THE INFLUENCE ON MASTICATORY PERFORMANCE OF JAW MOVEMENTS, CHEWING SIDE PREFERENCE, OCCLUSAL CONTACT AREA, MUSCLE ACTIVITY AND JAW TREMOR

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Submitted in fulfilment of the requirements for the degree of Ph.D in the Faculty of Dentistry of the University of the Western Cape.

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DECLARATION

I declare that "the influence on masticatory performance of jaw movements, chewing side preference, occlusal contact area, muscle activity and jaw tremor" is my own work and that all the sources I have used or quoted have been indicated and acknowledged by means of complete references.

Signed . . . .

R.J.C. Wilding

9 September 1996

Dedicated to

Professor J.F. (Frikkie) van Reenen

teacher, mentor and friend.

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R.J.C.W. 10 June 1996

List of Publications resulting from this project

Wilding R.J.C. and Lewin A. (1991) A computer analysis of normal masticatory movements recorded with a sirognathograph. Archives of Oral Biology. 36, 65-75.

Wilding R.J.C. and Lewin A. (1991) A model of optimum functional jaw movements based on values associated with preferred chewing patterns. Archives of Oral Biology. 36, 519-523.

Wilding R.J.C, Adams L. and Lewin A. (1992) Absence of association between a preferred chewing side and its area of functional occlusal contact. Archives of Oral Biology 37, 423,428.

Wilding R.J.C. (1993) The association between chewing efficiency and occlusal contact area in humans. Archives of Oral Biology. 38, 589-596.

Wilding R.J.C. and Lewin A. (1994) The determination of optimal human jaw movements based on their association with chewing performance. Archives of Oral Biology. 39, 333-343.

Wilding R.J.C. and Shaikh M. The relationship between muscle activity, jaw movements and chewing performance in normal subjects. J Orofacial Pain. In Press.

Wilding R.J.C. and Shaikh M. Jaw movement tremor as a predictor of chewing performance in normal human subjects. J Orofacial Pain. In Press.

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Chapter 1

Introduction

The primary function of the jaws and teeth in mammals is chewing and swallowing. In man there are additional functions of speech, non-verbal communication and cosmetic appeal. Chewing is a complex operation requiring both adequate skeletal structures, and a well co-ordinated muscle system. There is considerable variation in both these components of chewing within which adequate function appears to be possible, at least for a modern refined diet. For example, the dental arches may not conform to the modal arrangement and teeth may be missing, yet adequate function remains (Slagter et al 1993). There are unfortunately no baseline requirements for an adequate dentition nor the minimal chewing performance necessary to avoid indigestion. A common rule of thumb when replacing missing posterior teeth is that the extent of the prosthesis can be reduced to the premolars without seriously affecting chewing (Kayser, 1984). This arbitrary estimation has not been defined by a minimum area for functioning posterior occlusal surfaces.

The same lack of quantifiable measurement is a feature of assessing orthodontic treatment goals and outcomes (Omar, McEwen and Ogston 1987). The clinical rules for correcting malocclusions, usually, have more to do with the restoration of modal tooth, arch and skeletal relationships, than with the restoration of function; if restoration of function is a concern of treatment, it is not measurable in the same way that tooth positions can be assessed on plaster casts or angles measured on a radiograph.

Muscle tenderness and limited movement are both features of temporomandibular dysfunction. The boundary between normal subjects, who may have some signs of dysfunction and patients, who may not have distinctly more severe signs cannot always be made (Widmar 1992). By some definitions based on the morphology of the joint structures, even symptomless individuals could be categorised as abnormal. One of the difficulties in assessing functional incapacity of a patient with muscle pain is the absence of the same baseline data needed to assess malocclusion, or the handicap due to reduced occlusal area. It is encouraging to find that a simple test, such as measuring maximum opening, is a useful indicator of treatment progress in temporomandibular dysfunction. This sign, although simple and of limited diagnostic use, reflects the poverty of useful tests for masticatory function.

Devices which monitor jaw movement have been available for many years. Most of the early devices produced a pen drawing of the jaw movement, while later devices use computers and can store co-ordinates of movement. The vigorous marketing of these devices has in some countries lead to their abuse as quasi-diagnostic aids. There are no published data that jaw-tracking devices can even discriminate between normal and dysfunctional subjects let alone improve on the diagnostic acumen of the clinician (Feine Hutchins and Lund 1988). Much the same can be said for devices which record surface electrical activity of masticatory muscles (Lund and Widmar 1989). Manufacturers claim that the resting levels of masticatory muscle recorded by their equipment can be used to improve diagnosis and treatment planning. They also suggest that their devices are good practice builders, a virtue shared by jaw tracking devices and other forms of impressive looking technology.

The Sirognathograph is a jaw tracking device with accepatable accuracy. (Hannam et al., 1980; Mongini and Tempia-Valenta, 1984). The earliest analyses of movements were based on visual assessments and the use of categories based on the shape of the chewing cycle. (Mongini and Tempia-Valenta, 1984; Proschel and Hofmann, 1988). Later work involved the measurements of various displacements and areas (Evans and Lewin 1986, 1987). One of the problems encountered was the finding of large standard deviations within subjects when average displacements were calculated. In 1985 a Siemens machine was purchased by the Faculty of Dentistry at the University of the Western Cape. I started evaluating its capacity for providing a more reliable analysis of jaw movement during function than was possible using displacements.

