (bi-modal) to reach a mean peak of 833 N at 0.07 s, before cessation of foot-contact (Takahashi, Yoshida et al., 1983). The trained swimmers demonstrated higher mean impulse, maximal knee flexion and exit velocity values than the recreational swimmers. In addition, significant ($p < 0.05$) RTTs were reported by the female group (r [5 m and RTT] = -0.77; r [2.5 m and RTT] = -0.84). This relationship implied that the higher peak force applied to the wall during freestyle turns contributed to the faster turn times. Furthermore, WCT was positively correlated with the 5 m and 2.5 m RTTs (r [5 m and RTT] = 0.76; r [2.5 m and RTT] = 0.81), implying that the increased WCT resulted in slower turn performance.

In contrast, no such relationships were evidenced between wall kinetics and RTTs for the male swimmers (Patz, 2005). Blanksby, Hodgkinson et al. (1996) performed multiple stepwise regression analyses to determine the predictive capabilities of the measured variables to RTTs. The results showed the increased peak force to be the sole variable to predict 2.5 m RTT for females only, and the only kinetic variable in the equation to predict 5 m RTT. In contrast, impulse was the only kinetic variable entered in both equations that predicted 50 m RTT for males, with no kinetic measures present in the 5 m and 2.5 m RTTs (Patz, 2005). The variations in turning kinetics between genders were not explained by the authors. However, Lyttle (1999) believed this result simply highlights the differences between elite male and female swimmers. Furthermore, he added that the low subject-to-independent variable ratio present in the investigation strongly limited the application of the findings to elite swimmers exclusively. Tabachnick and Fidell (1989) recommended a minimum subject-to-independent variable ratio of 5:1 for conducting multiple regressions, with higher ratios needed for stepwise regression. Wall kinetics during freestyle turns, performed by age-group swimmers, has also been examined (Bahadoran et al., 2012). Blanksby, Gathercole et al. (1996) used a 2D underwater force plate and two submerged video cameras to investigate the numerous kinetic and kinematic features of tumble turns performed by 17 male and 19 female (11 – 13 year-old) swimmers. Each subject completed three 50 m maximum effort freestyle swims in a 25 m pool on a 3-minute departure time. The wall kinetic features consisted of peak perpendicular force, total impulse and WCT. Discriminant analysis revealed no significant differences ($p > 0.05$) between the male and female performances for 5 m RTT. Hence, all subjects were pooled into one group with a sample size of 36. For the kinetic measures, Pearson product-moment correlation coefficients revealed a significant, positive relationship between the 5 m RTT and WCT. This finding implied that decreasing the WCT resulted in decreased turn times. Furthermore, significant negative correlations were shown for peak force and impulse for the 5 m RTT. Therefore, increased peak force and impulse during wall-contact resulted in decreased turn times. Blanksby, Gathercole et al. (1996) conducted stepwise multiple regression analysis to determine the best possible predictors of the 5 m RTT. The results indicated that the best predictors in order of importance were peak force, swim resumption distance; turn start distance; and swimmer stature. These five variables were found to account for 55 % of the total variance in 5 m RTT ($r = 0.775$). Peak force was the best single predictor of 5 m RTT accounting for 33 % of the variance, suggesting that increased peak force applied to the turning surface contributed appreciably to the improved turn performance. A poor subject-to-independent variable ratio in this investigation limited the results to the present sample only.

2.4 Measuring Turning Performance

Human memory systems have limitations, and it is almost impossible to remember accurately all the meaningful events that occur during an entire training session or competition (Lee, 2011). Committing information to memory and retrieving it later is a complex process with many opportunities for interference (Lee, 2011). Distinctive portions of an exceptional technical performance are often easily remembered by coaches, while non-critical events are more likely to be forgotten (Lee, 2011). This form of highlighting selective feedback, when combined with the heightened emotions and personal bias of the coach, may cause a distorted perception of the swimmer's performance in total (Franks & Maslovat, 2008).

By using a video recorder, coaches can pinpoint the relevant information and focus the swimmer's attention on specific motor events recorded (Callaway et al., 2009). The swimmer can watch the replays as many times as required, and later attempt to correct the errors highlighted by either the coach or recorded on the swimming evaluation sheet.

Appropriate definition and measurement is necessary in order to accurately quantify swim turn performances. Methods of defining and, subsequently, quantifying turn performances vary within the literature (Lyttle, 2000). Interpretation of the differences in the commencement and completion of the turn bring about this variation.

The timing of the arm stroke has been used to represent the turn in some studies (Chow et al., 1984; Hay et al., 1983). Chow et al. (1984) defined commencement of the turn as the horizontal distance between the vertex of the head of the swimmer and the wall, at the instant of last hand-entry, before initiating the turn. Similarly, turn completion was defined as the horizontal distance between the vertex of the head of the swimmer and the wall, at the instant of first-hand entry, during the first stroke after turning. This approach was believed to have greater practical relevance, as some performances could be recorded from an above-water position, as viewed by spectators (Tourny-Chollet, Chollet, Hogie & Papparodopoulos, 2002; Chow et al., 1984). Arbitrary distances have also been used to define turn commencement and completion (Lyttle et al., 1999; Blanksby et al., 1998; Lyttle & Mason, 1997; Blanksby, Gathercole et al., 1996; Blanksby, Hodgkinson et al., 1996; Thayer & Hay, 1984; Takahashi, Sakata, Tsubakimoto & Ae, 1983; Newble, 1982; Scharf & King, 1964; Fox et al., 1963; King & Irwin, 1957). Early studies (Scharf & King, 1964; King & Irwin, 1957) defined turn commencement as the moment the swimmer's hand touched the wall (once a rule requirement), and turn completion as the moment the swimmer's hand reached a mark located 5 yards (4.57 m) from the wall. Fox et al. (1963), however, considered a freestyle turn to commence 3 feet 10 inches (1.17 m) from the wall, and to end as the feet left the wall. More recently, turns have been defined as pre-determined distances in and out the wall (Patz, 2005). Several fixed distances, ranging from 3 m in to 6.5 m out (Thayer & Hay, 1984) to 7.5 m in and 7.5 m out (Lyttle & Mason, 1997) have been employed and reported in relation to turn analysis. An important consideration in determining the fixed distances when defining the turn is whether these distances encompass all of the turn movement phases (Clothier, 2004).

The 7.5 m in and 7.5 m out distances adopted by Lyttle and Mason (1997) were employed to encompass the turn preparation, rotation, gliding and stroke preparation phases of the turn. However, it is likely that fixed distances that are too large may encompass larger amounts of stroke swimming, and do not accurately reflect turning performance. Conversely, fixed distances that are too small may not completely encapsulate the results emanating from the time spent on the wall (Blanksby, Gathercole et al., 1996). Although 2.5 m in and 2.5 m out distances would most closely incorporate the turning motion, measures such as peak wall exit velocity, and swim resumption distance and velocity could not be obtained, when this distance is used. Blanksby, Gathercole et al. (1996) suggest that 5 m in and 5 m out are convenient distances over which to study turns. Also, coaches can time swimmers as they pass the backstroke flags inwards and outwards from the wall, because they are located 5 m from the wall of the pool.

Turn technique changes can, therefore, be made and assessed using time comparisons for 5 m RTT (Patz, 2005). Several other turn investigations have also favoured 5 m RTT as a criterion definition of turn performance (Blanksby et al., 2004; Lyttle et al., 1999; Blanksby et al., 1998; Blanksby, Gathercole et al., 1996; Takahashi & Sakata et al., 1983; Newble, 1982). Although the use of arm stroke timing to define turn performance may provide a specific measure of a swimmer's individual turn, comparisons between swimmers is limited, due to individual variations in turning distances that result from different turn initiations and stroke resumption distances (Lyttle, 1999). Conversely, the use of fixed and rationally chosen distances to define turn performance enables a direct comparison to be made between swimmers. Therefore, fixed distances appear to be the most objective measures of assessing turn performance, and are well-suited for comparing variations in turn techniques.