This work lead to the realisation that it was possible to simplify the measurement and understanding of masticatory movements. It was also clear that there was little reliable information about normal function, without which it would be premature to begin analyzing patients with malfunction, dysfunction or muscle pain. This work has evolved into an enquiry into optimum values of jaw movement and electromyographic activity, based on their association with chewing performance. The application of these values is dependent on providing a bench mark for the assessment of dysfunction in myogenic facial pain and of the degree of malfunction in orthodontic malocclusions. Present- day assessments of dysfunction are made by measuring jaw opening with a ruler and palpating tender muscles with a finger; malocclusion is registered by measuring plaster casts and radiographs. It was hoped that once baseline data on masticatory function was available, jaw tracking and electromyographic devices could play a valuable role in diagnosis and treatment progress of disorders which affect masticatory function.

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Chapter 2

The computer analysis of jaw movements

SUMMARY - A method of analysing jaw movements was developed by converting jaw displacements into a matrix of frequency distributions. Low frequencies were first filtered out: then quartiles and modes were used to describe the proportions and density of a core of movement. These variables were repeatable at successive recording sessions, yet accurate enough to reveal differences in chewing patterns between right- and left-sided chewing. All eight variables of jaw displacement were required to discriminate between the chewing sides of 15 subjects. A statistical model was developed to express the principal components of jaw movement. The first component consisted of variables that expressed the shape of the chewing cycle; the second, its distribution about the midline; the third, the prevalence of a bimodal pathway in the sagittal plane. There was a wide variation in patterns of chewing movements, which appear to be consistent with normal masticatory function. A multivariate model appears to be required to describe chewing movements.

INTRODUCTION

Jaw movements have been described visually, in general terms or by classification of plots made by tracking devices (Neill and Howell, 1984; Proschel, 1987; Michler, Bakke and Moller, 1987). Jaw displacements have been measured by several investigators: Mongini and Tempia-Valenta (1984) calculated the means and standard deviations of the displacement at various levels of separation; Evans and Lewin (1986), 1987) used a weighted mean to analyse jaw displacements and the area and proportions of the chewing cycle; Chew et al. (1988) made similar measurements.

If the data from such studies are examined, it is apparent that the standard deviation of a series of jaw displacements is frequently as high as 40% of the mean. Even with this limited precision, these studies have made pioneering contributions. Mongini and Tempia-Valenta (1984) found that the differences between the mean lateral displacements on opening and on closing were greater in a group of normal subjects than in patients with signs of muscle dysfunction. Evans and Lewin reported that missing lower incisors were associated with differences in chewing area (1987) and that subjects with heavily worn dentitions had a wider chewing cycle (1986). Gibbs et al. (1981) had noticed much earlier, that the width of the chewing stroke increased when chewing hard foods. Others have confirmed that bolus consistency alters the dimensions of the chewing cycle (Neill and Howell, 1984; Jempt, 1986; Proschel and Hofmann, 1988; Chew et al., 1988).

In spite of the accumulated evidence from tracking devices, there is no set of established criteria that can be used to describe normal or optimum jaw displacements during chewing. Clinicians treating mandibular dysfunction may be persuaded by manufacturers' claims that tracking devices have diagnostic value. Yet at least one of these devices (the Mandibular Kinesiograph) is apparently incapable of distinguishing between symptomatic and asymptomatic subjects (Feine, Hutchins and Lund, 1988).

Limitations in the diagnostic use of tracking devices do not appear to be related to inaccuracies in the measuring device itself. While the linearity of the Mandibular Kinesiograph is questionable, the Sirognathograph is said to be accurate within 1% of actual jaw movement (Hannam et al., 1980; Mongini and Tempia-Valenta, 1984). However, the sample size and statistical management of the data have not always been appropriate. The results of those studies using measurable data indicate that values for displacements do not have a normal distribution, the occasional extreme value for a displacement having a disturbing effect on the mean and a gross effect on the range. The problem is evident when comparing sets of tracings from the same subject (Fig. 1). The outline and total area of each series of chewing cycles show little similarity, yet the dimensions and shape of a central core are quite similar. Some form of filter that can exclude the extreme displacements for a given subject, appears to be needed. However, if extreme displacements occur often, it would be incorrect to ignore them. It would therefore be more important to exclude unusual (low-frequency) displacements, than to filter out extreme displacements, which might be quite frequent.

The purpose of this study was to develop an analytical method that would reduce a series of jaw movements to a core. Measurements of the core would have to prove reliable when repeated at successive recordings, and as a minimum requirement, be accurate enough to discriminate between movements recorded from the same normal subject when chewing on different sides.

Figure 2.1 Tracings in a frontal plane of jaw movements made by the same subject (JT). Three separate trials were recorded while chewing on the right side. Although an outline produced by the maximum displacements is quite different for each tracing, there are similarities in the shape of the central core.

METHOD

The Sirognathograph (Siemens, Bensheim, Germany) is apparently able to reproduce jaw movements with a high degree of accuracy provided all head movement is constrained during recording (Michler et al., 1987). It was therefore chosen for this study, and set up following the recommendations made by Lewin (1985).

The computer analysis

It was of primary importance (see Introduction) to filter out unusual displacements of the jaw so as to reduce the variance of data from a series of chewing cycles and thus retain a core of data from the most frequently occurring displacements. A computer program was written (A.Lewin) to project the digital data from the Sironathograph on to a 2-dimensional matrix of frequency distributions (Fig.2). Separate matrices were used for frontal and sagittal projections. Each matrix was 40 columns wide, 20 each side of the midline, and 38 rows deep. Each bin or cell of the matrix was a square with sides such that 2.76 cells were equal to 1 mm. The value in each cell of the matrix represented the number of times the tracking point occupied the cell for 10ms. Each matrix contained the cumulated frequencies of 10 s continuous recording of jaw movement during chewing. The matrices for five trials were combined to produce the example given in Fig. 2.2. The starting point of the tracking device (at maximum intercuspation) has the co-ordinates, row zero, column zero.

Calculation of the displacement at each level of jaw separation.

The frequency distribution of level 15 from the right frontal matrix in Fig. 2.2 is reproduced in Fig. 2.3a. As the data are not normally distributed, mode and median values were used to describe the dimensions of the core.

The cumulative subtotals counting from the midline are given below each column number; the count in the last column (121) is the frequency total for that level. As the frequency values were counted into columns in a rank order from 1 to 20, the median column value was calculated by finding the midpoint of the frequencies for each level. Hence, for level 15, the median column value occurred where the frequency was 60.5. Counting from column zero, the median lies between the subtotal 56 (Sub1), which occurs at column 10, and the subtotal 65 (Sub2) which occurs at column 11 (Fig.3a). The exact position of the median column value can be described as the displacement of the median from the midline, and was calculated by the formula:

$$\text{median displacement} = N - \frac{(\text{Sub2} - \text{median})}{(\text{Sub2} - \text{Sub1})}$$

where N is the larger of the two column values (11). Sub1 is the lesser of the frequency subtotals (56) and Sub2 is the greater of the frequency subtotals (65). Hence

$$\text{median displacement} = N - \frac{(65 - 60.5)}{(65 - 56)}$$

$$= 10.5 \text{ column units.}$$

	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
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2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	35	91		99	99	84	99	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	49		99	99	99	99	99	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	7	22		47	51	66	42	80	54	26	4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	8		18	22	16	14	38	22	15	17	6	1	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	2	9		43	34	31	17	58	46	57	37	36	22	14	11	3	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	4	2	8		10	26	25	16	18	12	20	20	24	26	13	12	9	5	2	1	0	0	0	0
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11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	3	5	6		5	6	4	8	15	10	6	15	7	16	15	7	26	12	9	2	7	7	3	2
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37	0	1	0	0	0	1	0	0	1	0	0	0	1	0	2	1	2	2	3	1		3	2	0	2	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
38	0	4	2	0	3	0	1	2	1	4	4	7	2	8	4	5	19	10	11	16		11	2	2	7	5	2	4	6	4	0	1	0	0	0	0	0	0	0	0	0

Figure 2.2 The frequency distribution matrix in a frontal plane of the jaw movement recorded by JT (Fig. 2.1). The frequency values represent the number of 10 ms periods the tracking device was recorded in each cell of the matrix. The column numbers (1020 on each side) and rows (1-38) provide vertical and horizontal coordinates for each frequency value. Level 15 and 25 on the right side of the matrix are data used to illustrate the method used to find the mode and median displacements.