Irrespective of the method used for objectively defining turn performance, early turn research relied almost exclusively on the time taken to complete the whole turning motion as a criterion measure of performance (Scharf & King, 1964; Fox et al., 1963; King & Irwin, 1957). Fox et al. (1963) investigated the open and closed freestyle turn by comparing total turn time and the energy expenditure for each. The performances of six male subjects were examined to determine the relationship between both turns, and to ascertain which was faster and more energy-efficient. The closed turn was found to be significantly faster, despite no significant difference in energy cost between the two turns observed. The crude measurement methods utilised in these early investigations (hand-held stopwatches and tape measures) was quickly superseded with the introduction of cinematography and, more recently, videography. The introduction of these forms of measurement resulted in an increase in the accuracy of turn performance measurement.

Much of the early turn research was focussed on a comparison of the different turning techniques (Araujo et al., 2010). Schiessel (1966), as cited in Ward (1976), is reported to be the first researcher investigating freestyle flip turns. Schiessel (1966) reported results that favoured the pike turn as a superior flip turn technique. However, an assessment of the validity and reliability of Schiessel’s work remains questionable.

2.5 Importance of Turns

In a study done by Slawson et al. (2010), it was found that a 1% improvement in turning performance would affect the podium placing in the 100 m event for the first and second finishers. More significantly, it would change the entire finishing places in the 200 m event, where a 1% improvement equated to a reduction in finishing time by 0.24 s, which was greater than the time difference between each of the finishing times of each of the podium positions for this event (Slawson et al., 2010). In the case of the 200 m race, this contribution was 21% of the total race time (Slawson et al., 2010). In an article by Puel et al. (2011), they stated that the various Olympic race analyses and research studies have highlighted the importance of the turn times in the overall performance of an event. For example, in the men’s 100 m and 200 m freestyle times, both the turn-in and turn-out times contributed 21% of the race time (Arellano et al., 1994).

Chakravorti et al. (2012) stated that swimming turns have been identified as a crucial factor in overall race performance, especially in longer events. Tumble turns are frequently used in modern freestyle and backstroke events and involve a forward role approach to the wall with both feet pushing off the wall. Swimming can be defined as the time taken to complete a race and can be subdivided into starting, stroking and turning (Puel et al., 2010). The 5 m RTT is often used as a criterion value for turn time, because it represents 20% of the contribution to the overall performance in a 50 m event (Patz, 2005).

A comparison of the turn times between swimmers during competitions has also been investigated and reported in the literature (Arellano, Brown, Cappaert, & Nelson, 1994; Chow et al., 1984). Chow et al. (1984) recorded and examined the turning techniques employed by all finalists in 19 individual swimming events at the 1982 Brisbane Commonwealth Games. Turn performance was captured using two 16 mm motion picture cameras, and analysis consisted of seven performance measures. No arbitrary distances were selected to define a turn in their study. Instead, the timing of the arm stroke was used to signify initiation and completion of the turning motion. Distance-in was defined as the horizontal distance from the vertex of the head and the pool wall, at the instant the swimmer's forward-hand entered the water, during the last stroke before initiating the turn. Time-in was recorded as the duration from the point of distance-in to first-contact with the wall. Distance-out was defined as the horizontal distance from the vertex of the head and the pool wall, at the instant the swimmer completed the first stroke following the turn. Time-out was recorded as the time elapsed from the moment the swimmer first made contact with the wall to the point of distance out. Average velocity-in, velocity-out and total turn time were, subsequently, derived from these measurements. Chow et al. (1984) observed significant differences between male and female swimmers in most of the distances and velocity measures, with males exhibiting larger mean values than females in all variables. The taller males were thought to have recorded larger distances-in and -out on the basis of their physical size and, subsequent, pool position in relation to turn initiation and completion. Also, it was postulated that if the male swimmers possessed greater strength in the lower limbs, greater horizontal impulse could be generated during wall push-off that resulted in greater distance-out and velocity-out values. Therefore, known gender differences in body size (Mazza, Ackland, Bach, & Cosolito, 1994) and lower body power (Miyashita, Takahashi, Troup & Wakayoshi, 1992) between males and females appear likely to contribute to variation in turning performances, and warrant consideration in turning studies (Lyttle, 1999).

An analysis of the freestyle events demonstrated that the mean values for distance-in and average velocity tended to decrease as race distance increased, for both male and female events (Clothier, 2004). This finding was suggested to result from an increase in approach velocity to the turn, due to increased swimming velocities in the shorter events (Chow et al., 1984). It was also hypothesised that swimmers in the longer events may attempt to conserve energy by not executing their turns with maximal effort. In contrast, Hay et al. (1983) concluded that the opposing influences of approach velocity and vigour of turning effectively offset each other, and distance-in does not vary significantly with race distance. For the longer freestyle events (1500 m for males and 800 m for females), significant negative correlations were found to exist for average velocity-out with total event time and the order of finishing (Chow et al., 1984). That is, the greater the average velocity-out, the less the race time and the higher the placing. Not surprisingly the correlation between total turn time and event time for the men’s freestyle events increased with an increase in race distance (Chow et al., 1984). Thayer and Hay (1984) assessed the turn performances of male swimmers during competitions by using arbitrary distances to define turn performance. These set distances were based on earlier work (Hay et al., 1983) that identified consistent turn start and completion distances, based on arm stroke timing, over all freestyle race distances. Total turn distance was set at 9.5 m for freestyle events and comprised distance-in and distance-out lengths of 3 and 6.5 m, respectively. Turn time was defined as the time from the swimmer's head reaching the distance-in mark to the head reaching the distance-out mark. Freestyle swimming results showed that turn times increased systematically with increases in race distance, and the percentage of total race time spent turning ranged from 20.5% for the 50 yard (45.72 m) event through to 36.5% for the 1000 yard (914.4 m) events. Arellano et al. (1994) also demonstrated an increase in freestyle turn times with increased race distance, when using arbitrary distances to define turn performance. Their investigation examined the performances of elite male and female competitors in the 50, 100 and 200 m freestyle events at the 1992 Barcelona Olympic Games. Total turn distance was set at 15 m and comprised equal distance-in and distance-out lengths of 7.5 m. Turn time-in, time-out and total turn time increased with an increase in race distance from 100 to 200 m, for both male and female swimmers. The percentage of total race time spent turning also increased from 14.42% for males and 14.75% for females in the 100 m event to 21.69% and 22.02% in the 200 m event, respectively. The uses of different methods for defining turn performance (arm stroking versus fixed distances) and variations within these methods make comparisons between the investigations described above somewhat difficult and inappropriate. Nonetheless, the findings of these investigations highlight the importance of turning, and the effect that improved freestyle turn performance may have on total swim performance.

The freestyle and backstroke turns can be divided into the approach, turn, push-off, glide and pull-out phases (Webster et al 2011; Patz, 2005). The approach phase is important in order to maintain momentum into the wall. This phase is usually defined as beginning at a fixed distance from the wall (e.g., 5 or 7.5 m) and ending with both arms at the swimmer's side, prior to the forward somersault (Lyttle et al., 2000).

The rotation phase is usually initiated by flexion of the head and spine in conjunction with a pronounced dolphin (or freestyle) kick, which drives the head and shoulders downwards and raises the hips (Patz, 2005; Lyttle et al., 1998). The increased resistance experienced by the head and shoulders, as they move out of alignment with the rest of the body, together with the propulsion produced by the final kick, causes the swimmer to somersault forward (Lyttle et al., 1998).

The underwater, push-off phase has been found to be a critical aspect of the overall swimming turn (Patz, 2005). Mason and Cassor (2000) found that the most significant aspect of the turn performance was the underwater phase, including the action of pushing off from the wall. A critical variable regarding the body position at foot-contact is how far the swimmer is from the wall (Patz, 2005). In a study investigating the role of the tuck index in freestyle and backstroke flip turns, a higher tuck index at wall-contact resulted in faster RTTs (Blanksby et al., 2004).

Patz (2005) showed that a flip turn, with the feet placed too high up on the wall, would result in a push-off that was too deep. In contrast, allowing the feet to drop too low on the wall might result in surfacing too quickly (Patz, 2005; Maglisco, 2003). Maglisco (2003) recommended that the feet should hit the wall at a depth of approximately 30 to 40 cm below the water surface in order to ensure a horizontal push-off.

The wall-contact phase is initiated by both feet making contact with the pool wall, and is finished at toe-off by both feet (Riedweld & Rodeo, 2015). The degree of hip and knee flexion at wall impact varies between swimmers. Blanksby et al. (1996) found that the tuck index (the ratio of the hip-to-wall distance to total leg length) was negatively correlated with turn times.

Ideally, the angle of the knees should be in the region of 110 – 120° in the tuck index phase (Smith, 2008). A reduction in the angle of flexion at the knee (past 90º) places the quadriceps muscle group (the prime muscle group in the wall push-off) at an inefficient muscle length and this, in turn, inhibits its ability to produce maximal force quickly (Mosavi, 2012). An advantage of a greater knee angle (i.e., less flexion) is that the swimmer has to swim less distance before turning, and this can result in significant saving of time and energy, especially with multiple turns (Mosavi, 2012). Flexing the knees to any great degree after wall-contact will result in a dissipation of any stored elastic energy and an increase in the passive wall-contact phase, both of which should be discouraged (Lyttle et al., 1998). Araujo et al. (2010) found that wall-contact time and the angle of knee flexion may have a significant correlation with the total turn time. Urabe et al. (2005) found that in a vertical jump, greater activation of the vastus medialis and vastus lateralis muscles was responsible for knee extension, when near 130º of knee flexion. Such results support the findings and theories of Hay and Guimara˜es (1983), Blanksby and colleagues (Blanksby, Skender, Elliott, McElroy, & Landers, 2004; Blanksby, Simpson, Elliott, & McElroy, 1998), and Little (2000), which suggest that maximum extension torque is obtained at 100–120º of knee flexion, and that of Takahashi et al. (1982) and Ling and colleagues (Ling, Blanksby, Elliott, & McElroy, 2004), which state that the angle of knee flexion during a turn should be 120º (Araujo et al., 2010). Studies done by Hubert et al. (2003) and Payton et al. (2002) confirmed these results by identifying in their studies a tendency for better results with shorter turn times, leading to faster turns. Araujo et al. (2010) concluded that a turn executed with angles of knee flexion between 100 and 120º provides more favourable peak forces. This leads the swimmer to lose less time in the turn, without the necessity of an exaggerated application of force, with less energy spent in the execution of the skill. Takahashi, Yoshida et al. (1983) reported that the knee joint was at about 120º of flexion, when peak force was observed during the push-off phase of the tumble turn. These researchers also stated that peak force during the vertical jump was observed at a similar range of motion (120 - 140º) (Puel et al., 2010).

The glide phase incorporates maintaining a streamlined position, so as to minimize the resistive forces at higher velocities (Lyttle et al., 2000). In order to maximize the overall efficiency of the turn, it is important to reduce the deleterious drag experienced by the swimmer, during the streamlined glide. Thus, reductions in drag will translate directly into improved turn times (Patz, 2005; Lyttle, 2000). Research has shown that swimmers should aim to perform their glides at a distance of between 0.4 m and 0.5 m underwater in order to benefit from the reduced drag forces (Lyttle et al., 1998).

Performance in competitive swimming is measured by the total race time, and is made up of the sum of the times taken in starting, stroking and turning (Veiga, 2014). Therefore, gains or losses in any of these three swimming components can significantly affect a swimmer's performance (Bhurkett, 2010). In the freestyle turn, there are chances to improve swimming performance through maximising WCT and reducing drag throughout the push-off and glide phases (Lyttle & Benjanuvatra, 2004; Sanders & Byatt-Smith, 2003). In addition, minimising drag and optimising propulsion during the underwater kicking phase, prior to stroke resumption, could further enhance performance. However, a comparative lack of studies investigating underwater kicking techniques, specific to turn exits, means there is limited scientific evidence upon which underwater kick selection and technique can be based (Patz, 2005).

Methods of defining and, subsequently, quantifying swimming turn performance were found to vary within the literature (Vantore, 2014; Patz, 2005; Blanksby et al., 2004; Lyttle et al., 1999; Blanksby et al., 1998; Blanksby, Gathercole et al., 1996; Takahashi, Sakata et al., 1983). Differences in the definition of the commencement and completion of the turn bring about this variation in interpretation. Fixed arbitrary distances appear to be the preferred method for measuring swimming turns, as they provide an objective measure of turn performance, suitable for comparing variations in turning techniques (Veiga, 2014; Lyttle, 2000). The set distances of 5 m in and 5 m out of the swimming turn (i.e., 5 m RTT) have been used commonly in recent investigations (Blanksby et al., 2004; Lyttle et al., 1999; Blanksby et al., 1998; Blanksby, Gathercole et al., 1996; Takahashi, Sakata et al., 1983).

Despite a growing body of knowledge pertaining to this area of interest (Araujo et al., 2010; Patz, 2005), the majority of freestyle turn investigations have focussed predominantly on making comparisons of the total turn time and describing the kinetics of wall-contact (Araujo et al., 2010; Patz, 2005). Various authors highlight the importance of the optimal force applied to the wall during turns (Lyttle et al., 1999; Blanksby, 1998; Gathercole et al., 1996; Blanksby et al., 1996; Hodgkinson et al., 1996) and the need to reduce deleterious drag during the streamlined glide, following push-off from the turn (Lyttle & Benjanuvatra, 2004; Sanders & Byatt-Smith, 2003). Specifically, higher push-off velocities from freestyle turns are achievable when combinations of low peak drag force, high peak propulsive force and an increased wall push-off time are optimised (Lyttle et al., 1999). However, empirical data of 3-dimensional forces in freestyle turns is lacking across all swimming proficiencies and warrants further investigation (Araujo et al., 2010; Lyttle et al., 1999).

The importance of turns in swimming events is becoming increasingly evident (Vantorre et al., 2014). During some swimming events, turning can comprise over a third of the total event time, and is often a factor in determining the final placings of the swimmers (Huellhorst et al., 1988). Despite swimming turns being an integral part of competitive performance (Beckett, 1985; Newble, 1982) and influencing who will win an event (Adler, 1979; Ward, 1976;

Carpinter, 1968), attention to this aspect of swim performance has only re-emerged in recent years.

Early research by Fox et al. (1963) focussed on comparing the time taken to perform different turn techniques. They found the energy expenditure between the open and closed turn (tumble turn) was similar, but that the tumble turn was significantly faster. Studies have also investigated whether modifications, such as the ‘piked’ versus the ‘tuck’ turns (Ward, 1976), and a double arm-pull off the wall turn (Beckett,1985; Adler, 1979) were faster methods of performing the tumble turn. Nicol and Kruger (1979) compared the swimming speeds and impulses generated by the freestyle flip turn and the open turn. No significant differences were evident between the two techniques for return swimming velocity, impulse and duration of impulse. However, complete turn time for the freestyle flip turn was significantly shorter than those of the open turn, and resulted from differences in wall approach swimming times.

The availability of underwater force plates has led to the collection of kinematic and kinetic data that affect turn performance (Lyttle & Mason, 1997; Blanksby, Gathercole et al., 1996; Huellhorst et al., 1988; Chow et al., 1984). Takahashi, Yoshida et al. (1983) investigated the propulsive forces generated by swimmers during a flip turn and during push-off from the wall and glide. Analysis of the force profiles revealed no significant differences in peak force and duration of push-off between the two conditions. Total impulse was, however, significantly higher for the flip turn (Takahashi, Yoshida et al., 1983). Lyttle and Mason (1997) highlighted the difficulty in comparing turn studies, due to differences in the operational definitions of when the turn commenced and finished. Hay and Guimaraes (1983) and Chow et al. (1984) defined turn commencement as the last hand-entry before the wall (distance-in) to the end of the first stroke taken after the turn (distance-out). Fixed arbitrary distances of 3.0 m in to 6.5 m out (Thayer & Hay, 1984), 7.5 m in to 7.5 m out (Newble, 1982) and 5 m in to 5 m out

(Blanksby, Gathercole et al., 1996) have also been used. Despite these differences, key elements of the current freestyle tumble turn have been identified. Time out can be minimised by increasing the impulse applied to the wall during push-off (Blanksby, Gathercole et al., 1996; Blanksby, Hodgkinson et al., 1996; Chow et al., 1984; Takahashi, Yoshida et al., 1983). Blanksby, Gathercole et al. (1996) also stated that it was an advantage to have more extended lower limbs (greater tuck index), decreased WCT, and high peak force on the wall in order to optimise the push-off and glide in decreasing turn times.