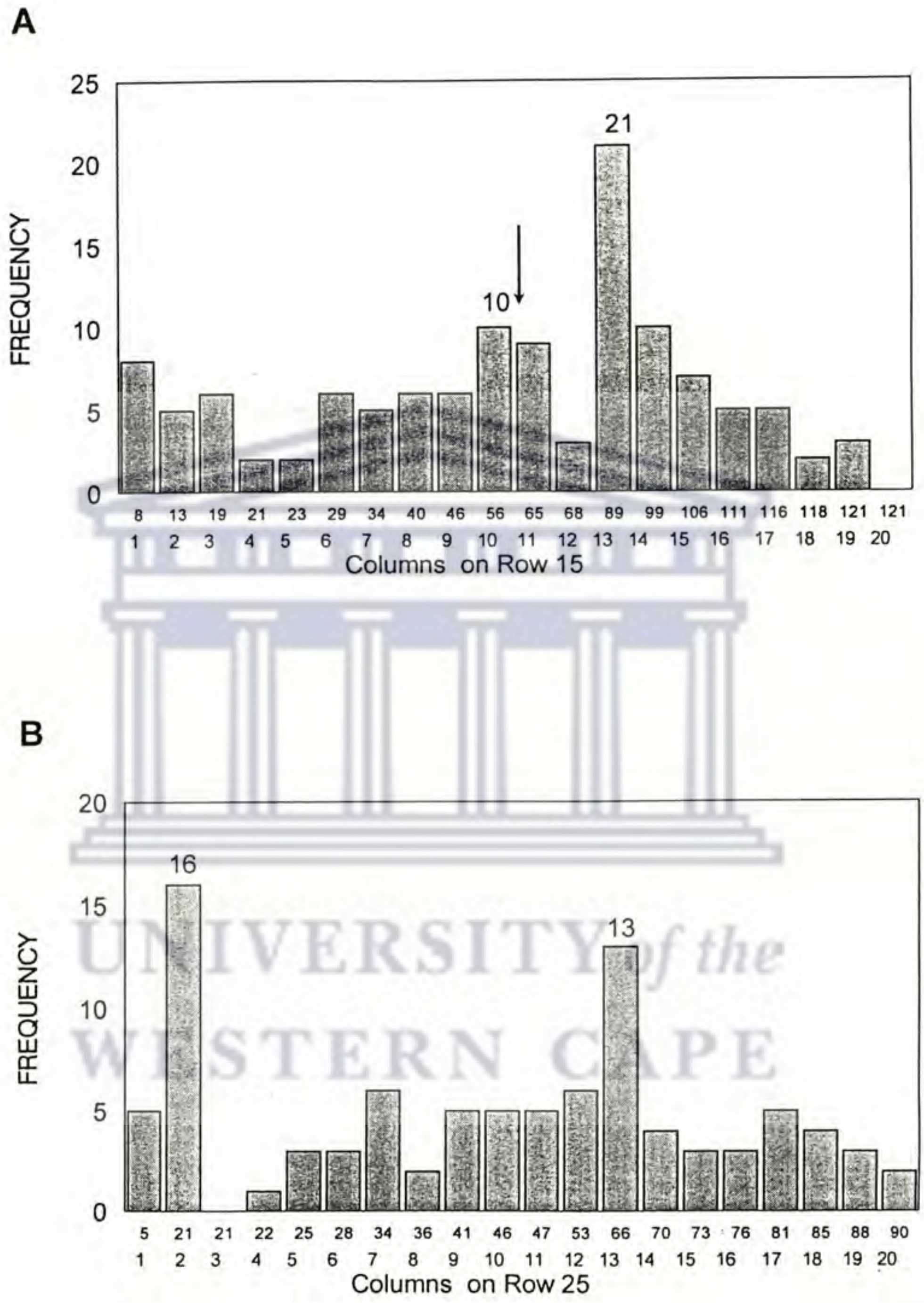

Figure 2.3. The frequency values for level 15 and 25 from the matrix in Fig 2.2 are represented in histograms. A) the frequencies for level 15 with the mode (21) at column number 13. The frequency subtotals are shown below the numbers. The arrow at column 10.5 indicates the position of the median frequency (60.5). B). The frequencies for level 25 fall into two high frequency zones at column 2 and 13. The data on this level fulfilled criteria for a bimodal distribution.

As the median displacement occurs halfway (50%) along the ranked frequency values, the 1st and 3rd quartile displacements occur at 25% and 76% of the frequency values. The position of the 1st and 3rd quartiles was found to be 6.3 and 13.2 column units from the midline, using the method for finding the median displacement. The distance between them was therefore 5.9 column units. Thus at level 15, 50% (25-75%) of the visitations to cells of the matrix occurred within a zone 5.9 column units wide. A second computer programme was written (R.Wilding) to read the frequency distribution data and to make the following calculations.

Frontal areas (horizontal and vertical). The position of the 1st and 3rd quartiles, and the distance between them, was calculated for each row (level of jaw separation of the frequency distribution marix). The sum of these values for each side of the matrix was used to describe the area within which 50% of the cell visits occurred on the chewing and non-chewing sides of the cycle. The area (in SI units) of the chewing side was calculated from the following formula:

$$\text{area} = \frac{\text{sum of interquartile distance}}{(\text{the bin factor})^2}$$

$$\text{area of Fig.2} = \frac{243.3}{(2.76)^2} = 31{,}4\ \text{mm}^2$$

(Chewing side)

The same calculations were made of the vertical displacements for each column of the matrix. The vertical area on the chewing side of the matrix in Fig. 2.2 was 27.5 mm^2. The quartiles for each level of the matrix were plotted to provide a visual representation of the shape and area of a core outline in which 50% of the cell visits occurred (Fig. 2.4). A similar plot was made to represent the quartiles for each vertical column (Fig. 2.5).

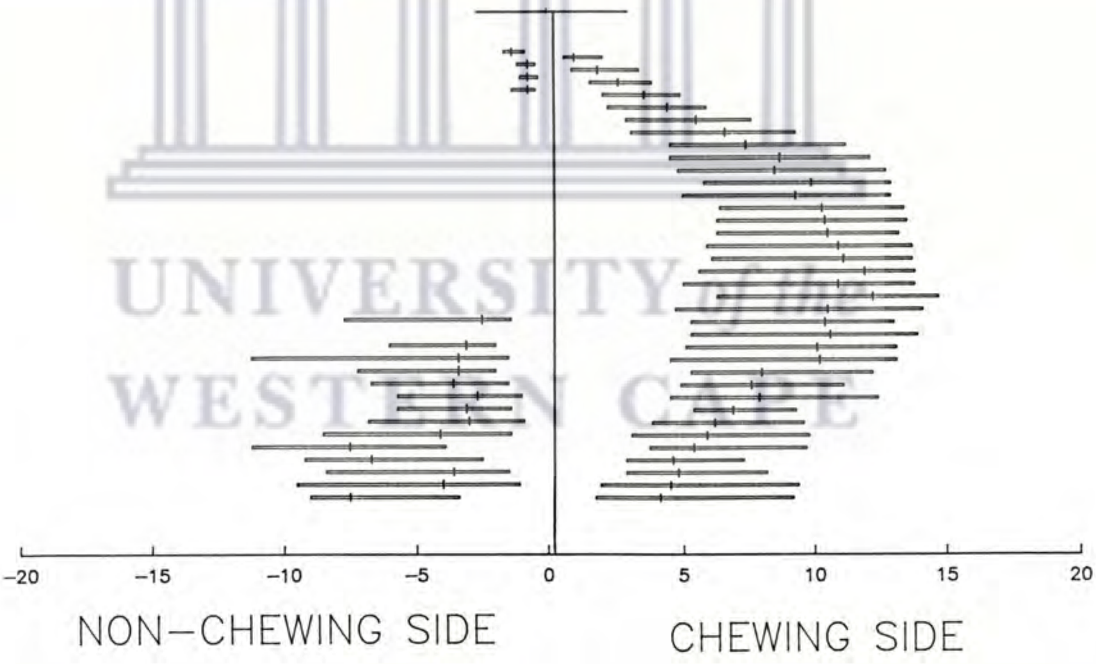

Figure 2.4 Horizontal bars represent the 1st and 3rd quartiles for each level on the chewing side and non-chewing side of the frontal frequency distributions of Fig 2.2 . Medians within each bar are shown with a vertical tick mark. The absence of plots in parts of the non-chewing side is due to frequency filtering. The variable, area ratio, was calculated to express the ratio between the area formed by the plots on each side of the chewing cycle.