Previous turn research has attributed decreases in RTT to improvements in those measures occurring prior to and during wall-contact (Blanksby, Gathercole et al., 1996; Blanksby, Hodgkinson et al., 1996; Chow et al., 1984; Takahashi, Yoshida et al., 1983). While the importance of having more extended lower limbs (greater tuck index), decreased WCT and high peak force on the wall with decreasing turn RTT is recognised, the technique occurring during 'time-out' from the turn has been neglected and warrants investigation. Isolating the events following wall push-off allows the importance of the glide, the timing and the duration of underwater kicking, and the timing of stroke resumption (in decreasing turn times) to be quantified.

CHAPTER THREE: RESEARCH METHODS

3.1 Introduction

This chapter begins with an outline of the research design of the study. This is followed by an explanation of the methods of data collection which includes the selection of participants, description of the research setting, and an overview of the data collection. Thereafter, the aspects of study validity and reliability are addressed, and a description of the data analysis is offered. Ethical considerations are also mentioned.

A cross-sectional, quantitative methodology with a descriptive design was used in this study.

3.2 Study Population and Sample

A sample of 10 swimmers, five male and five female subjects, ranging from ages 12 to 18 years were drawn from the level 3 swimmers who trained and belonged to the University of the Western Cape's swimming club. This study was conducted at the University of the Western Cape's swimming pool between July 2015 and August 2016. The participants were recruited through convenience sampling.

Each swimmer performed 30 swimming trials each, therefore, the unit of analysis was 300 swimming trials for all the subjects (i.e., total of 10 swimmers x 30 trials per swimmer = 300 trials in total). This sampling format was determined in consultation with the Department of Statistics at UWC to ensure the statistical power of the study was achieved.

3.3 Testing Equipment

The following testing equipment was used, namely, two Panasonic HDC-HS 300 video cameras to record and conduct a video analysis of the turns. The cameras can record up to 50 hours of full 1920 x 1080 high definition video to the HDD with the option of storing overflow footage to SD/SDHC memory cards. In order to capture the video material, three 1/4.1" CMOS sensors were used, which added up to a total 9.15MP, named "3MOS" by Panasonic. The sensors also record 10.6MP stills and 8.3MP when recording both video and still images simultaneously. One camera was located 2 m from the end of the pool, 7 m lateral to the surface, and the other was positioned overhead by the turning wall. Video analysis was performed in the sagittal plane, using current motion analysis software (Elite Sports Analysis Focus X3, which allowed one to zoom in on the technical aspects. Up to four views could be seen, giving the same performance from different angles or comparing good and bad examples with a model performance. It was also possible to draw, annotate and make measurements on images to create instructional or motivational diagrams. Focus X3 showed the swim start from two angles with full control over the speed and the synchronization of each clip, so one could see exactly the right detail. There were also set markers to show critical points that one might want to see again in future. The annotated images could be used to measure change and improvement or used as good/bad examples to motivate the athletes.

All equipment used in the collection of research data was accurately calibrated following approved guidelines, and remained consistent throughout the study.

3.4 Participant Recruitment

Approval for the study was obtained from the senior coach of the UWC swimming club and the chief executive officer of Swimming South Africa. The researcher verbally informed the swimmers about the nature and scope of the study a week before testing commenced. Each swimmer received an information letter (Appendix A) and an consent/assent form (Appendix B), describing the purpose of the research, the benefits of participating in the study, the procedures that would take place, possible risks and discomforts that might occur, and how the participant's information would be kept confidential and secure.

3.4.1 Participant Selection, Preparation and Screening

The participants selected for the study where only those who granted their written consent/assent (Appendix C: Consent/Assent form for swimmers).

The parents and swimmers each received a letter with pre-test instructions (Appendix D: Pre-test instructions), at least 48 hours prior to testing, informing them about the mandatory preparatory requirements for the swimming trial and a demographic questionnaire. Testing was scheduled for approximately 45 - 60 minutes per participant.

3.4.2 Test Measurements

For the purpose of the study, each subject was required to do 30 swimming trials in total, each consisting of a 50 m freestyle swim. Subjects were instructed to perform flip turns at race pace swimming at maximum speed 5 m before and after the tumble turn. The swimmers were asked to perform the turns in their normal manner, as they did when they competed. Each trial was video recorded and analyzed by the researcher. The swimmers were numbered 1 to 10 and they completed their trials in random order. The swimming took place at the University of the Western Cape's swimming pool. The swimmers warmed up according to their normal routine that consisted of a warm up swim in the pool for 15 minutes, switching from stroke to stroke as indicated by their coach. The distance covered during the warm-up was 400 m and this was done at a moderate intensity. To help with recovery and reduce delayed onset of muscle soreness after the 30 trials, swimmers did a cool down swim with 10 minutes of static stretching on the pool deck. The static stretches were full body stretches, with the major muscles groups being targeted.

At the command of the coach, the respective swimmer, who was positioned under the starting block, started their swim within the pool lane and completed a 50 m front crawl swim, while executing a tumble turn. This required the swimmer to complete a series of complex movements to allow him/her to change direction through the turn, while maintaining speed, until he/she returned to the start. A camera captured the turn segment from 35 m to 50 m of the swim. Each trial was timed (independent variable) and evaluated the effect of 3 critical tumble turn performance variables (dependent variables). Each swimmer performed all 30 trials on the same day with only a 2 minute break after each tenth trail, if required by the swimmer. This swimming protocol was under the advisement of the coach, who wanted the swimmer to maintain a constant swimming rhythm, while performing each trial, which simulated how they trained and competed.

This study focused primarily on the video recordings of the turn segments. The analyses of the flip turn comprised the following four phases (Mosavi et al., 2012), namely:

1. Rolling, which started on the last frame, and referred to one of the many still images which composed the complete moving picture, before hand-entry of the last swimming

stroke and before turning, and ended on the last frame, before the first touch on the wall with the feet;

2. Wall contact, which started on the frame that corresponded with the first wall-contact, and ended on the last frame, before the swimmer started to extend the knees in order to project the body away from the wall;

3. Pushing, which started on the frame that corresponded to the first knee extension, and ended on the frame that corresponded to the last wall-contact; and

4. Gliding, which started on the first frame after the swimmer completely left the wall, and ended on the frame that corresponded to the first leg kick out of the wall.

The variables analyzed were the time (duration in seconds) of each turn phase, i.e., WCT and RTT, the degree of hip-to-knee flexion at wall-contact for determining the tuck index (the ratio of the smallest hip-to-wall distance to total leg length), the alignment of the feet, and the depth of foot-contact in order to determine whether they were in a beneficial position for push off. In order to obtain these variables, the video images were slowed down to allow for analysis using the motion analysis software (Elite Sports Analysis Focus X3).

3.5 Tester Reliability

With regard to test validity, previous researchers have used the same or similar testing instruments to quantify the variables measured in this study, which have been shown to be valid (Mosavi et al., 2012; Patz, 2005). Elite sports analysis using digitized video image motion analysis software is a dynamic tool that provides real-time analysis capabilities in order to identify the problems associated with poor sports performance, as well as a means of reviewing critical aspects of sports performance that need remediation (Mosavi et al., 2012; Patz, 2005). In addition, the analysis and interpretation of the research data reported in previous studies was consistent with the procedures of data analysis and interpretation applied in this study as well (Mosavi et al., 2012; Patz, 2005).

Only one tester was used in the study. In order to ensure intra-tester reliability, a test-retest reliability coefficient of 0.8 minimum was required to ensure reliable results. This was done by the researcher re-analyzing the tumble turn to ensure reliability of the analysis

With regard to subject integrity, the tester was instructed when taking measurements not to compromise the physical and emotional well-being of participants. Similarly, the tester was also sensitized to the cultural practices and traditions of the participants, and encouraged to be mindful of these throughout the study, in addition to observing basic practices of hygiene, i.e., keeping the fingernails trimmed and hands washed at all times.

3.6 Data Management

During testing, a recorder accompanied the tester, who entered and verified the accuracy of the data. The quality of testing was standardized by carefully preparing both the participants and the tester. All participants' data was captured electronically on computer into Microsoft Excel and stored against a private access code. Data entry was performed by an experienced data-capturer with duplicate entry and crosschecking by a senior statistician. Queries were sent in batches to the principle researcher for resolution and verification.

3.7 Ethical Considerations

The following additional ethical considerations were addressed:

- Confidentiality: Provision was made for the confidential safekeeping of participants' information at all times. The identities of the subjects were protected in so far as their names or personal information was not included in the reporting of the findings. In addition, the names of the subjects were not recorded on the data collection sheets, but rather numeric codes were used for each subject.

- Privacy: Throughout the study, participants were consulted individually and tested privately at the swimming pool.

- Safety: Every effort was made to ensure that no harm came to any participant. Universal precautions of safety and standardized emergency procedures were observed when testing the participants. Also, reasonable precautions were taken to ensure that the participants did not endure unnecessary discomfort, while simultaneously adhering to standards of best practice.

Permission to conduct the study was obtained from the Senate Biomedical Research Ethics Committee of the University of the Western Cape. The subjects were invited voluntarily to be part of the study. They were briefed on the aims and objectives of the study (Appendix A: Information letter). It was explained to them that their participation in the study was voluntary and that they could withdraw at any point from the study without any negative consequences. They were given a consent form to sign (Appendix C: Consent/Assent form for swimmers). In the case of swimmers who were under the age of 18 years, they completed an assent form (Appendix C: Consent/Assent form for swimmers), and written consent (Appendix B: Consent form for parents) was obtained from their parents as well.

The testing was conducted at the swimming pool with each swimmer being tested individually. All information was treated with the strictest confidentiality, and the identities of the subjects were protected in so far as their names or personal information was not included in the reporting of the findings. In addition, the names of the subjects were not recorded on the data collection sheets, but rather numeric codes were used for each subject. All data and video recordings will be kept for 5 years and stored in a locked filing cabinet on the university premises, and will only be accessible to the researcher and supervisor.

3.8 Statistical Analyses

The objective of this study was to analyse a total of 300 swim turn trials, based on 10 swimmers doing 30 trials each. All participant data was transferred, in duplicate, into an MS Office Excel 2013 spreadsheet by double entry to ensure accuracy. It was then exported to the Statistical Package for the Social Sciences (SPSS) version 22 for data analysis.

Each participant was allocated an identity code to protect their identity when capturing the data either on datasheets or on computer. Once the data was collected, only the researcher had access to the participant's files and database. All participant files were stored in a locked cabinet. Confidentiality and privacy were assured at all times. All electronic back-up copies of the data were stored on computer against password access restrictions that were controlled by the researcher. Descriptive statistics [mean (X) and standard deviation (±SD)] were obtained for all the selected variables. A p-value of below 0.05 was considered to indicate statistical significance.

A stepwise regression model was conducted using the RTT as the dependent variable in order to determine the overall predictive characteristics of the independent variables of tuck index, foot-plant index and WCT. The interpretation of the results of the regression analysis included determining whether the predictor variables were significant for the purpose of predicting criterion variables. The following values were determined: the determinant coefficient (R^2) and the multiple correlation coefficient (R). A p-value of below 0.05 was considered to indicate statistical significance.

Since the multiple regression performed was stepwise, only those variables that significantly contributed to variance of the dependent variable were entered into the model. The variables that were entered into the model were the tuck index, foot plant index and WCT.

The regression equation was calculated for each variable and the significance level of the regression coefficient was given. If a regression coefficient was not significant, that variable was removed from the equation. Levels of F to enter and F to remove were set to correspond to p-levels of 0.05, in order to adjust for familywise alpha error rates associated with multiple significance tests.

CHAPTER FOUR: RESULTS

4.1 Introduction

The objective of the current study was to analyse 300 flip turns of 10 swimmers who each performed 30 trials. For each swimmer, the most representative turn for each category was chosen for analysis

There were several study objectives, namely:

- To determine the optimal distance a swimmer's hips should be from the wall at foot contact.
- To determine the optimal depth of foot-plant on the wall.
- To measure and determine the optimal percentage of WCT spent by the swimmer, when pushing off the wall.
- To determine the RTT of the swimmer when performing the tumble turn.

4.2 Impact of Tuck index, Foot-Plant Index and Wall-Contact Time on Tumble Turn Performance

The group comprised five males of mean age, 11.02 ± 1.19 years, stature 150.64 ± 10.37 cm, and body mass, 41.25 ± 8.08 kg; and five females of mean age, 11.69 ± 1.29 years, stature, 155.28 ± 9.29 cm, and body mass, 40.57 ± 7.15 kg.

Table 4.1. Means and standard deviations of swimmers age, stature and body mass.

Variables	Males			Females		
	n	Mean	SD	n	Mean	SD
Age (years)	5	11.02	1.19	5	11.69	1.29
Stature (cm)	5	150.64	10.37	5	155.28	9.29
Body Mass (kg)	5	41.25	8.08	5	40.57	7.15

The mean tuck index was 0.57 ± 0.14°. The mean foot plant index was 0.45 ± 0.10 cm. The mean WCT was 74.31 ± 11.57 s (Table 4.2). The mean percentage of wall-contact time was 74.31%, and the minimum percentage was 35% and the maximum was 95%. The mean RTT was 2.47 ± 0.40 s

Table 4.2. Means and standard deviations of swimmers performance variables.

Performance Variables	N	Mean	SD
Tuck Index (degrees)	109	0.57	0.14
Foot-Plant Index (cm)	109	0.45	0.10
Wall-Contact Time (%)	109	74.31	11.57
Round-Trip Time (s)	109	2.47	0.40

Table 4.3 contains information about the relationships between the dependent and the three independent variables. The relationship between the dependent variable and each independent variable was examined. A significant negative correlation was found between tuck index and RTT ($r = -0.41$; $p < 0.05$). No significant relationship was found between foot-plant index and

WCT. Similarly, no significant relationship was found between foot-plant index and RTT, as well as between WCT and RTT.

Table 4.3. Relationship between various performance variables.

Variables	Round-Trip Time	Tuck index	Foot-Plant Index	Wall-Contact Time
Round-Trip Time	1.000	-.411*	-0.142	0.211
Tuck Index		1.000	0.185	-0.393
Foot-Plant Index			1.000	0.119
Wall-Contact Time				1.000

*Significant at $p < 0.05$.

The results of the stepwise regression (Table 4.4) indicates that the three independent variables predicted approximately 18% of the variance ($R^2 = .178$) in RTT.

Table 4.4. Results of the stepwise regression.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.422a	.178	.155	.37043

a. Predictors : Constant, Tuck Index, Foot-Plant Index, Wall-Contact Time

Table 4.5 provides the results on the individual predictor variables in the model. Since neither foot-plant index nor WCT were significant, the tuck index was re-run as the sole predictor of RTT in a stepwise regression, because it was the only statistically significant predictor ($p < 0.05$).

Table 4.5. Coefficients of round-trip time.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std.Error	Beta		
(Constant)	3.017	.351		8.602	.000
Tuck Index	-1.033	.282	-.365	-3.669	.000
Foot Plant Index	-.338	.369	-.084	-.915	.362
Wall-Contact Time	.003	.003	.078	.788	.433

a. Dependant Variable: Round-trip time

Table 4.6 provides the results of the stepwise regression analysis which indicate that 16.9% of the variance ($R^2 = 0.169$) in the RTT can be accounted for by the tuck index alone.

Table 4.6. Results of stepwise regression using tuck index as the sole independent variable.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.411a	.169	.161	.36905

a. Predictors : (Constant), Tuck index
b. Dependent variable: Round-trip time

The results in Table 4.7 indicate that the model using only the tuck index accounts for a statistically significant amount of variance in RTT ($F = 21.745$, $p < 0.001$)

Table 4.7. Analysis of variance for round-trip time using tuck index as the sole independent variable.

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2.962	3	2.962	21.745	.000a
	Residual	14.573	107	.136		
	Total	17.535	106			

a. Predictors : (Constant), Tuck index
b. Dependant variable: Round-trip time

Table 4.8 provides the results on tuck index as the individual predictor variable, which shows that it makes a significant contribution to RTT ($p < 0.001$)

Table 4.8. Coefficients for tuck index.