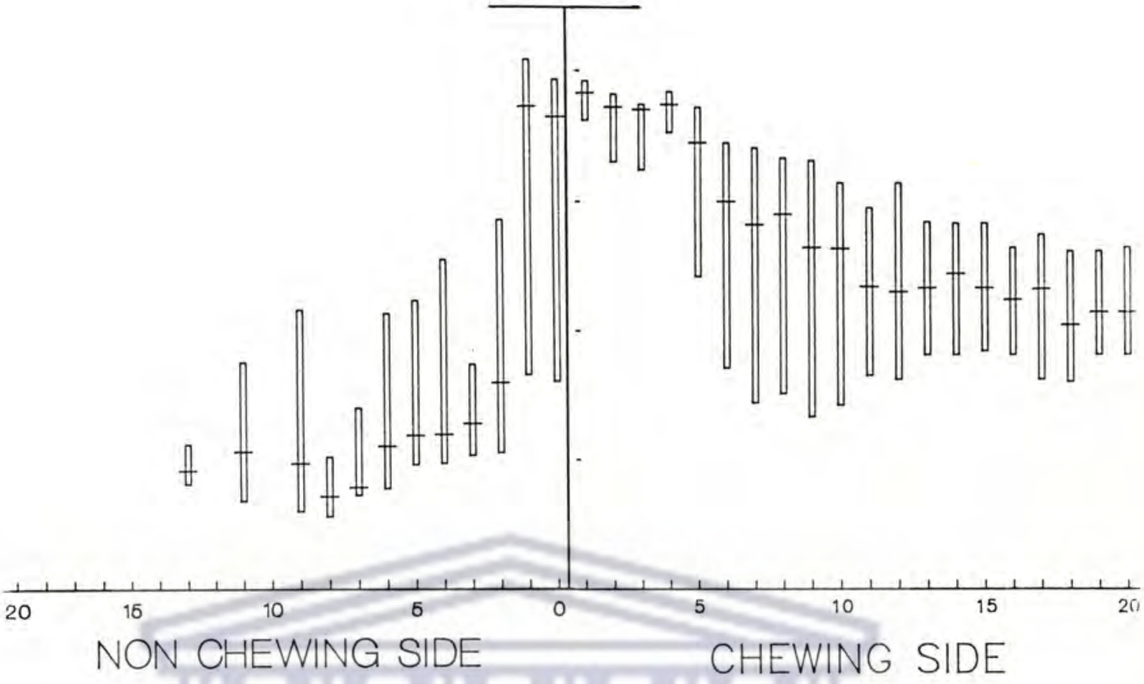

Figure 2.5 Vertical bars represent the 1st and 3rd quartiles for each column on the chewing and non-chewing side of the frontal frequency distribution in Fig. 2.2.

Frequency filtering.

In some parts of the matrix, there were low-frequency values, which indicated that only one or two sporadic jaw excursions had occurred there. If, in a particular level, the tracking device was not recorded at least every second cycle, the displacements in that level were not considered significant and were excluded.

This procedure was applied to filter the data in Fig. 2.1. On the chewing side, the frequency per cycle exceeded 1 for every level and so no filtering occurred. However, on the non-chewing side, filtering caused the exclusion of the data from level 5 to 25 (Fig. 2.4).

Area ratios.

In the sample data given, the area calculated by summing the interquartile distances for the non-chewing side, excluding those from levels 5-25, was 16.64 mm^2. A comparison between the areas on the chewing and non-chewing sides was made in order to estimate the extent to which chewing displacements were bilateral. Thus in Fig. 2.2;

area ratio (horizontal) =

$$\text{area for Fig.2.2} = \frac{\text{chewing side}}{\text{chewing side + non-chewing side}} \text{ areas}$$

$$\text{area ratio for Fig. 2.2} = \frac{31.4}{31.4 + 16.6} = 0.65$$

A value for the vertical area ratio was also calculated, using the data derived from column interquartile distance.

Zones of frequency distribution (sextants).

The frequency distribution matrix was divided into six equal zones or sextants (S1-S6) horizontally between levels 12 and 13 and between levels 25 and 26, and vertically into chewing and non-chewing sides (Fig. 6). Each sextant S1-S6 was then further subdivided into three equal vertical parts, V1, V2, V3, representing displacements of .1-7, 8-13 and 14-20, respectively. The average of the median horizontal displacements within each sextant was calculated and located into the appropriate vertical subdivision. Hence, if the average median horizontal displacement of S2 on the chewing side was 10.8 it was placed in subdivision V2. The vertical medians within V2 were averaged to provide a vertical co-ordinate for S2 (16.7). A centre for each sextant with horizontal and vertical co-ordinates was thereby found. Sextant centres were excluded if the average frequency per double cycle was less than one. In Fig. 2.2, therefore, sextants S5 and S6 were excluded.

Bearing between sextant centres.

The relative position of the sextant centres thus derived was calculated. The co-ordinates of the first sextant were used to calculate its bearing in degrees from intercuspation by routine trigonometrical methods. The co-ordinates of the next sextant were used to calculate its bearing from the path to the first sextant. The angles between lines connecting the sextant centres indicated the change in direction taken by the magnet in order to arrive at each sextant centre.

The total of the bearing changes on each chewing side described the core shape of the chewing cycle.

Angle at intercuspation. The line joining the first sextant centre on the chewing side at the point of intercuspation formed an angle with the horizontal which decreased as the lateral component of the chewing pathway increased.

Prevalence of a bimodal frequency. The mode of the frequency distribution in Fig. 2.3a is 21 at column 13. The next most frequently visited cells (10) are at columns 10 and 14. The most frequented positions on level 15 were thus reasonably close to each other. At level 25 the two most frequently visited cells are at columns 2 and 13, respectively, indicating the presence of two separate but substantial high-frequency zones (Fig. 2.3b).

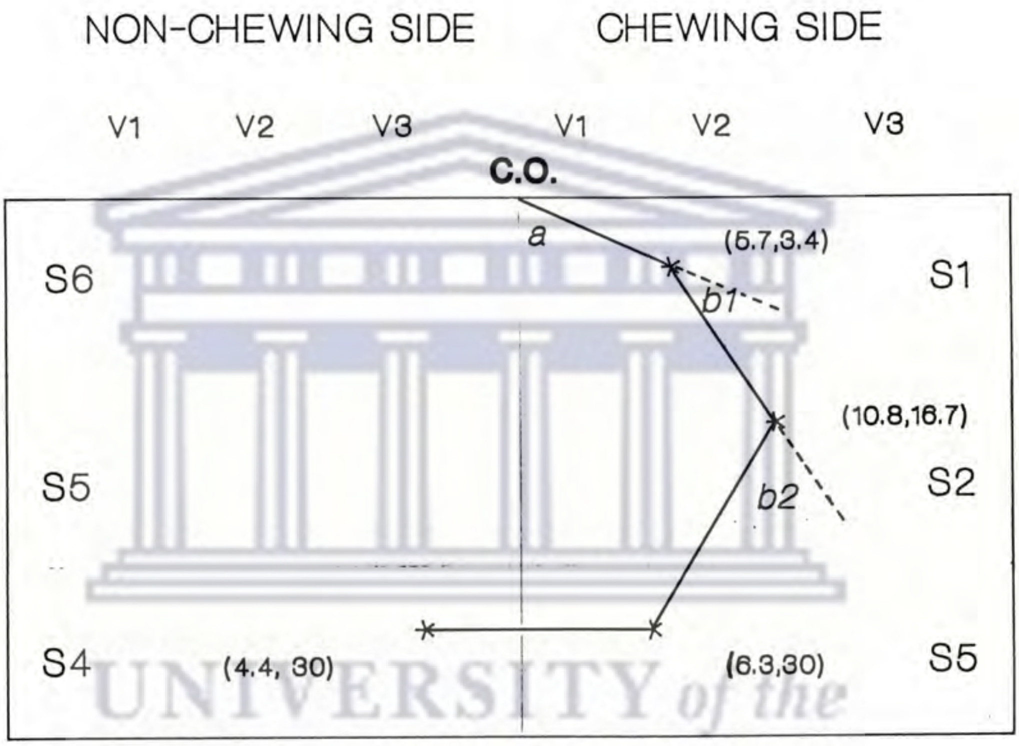

Figure 2.6 The frontal displacements were divided into sextants (S1-S6) and each chewing side into three vertical divisions (V1-V3). Horizontal and vertical medians for each sextant provided centres "*" with level sand column coordinates (given in bin values at each centre). The angle at intercuspation is the angle α between the centre of S1 and the horizontal. The bearing between centres is the total of angles ß1 and ß2 which measure the directional changes between centres on the chewing side.

To obtain a quantitative expression of the prevalence of such bimodal patterns, the data for each level of the entire frontal and sagittal frequency distribution (left and right sides) were analysed and the position of the mode determined. The presence of a second mode position was recorded if:

(a) Frequency of visitation was at least 70% of the mode for that level (this condition excluded insignificant second modes); and

(b) The second mode position occurred at least 5 columns from the mode (this condition excluded a high frequency of visitation adjacent to the mode from being categorised as a separate high-frequency zone).

If both these criteria were met, the inter-mode distance was calculated. From the data selected in Fig. 2.3a, the second mode was not recorded for level 15 as it occurred within 5 column units of the mode; it was also excluded on the grounds of being less than 70% of the first mode. But for level 25 the second mode was recorded and the distance between the modes calculated, as this second mode fulfilled both criteria, the inter-mode distance being 11 column units. This inter-mode distance was converted from the column units to millimetres (11/2.76 = 3.99 mm). The prevalence of acceptable, bimodal frequency distributions was calculated as a percentage of rows with bimodal distributions.

Mode percent. The mode frequency for each level was expressed as a percentage of the total frequency for that level. The mode percent was used to define the breadth of the chewing pathway, the high values indicating that movements were concentrated in a narrow track.

A visual representation of the distribution of high frequencies and bimodal distributions was generated by transforming the matrix values into a graphic display using patter codes. Low frequencies were represented by a horizontal line; a zone of high frequencies around the mode was represented by filled boxes (Fig. 2.7).

Summary of variables measured.