Model 1	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std.Error	Beta		
(Constant)	3.140	.147		21.368	.000
Tuck Index	-1.163	.249	-.411	-4.663	.000

CHAPTER FIVE: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The purpose of this study was to determine the effect of the tuck index, foot-plant index and WCT on RTT of the tumble turn performance in level 3 swimmers for the freestyle swimming stroke. In this study, a significant negative correlation was found between tuck index and RTT. No significant relationship was found between foot-plant index and RTT. Similarly, no significant relationship was found between WCT and RTT.

Tuck index is the measurement used to indicate how close the swimmer is to the wall. A higher tuck index indicates straighter legs (Patz, 2005). In the present study, the mean tuck index for all the turns was 0.57 ± 0.14° indicating that the swimmers hips were approximately 57% from the wall, when executing the tumble turn. The tuck index of elite freestyle swimmers with mean age of 20.1 years for males and 15.6 years for females was examined by Blanksby, Hodgkinson, et al (1996). All were Australian national finalists in freestyle events. The mean tuck index was 0.65° indicating that these elite swimmers had straighter legs than the swimmers in the present study. Tuck index was also measured in trained adolescents between the ages of 9 to 15 years in two separate studies. The mean tuck indexes for the freestyle turns were 0.65 (Cossor, 1999), and 0.56 (Blanksby, Hodgkinson, et al., 1996). In a sample of age-group swimmers, a mean tuck index of 56.6 ± 17.2% was recorded (Smith, 2008; Blanksby, Gathercole, et al., 1996). For these swimmers, the tuck index was significantly correlated to time spent on the wall during the tumble turn, to the peak force generated, and to the 2.5 m, 5.0 m, and 50 m RTTs. This is interpreted to mean that when the swimmers' legs get straighter (i.e., less knee flexion), the tumble turn times get faster. It demonstrated that the experienced or trained swimmers had a higher, although not statistically significant, tuck index than the recreational swimmers, these values were 62.7 ± 19.1% and 49.3 ± 15.6%, respectively (Smith, 2008).

Tuck index was the only significant predictor of RTT in the present study. Tuck index was negatively correlated with RTT, indicating that a lower tuck index predicted a faster RTT. Other studies (Prins et al., 2006; Blanksby et al., 2004; Cossor et al., 1999; Blanksby, Gathercole, et al., 1996) measured RTT as the dependant variable and indicated that a lower tuck index resulted in a faster turn, similar to the results in the present study. This result, however, appears to be in contrast with the results of two other studies on tuck index, which showed that a higher tuck index resulted in a faster turn (Prins et al., 2006; Blanksby et al., 2004; Cossor et al., 1999; Blanksby, Gathercole et al., 1996; Blanksby, Hodgkinson, et al., 1996). However, all of these studies measured RTT (2.5 m and 5 m) as the dependant variable. In these cases, RTT was faster possibly due to the centre of mass being further from the wall during foot-contact. These studies did not look at velocity upon push-off or the distance after push-off. In a study done by Patz (2005) using a curvilinear model, a tuck index of 46° was suggested to produce the maximum push-off velocity for the tumble turn. For the optimal tuck index, the swimmers hips were a distance of 46% of the swimmer's leg length from the wall.

Performing a tumble turn with the hips either very close to the wall or in a straight position would not allow the leg muscles the desirable space to generate optimal muscular force (Patz, 2005). This concept was illustrated by Linthorne (2000), who examined optimal take-off range in the vertical jump by having track athletes perform squat jumps and countermovement jumps using a force platform. When track athletes began squat jumps from a deep squat position, these jumps had a two phase vertical force profile and they generated approximately 30% less vertical ground reaction force, when compared to the more conventional vertical jump starting position (Linthorne, 2000). It was speculated that the reduced force production in the vertical jump resulted from the sharp decrease in knee extensor strength in the deep squat position, due to compromised muscle length and, thereby, reduced force velocity and momentum of the muscles in the lower body (Linthorne, 2000). Squat jumps performed with the legs close to full extension, produced approximately 25% less vertical ground reaction force than those with the more optimal starting position (Linthorne, 2000).

Urabe et al. (2005) found that in the vertical jump, greater activation of the vastus medialis and vastus lateralis was responsible for knee extension, when near 130° of knee flexion. Such evidence support the findings and theories of Hay and Guimara˜es (1983), Blanksby and colleagues (Blanksby, Skender, Elliott, McElroy, & Landers, 2004; Blanksby, Simpson, Elliott, & McElroy, 1998), and Little (2000), which suggest that maximum extension torque is obtained at 100 – 120° of knee flexion, and that of Takahashi et al. (1982) and Ling and colleagues (Ling, Blanksby, Elliott, & McElroy, 2004), which state that the angle of knee flexion during a turn should be 120° (Araujo et al., 2010).

Tumble turn studies have shown that peak forces were noted at knee angles of 60° (0° being full extension) (Takahashi, Yoshida, et al., 1983), which was consistent with a finding that peak force during a vertical (not squat) jump was recorded between knee angles of 60° and 80° (Smith, 2008). Furthermore, the average maximum knee flexion value during a flip turn has been recorded as 59.3°, with the range being from 33° to 98° (Takahashi, Yoshida et al., 1983). This indicates that tumble turns occur at a wide range of knee flexion values, and that the knee is capable of performing this task through a large range of motion (Smith, 2008).

While these results do not take into account possible variations in leg length, they provide general support for the notion that the relationship between tuck index and RTTT may be a curvilinear than linear one (Patz, 2005). It was concluded that there is a position where the combination of distance from the wall, time spent on the wall, and force exerted on the wall are optimal (Patz, 2005). A swimmer with a tuck index of 100% cannot generate sufficient force, because his or her legs are completely straight, while a swimmer with a very small tuck index spends too much time pushing off from the wall (Smith 2008; Blanksby, Gathercole, et al., 1996). Finally, the negative correlation between tuck index and the three RTT measures suggests that a swimmer who turns with straighter legs covers less total distance with their swimming than does a swimmer who turns with more flexed legs. This association is stronger as the RTT distance decreases, suggesting that the turning component represents a higher fraction of the total swimming time, stressing the importance of optimal tumble turn performance (Smith 2008; Blanksby, Gathercole, et al., 1996). Further evidence of the involvement of tuck index is reported in a sample of national level swimmers (Smith 2008). It was found that a decrease in 2.5 m RTT was related to a higher tuck index, which is in agreement with the previous study (Smith 2008; Blanksby Gathercole, et al., 1996).

Foot-plant index is a measure the distance of the feet from the water's surface, while taking into account the length of the swimmers legs (Patz, 2005). A high number for foot-plant index indicates a deeper foot-plant measurement. The mean foot-plant index for the present study was 0.45 ± 0.10 cm, indicating that the mean foot-plant index was 45% of the swimmers leg length below the water. There was no significant relationship between foot-plant index and RTT in the present study. No other research has been conducted to-date that tested the possible association between foot-plant depth and flip turn performance. Lyttle (1998) found that gliding at a depth of 0.4 m under the water's surface effectively reduced wave drag. Thirty three of the 109 turns in this study resulted in glides being performed above the 0.40 m optimal depth, indicating a glide that is too shallow (Patz, 2005). Further examination of the data could consider the possible link between foot-plant depth and push-off force. A study examining the relationship between foot-plant depth and push-off force might provide insight into the optimal foot-plant depth for achieving a 0.4 - 0.6 m gliding depth range upon push-off.

The longer the duration of WCT the, the greater is the push-off speed (Puel et al., 2012; Patz, 2005). To obtain optimal push-off time, sufficient contact time is required (Lyttle et al., 1998). When the feet make contact with the wall and, then, vigorously push away, there is a stretch-shortening cycle of the extensors, which improves the mechanical output of these muscles (Tourney-Chollet, Chollet, Hogie, & Papparodopoulus, 2002). This storage-restitution process involves an overproduction of energy that results in a force
greater than the maximal isometric force. This process produces an increased speed at the end of push-off. The quantity of mechanical energy of elastic origin depends on the contact time of the feet on the wall, particularly when the leg extensor force is increased (Tourney-Chollet et al., 2002).

The WCT of all swims in the present study was 0.31 seconds. This WCT was among the shortest compared to previous studies (Patz, 2005; Lyttle, 1999; Lyttle & Mason 1997; Blanksby, 1996). Compared to the current study, the mean WCT among normal freestyle turns was 0.28 s (Patz, 2005). Lyttle and Mason (1997) showed a mean WCT of 0.29 s for a study on three international level male swimmers. Similarly, Lyttle (1999) showed a mean WCT of 0.32 s for a study on 30 experienced male adult swimmers, whereas Blanksby et al. (1996) showed a mean wall-contact time of 0.58 s for a study on 36 competitive age-group swimmers. Clothier (2004) demonstrated WCTs ranging from 0.56 to 0.62 s. While similar to those shown by Blanksby, Gathercole et al. (1996), the present results are substantially slower than those reported in previous studies (Lyttle & Mason, 1997; Takahashi, Yoshida et al., 1983 Nicol & Kruger, 1979). Lyttle et al. (1999) stated that although a high WCT may not directly affect the final push-off velocity, but it could negatively affect overall turn speed.

A study by Chakravortia, Slawsonb, Cossora, Conwaya, and West (2012) showed that the relationship between the normalised force and WCT for tumble turns and open turns were -0.192 and -0.177, respectively, which indicates that when the contact time is greater, the normalised force (per body mass) is reduced. This finding was also supported by the results reported by Araujo, Pereira, Gatti, Freitas, Jacomel, and Roesler (2010).

In the present study, the mean percentage of WCT was 74.31%, and the minimum percentage was 35% and the maximum was 95%. Surprisingly, Lyttle (1999) found that the active push-off segment for elite swimmers ranged from 33 to 94% of the total WCT. The mean was 67.5 ± 15.3% in the study by Lyttle (1999). A positive correlation showed that a longer WCT resulted in faster push-off velocities (Lyttle, 1999). This finding was also supported by results detailed by Tourney-Chollet, Chollet, Hogie, and Papparodopoulus (2002) on 22 swimmers doing 200 m swim performance of butterfly turns. Therefore, it is considered that the poorer turn performances demonstrated by age-group swimmers could partly be attributed to the longer duration of the WCT.

The results of numerous studies suggest that the optimal tumble turn should be performed at a tuck index of approximately 73.8%, as it was the ideal position that required the least amount of time to generate the similar impulses across various conditions (Smith, 2008). Wall-contact time has been reported to have a significant and positive relationship with 50 m, 5.0 m, and 2.5 m RTT in swimmers (Smith 2008; Patz 2005; Blanksby et al., 2004; Blanksby, Gathercole, et al., 1996). The turning component comprises 21% of a 50 m freestyle swim race, and up to 33% in a 200 m race (Smith, 2008; Chow et al., 1984). It can be seen, then, that minimizing the turn time would decrease these percentages and allow for a greater percentage of each race to be spent actually swimming.

5.2 Strengths of the Study

The knowledge that was generated in this study could be used in the development of swimmers and coaches in various swimming clubs. From a practical perspective, the research could be utilised by coaches instructing swimmers about their turns, so as to facilitate effective technique to improve individual performance. The scientific investigation of tumble turns attempts to assist future sport science researchers to broaden the science of swimming within Level 1 to Level 3 swimmers in South Africa.

5.3 Limitations of the Study

Since the water temperature of the swimming pool was not thermostatically controlled, it could have a negative impact on the swimmers' performances, i.e., the colder the water, the less likely it is that the participants will be able to swim at race pace. The recommended water temperature for competitive swimming is from 22 to 26^{o} Celsius.

Subjects were required to swim thirty (30) trials in total with each trial performed at race pace. The trials were performed at four to six trials per swimming session over a period of seven to ten swimming sessions. This could adversely impact on the subjects' level of motivation to continue with the testing, especially in the later stages of the study.

The sample of subjects recruited for the study was not random, so the external validity and broad generalizations based upon the convenient sample used in the study will also be limited. The study experienced many obstacles with the pool not being available, due to maintenance work done at the time the study was being conducted, as well as the pool being closed for a period of time, due to municipal water restrictions and technical faults with the facility. This resulted in the swimmers leaving the UWC swimming club, which negatively affected the data collection and subsequent statistical analysis.

Unfortunately, the swimmers did not complete all the trials, due to various reasons, such as not being available on the day of testing, because of clashes with training schedules and prior commitments at school. In addition, technical difficulties with the video equipment that resulted in the researcher not being able to view the swimming turns also resulted in some of the swimming data being eliminated. As a result only 109 swimming turns were finally selected and analysed.

5.4 Conclusion

A significant negative correlation was found between tuck index and RTT in this study. Further regression analysis showed that the tuck index was a significant predictor of RTT. Following the freestyle tumble turn, the flutter kick technique remained the superior method of exiting the wall, based on 5 m RTT. Therefore, the introduction of optimal turning practice for age-group swimmers is likely to result in significant reductions in turning times and should be noted and implemented by coaches and swimmers alike.

5.5 Recommendations

Future studies using more sophisticated motion analysis software should be used to analyse the tumble turns of swimmers. This will help explain more variables and their effect on the tumble turn. A tumble turn in which the legs are less tucked is seemingly preferred. These results suggest that swimmers should be coached into the flip turn positions in which the legs are more extended in order to take advantage of the faster tumble turn times to improve swimming performance. Future tumble turn research that intends to determine critical elements of performance should, therefore, be conducted on swimmers with mature movement patterns and greater ability in order to consistently reproduce performances.

In addition, the limited data on tuck index, especially foot-plant index and WCT, and the scarcity of data on South African Level 3 swimmers, signifies that there is a need for research to address these shortcomings. More research is needed in this area that will aid coaches and swimmers to enhance their knowledge in order to address the effect of the tumble turn on swimming performance.

5.6 Summary

The results of the current study suggest that when executed correctly, the tuck index improves tumble turn, thereby, leading to an increase in swimming performance. The mean tuck index for all the turns was 0.57 ± 0.14^{o} indicating that the swimmers hips were approximately 57% from the wall, when executing the tumble turn. Tuck index was the only significant predictor of RTT in the present study. Tuck index was negatively correlated with RTT, indicating that a lower tuck index predicted a faster RTT.

The mean foot-plant index for the present study was 0.45 ± 0.10 cm, indicating that the mean foot-plant index was 45% of the swimmers leg length below the water. There was no significant relationship between foot-plant index and RTT in the present study. No other research has been conducted to-date testing the possible involvement of foot-plant depth on flip turn performance.

The WCT in the present study was 0.31 s compared to other studies on WCT with values that ranged from 0.56 to 0.62 s. Therefore, it is considered that the poorer turn performances demonstrated by age-group swimmers could partly be attributed to the greater duration of the WCT.

This current study suggests that tuck index, foot depth and WCT have substantial effects on tumble turn performance. Tuck index showed a significant inverse relationship with RTT. Therefore, it is imperative that coaches and sport scientists educate their swimmers, and use video analysis in their coaching methods to increase the swimmers knowledge and understanding of the effect of these variables on tumble turn performance, which is likely to improve overall swimming performance.

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Appendix A: Information Sheet

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville 7535, South Africa

Tel: +27 21-959 2350, Fax: 27 21-959 3688

E-mail: lleach@uwc.ac.za

INFORMATION ABOUT THE STUDY

Title of Research Project: The Effect of Tumble Turns on Swimming Performance in Level 3 Swimmers.

What is this study about?

This research project is conducted by Gareth Smithdorf, a Master's student in Biokinetics at the University of the Western Cape. The study will investigate the effect of tumble turns on swimming performance in level 3 swimmers. We are inviting you to participate in this research project because you meet the requirements for this study by being a male or female level 3 swimmer from ages of 12 to 18 years. The purpose of this research project is to examine the effect of foot-plant, tuck index and wall-contact time on tumble turn performance in freestyle level 3 swimmers.

What will I be asked to do if I agree to participate?

You will ask to perform 30 trials, each consisting of a 50m freestyle swim at University of the Western Cape swimming pool. You are required to perform tumble turns at race pace and swimming at maximum speed 5m before and after the tumble turn. Tumble-turns will be performed during the freestyle trials while being captured on video cameras. After each trial you will be informed of your performance, which will be expected to be within the requirements of the instructed turn, if this is not the case, you could be asked to repeat the trial.

Would my participation in this study be kept confidential?