1. *Bearing between centres.* The angles formed between imaginary lines joining the three sextant centres on the chewing side.
2. *Angle at intercuspation.* The angle at intercuspation, formed between the horizontal and the first sextant centre.
3. *Area ratio.* The ratio of the areas on the chewing and non-chewing sides of the frontal frequency distribution.
4. *Mode percent.* The average of the mode expressed as a percentage of the total frequency for that level.
5. *Frontal bimodal prevalence.* The percentage of levels in the frontal frequency matrix in which a significant second mode was recorded.
6. *Sagittal bimodal prevalence.* The percentage of levels in the sagittal frequency matrix in which a significant second mode was recorded.
7. *Frontal mode distance.* The average distance between the first and second modes on the frontal frequency matrix.
8. *Sagittal mode distance.* The average distance between the first and second modes and the sagittal frequency matrix.

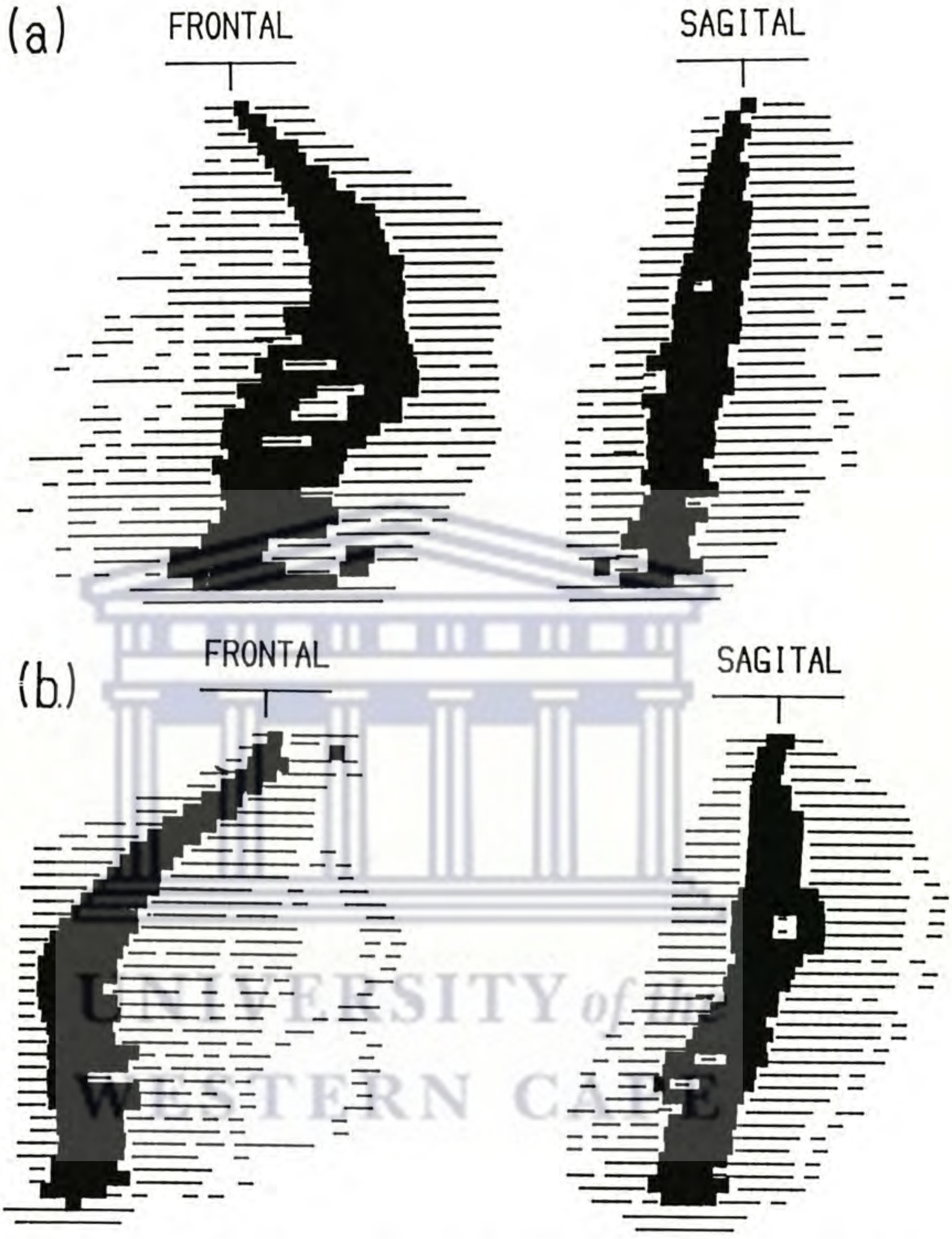

Figure 2.7 Graphic representations of the frontal and sagittal frequency matrix of JT chewing on (a) the right side and (b) on the left side. Horizontal lines indicate frequencies greater than zero. The central core (filled boxes) represents the zone around the mode in which 33% of the frequencies occurred and gives an indication of the width of the most common pathways during chewing. When chewing on the right side (a) the frontal core crosses the midline whereas is completely unilateral when chewing on the left (see area ratio for JT in Tables 2.1 and 2.3. The presence of a bimodal distribution of frequencies is revealed by the separation of the core into two parts (see also frontal bimodal prevalence for JT in Tables 2.1 and 2.3)

Evaluation of the computer analysis

The second part of this study was designed to evaluate the reliability of measurement and accuracy of each of the above variables when recorded from the same subject. Fifteen healthy young adults (6 females and 9 males) volunteered to take part in the study. Individuals were excluded if they reported a history of temporomandiblar dysfunction syndrome. None of the subjects had a deviation on opening or experienced any pain on wide opening or chewing. All subjects had an Angle Class 1 incisal relationships and a full complement of teeth with the exception of the third molar which was not present in all individuals. All subjects had some occlusal restoration, though no subjects had posterior bridges.