We will do our best to keep your personal information confidential. To help protect your confidentiality, procedures to maintain the confidentiality of the data, will include having a locked filing cabinets and storage areas, using identification codes only on data forms, and using password-protected computer files. This research project involves making video recordings of you. The video recording of you is to allow the researcher to analyse the different components of the tumble turn for this research study. Access to the video recordings will only be by the researcher and supervisor only. The video recordings will be kept and not destroyed. If we write a report or article about this research project, your identity will be protected to the maximum extent possible.

What are the risks of this research?

There may be some risks from participating in this research study. The possibility exists that certain abnormal changes can occur during the tests. These might include abnormal blood pressure, disorder of heart beat, fatigue and in rare instances, heart attack, stroke, or death. Every effort will be made to minimize the risks by evaluating preliminary information related to your health and fitness and by observations during testing. If any injury should occur, trained personal with level 3 first aid qualifications will be available.

What are the benefits of this research?

The results obtained from the study will be used to evaluate your progress in acquiring improved turning technique during the tumble turn phase of your swimming technique. Additionally it may assist you in evaluating your turn technique in freestyle.

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.

What if I have questions?

This research is being conducted by Gareth Smithdorf from department of Sport, Recreation and Exercise Science at the University of the Western Cape. If you have any questions about the research study itself, please contact Gareth Smithdorf at:

UNIVERSITY OF THE WESTERN CAPE

Department of Sport, Recreation and Exercise Science

Private Bag X 17, Bellville 7535, South Africa

Telephone: 021 959 2688

Cell: 072 672 1288

Email: gsmithdorf@uwc.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:

Supervisor: Dr L. Leach

Department of Sport, Recreation and Exercise Science, UWC

Telephone: (021) 959-2653

Fax: (021) 959-3688

Email: lleach@uwc.ac.za

Dean of the Faculty of Community and Health Sciences: Prof Jose Frantz

University of the Western Cape

Private Bag X17

Bellville

7535

Tel: (021) 959-2631

Email: jfrantz@uwc.ac.za

This research has been approved by the University of the Western Cape's Senate Research Committee and Ethics Committee.

Appendix B: Consent Form for Parents

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville 7535, South Africa

Tel: +27 21-959 2653, Fax: 27 21-959 3688

E-mail: lleach@uwc.ac.za

CONSENT FORM FOR PARENTS

Title of Research Project: The Effect of Tumble Turns on Swimming Performance in Level 3 Swimmers.

The study has been described to me in a language that I understand and I freely and voluntarily agree to have my daughter or son participate. My questions about the study have been answered. I understand that the identity of my child will not be disclosed and that he or she may withdraw from the study at any time without giving a reason, and this will not negatively affect them in any way.

___ I agree to have my daughter or son video recorded during their participation in this study.

___ I do not agree to have my daughter or son video recorded during their participation in this study.

Parent's name…………………………………..…..

Parent's signature……………………………….

Witness………………………………………….

Date……………………………..……………

Should you have any questions regarding this study or wish to report any problems you have experienced related to the study, please contact the study supervisor:

Study Supervisor's Name: Dr L. Leach

Telephone: (021) 959- 2653

Fax: (021) 959- 3688

Email: lleach@uwc.ac.za

Appendix C: Consent/Assent Form for Swimmers

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville 7535, South Africa

Tel: +27 21-959 2653, Fax: 27 21-959 3688

E-mail: lleach@uwc.ac.za

CONSENT/ASSENT FORM FOR SWIMMERS

Title of Research Project: The Effect of Tumble Turns on Swimming Performance in Level 3 Swimmers.

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.

___ I agree to be video recorded during my participation in this study.

___ I do not agree to be video recorded during my participation in this study.

Participant's name…………………….………………..

Participant's signature……………………………….

Witness…………………………………...……….

Date……………………………..……………...……

Should you have any questions regarding this study or wish to report any problems you have experienced related to the study, please contact the study supervisor:

Study Supervisor's Name: Dr L. Leach

Telephone: (021) 959- 2653

Fax: (021) 959- 3688

Email: lleach@uwc.ac.za

Appendix D: Pre-Test Instructions

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville 7535, South Africa

E-mail: gsmithdorf@uwc.ac.za

PRE-TEST INSTRUCTIONS

In order to increase the validity and accuracy of the physical fitness test data, the pre-test instructions should be adhered to strictly.

1. Participant's should refrain from ingesting food, alcohol, or caffeine or using tobacco products within 3 hours of testing.

2. Participant's should be rested for the assessment, avoiding significant exercise or exercise on the day of the assessment.

3. Clothing worn for the assessment should be your swimming costume that you will compete in a normal swimming event.

4. If you are currently on medication (for example, asthma pump), please make sure that you have it available when you report for testing, as the tests may affect you adversely. Also report to the biokineticist the last actual dose taken.

5. Candidates with any injuries or illness on the day of testing must report them to the biokineticist immediately and, if possible, schedule another appointment so as not to be unduly penalized before or during testing.

6. Drink plenty of fluids over the 24-hour period preceding the test to ensure normal hydration prior to testing.

7. Get an adequate amount of sleep (6 to 8 hours) the night before the test.

N.B: Please observe the above instructions strictly when preparing for testing, since failing to do so can have a negative impact on the outcome of your evaluations

Appendix E: Data Recording Sheet

Subject Information	*Swimmer ID NO.*	
	NUMERIC CODE	*01*
	Age	
	Ethnicity (B, C, I, W)	
	Sex (Male=1, female=2)	
	Stroke	
	Date of Birth	

TEST	***Date of Measurement:***	**Variable Measurements**			
	Time of Measurement:	***Tuck Index***	***Foot Plant***	***WCT***	***50m Swim time***
	Swimmer 1	*1*	*2*	*3*	***4***
	Trial 1				
	Trial 2				
	Trial 3				
	Trial 4				
	Trial 5				
	Trial 6				
	Trial 7				
	Trial 8				
	Trial 9				

Trial 10				
Trial 11				
Trial 12				
Trail 13				
Trial 14				
Trial 15				
Trial 16				
Trial 17				
Trial 18				
Trial 19				
Trial 20				
Trial 21				
Trial 22				
Trail 23				
Trail 24				
Trail 25				
Trail 26				
Trail 27				
Trail 28				
Trail 29				
Trail 30				

Appendix F: Testing Preparation Checklist

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville 7535, South Africa

E-mail: gsmithdorf@uwc.ac.za

TESTING PREPARATION CHECKLIST

Participant confirmation

Yes **No**

The participant has:

1. read and understood the test procedures ☐ ☐
2. signed the consent form ☐ ☐
3. been familiarized with the test(s) and is comfortable with it (them) ☐ ☐
4. understood the starting and stopping procedures ☐ ☐
5. understood the expectations before, during and after testing ☐ ☐
6. complied with all pre-test instructions concerning: rest, food and drink, smoking, clothing and shoes. ☐ ☐
7. confirmed being physically and psychologically ready for testing ☐ ☐

Tester confirmation

The tester has:

1. determined the tests to be administered ☐ ☐
2. checked the equipment (and calibration, if required) ☐ ☐
3. checked the recording sheets and other supplies, such as stationery, etc. ☐ ☐
4. checked the testing area ☐ ☐
5. understood the responsibilities clearly ☐ ☐
6. confirmed who will be the recorder or assistant ☐ ☐
7. understood the testing sequence ☐ ☐
8. understood and rehearsed the emergency or safety procedures ☐ ☐
9. understood the procedures before during and after testing ☐ ☐
10. controlled the testing environment to ensure an atmosphere of privacy, safety and calmness

Comments:

____

Appendix G: Ethical Clearance Letter

UNIVERSITY of the WESTERN CAPE

DEPARTMENT OF RESEARCH DEVELOPMENT

04 March 2019

To Whom It May Concern

I hereby certify that the Senate Research Committee of the University of the Western Cape, at its meeting held on 25 October 2013, approved the methodology and ethics of the following research project by: Mr G Smithdorf (SRES)

Research Project:	The effects of tumble turns on swimming performance in level 3 swimmers
Registration no:	13/9/26

Any amendments, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

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
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T: +27 21 959 2988/2948 . F: +27 21 959 3170
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A place of quality,
a place to grow, from hope
to action through knowledge