Each subject was seated in an upright chair and the head fixed using a modified cephalostat apparatus, which held the head at the bridge of the nose and at each external auditory meatus. The aerial of the sirognathograph was held in place using a head band removed from a welding helmet. The settings on the cephalostat and on the bars of the aerial were recorded for each subject. At subsequent recording sessions the same settings were used to insure similar head placement.

Each subject carried out 2 separate sets of 10 chewing trials, 5 on the right side and 5 on the left side. Each trial lasted 10 seconds. The test food was a tough variety of wine gum. A Wilcoxon paired-rank test was used to test for significant differences between sets of data for each subject and between data from left and right chewing sides. Discriminant analysis was used to investigate the possibility that a combination of measurements might be necessary to reveal differences between data from different sets or between different chewing sides. The data from each subject were pooled and a principal component analysis used to determine which combination of measurements best described displacements during chewing. Multivariate analysis was used to determine whether displacement measurements were related to the sequence of the chewing trials.

RESULTS

Comparisons between independent sets of recordings

For each variable, the values of the 5 right and 5 left trials were combined (Table 2.1). The 10 values for each variable from the first set of recordings were compared with the 10 values from the second set of recordings using a Wilcoxon paired-ranks test (Table 2.2). Of the 120 pairs of variables compared, 9 pairs showed significant differences between the first and second recording. These differences were not all found within the same subject or within the same variable.

Comparisons between left and right recordings

The data for left-sided chewing from the first and second sets were combined, as were those for right-sided chewing (Table 2.1). The 10 values for right-sided chewing were compared with those of the left using a Wilcoxon paired-ranks test (Table 2.3). For each subject there were significant differences between chewing sides in at least one of the eight variables. For each variable, significant differences between the data for right and left chewing occurred in at least 4 out of 15 subjects.

Table 2.1 Data for each variable for one subject (JT)

		Trial Number												
		1	2	3	4	5	1	2	3	4	5		Median	
		Chewing left side					Chewing right side					SE	Lt	R
BEAR	Set 1	44	62	37	43	49	78	76	40	76	70	54	40	74
	Set 2	60	64	19	38	37	80	60	78	69	53	60		
ANGLE	Set 1	46	27	44	44	40	35	41	48	40	38	40	44	39
	Set 2	40	29	66	49	53	26	41	29	38	51	40		
AREAR	Set 1	93	97	99	99	86	73	68	81	56	80	77	95	63
	Set 2	82	99	92	97	98	75	57	53	77	66	74		
MOPER	Set 1	34	23	31	23	37	30	23	20	22	24	24	27	23
	Set 2	37	26	22	29	26	17	19	15	23	24	24		
FBIMOD	Set 1	24	32	27	32	56	43	45	51	45	43	43	31	46
	Set 2	29	32	32	21	29	45	51	54	37	56	35		
SBIMOD	Set 1	29	54	33	43	45	40	62	18	51	54	44	48	47
	Set 2	59	59	56	48	48	37	43	62	51	43	50		
FMODIS	Set 1	4.9	4.5	2.9	4.4	9.1	5.8	5.6	4.1	6.9	5.5	5.2	4.7	5.2
	Set 2	7.4	5.8	6.2	3.4	4.4	4.7	6.4	4.9	4.5	4.4	4.8		
SMODIS	Set 1	2.3	2.4	1.2	1.9	2.4	2.1	2.2	1.4	1.8	1.3	2.1	2.4	1.8
	Set 2	2.3	2.3	2.4	1.8	2.3	1.3	1.8	1.8	2.4	2.7	2.3		

The median values for set 1 and set 2 were calculated after having pooled the data from right and left recordings for each set. The median values for left and right chewing were calculated after from having pooled data from the same sides. BEAR = bearing between centres; ANGLE = angle at intercuspation; AREAR = ratio chew:non-chew area (%); MOPER = ratio mode:frequency (%); FBIMOD = frontal bimodal prevalence (%); SBIMOD = sagittal bimodal prevalence (%); FMODIS = frontal inter-mode distance (mm); SMODIS = sagittal inter-mode distance (mm).

Table 2.2 Results of Wilcoxon paired-rank tests for differences between the data from the first and second set of recordings.

Subject	BEAR	ANGLE	AREAR	MOPER	FBIMOD	SBIMOD	FMODIS	SMODIS
SA	-	-	-	-	-	-	-	*
JE	-	-	-	-	-	-	-	-
CH	-	-	-	*	-	-	-	-
AK	-	-	-	-	-	-	-	-
GL	-	*	-	-	**	-	*	-
GM	-	-	-	-	-	-	-	-
RM	-	*	-	-	-	-	-	-
JO	-	-	-	-	-	-	-	-
NR	-	-	-	-	-	-	-	-
SS	-	*	-	-	-	-	-	*
DS	-	-	-	-	**	-	-	-
ET	-	-	-	-	-	-	-	-
JT	-	-	-	-	-	-	-	-
RW	-	-	-	-	-	-	-	-
JW	-	-	-	-	-	-	-	-

Key for variables as for Table 2.1.
Key to *p* value codes; - $p > 0.05$; *$p < 0.01$; ***$p < 0.001$.

The variables in which significant differences occurred most often were: area ratio (10 subjects); bearing between centres (7 subjects); and the sagittal-mode-distance (6). Significance varied from $p < 0.05$ to $p < 0.001$.

Table 2.3. Results of Wilcoxon paired-rank tests for differences between data from right and left sided chewing

Subject	BEAR	ANGLE	AREAR	MOPER	FBIMOD	SBIMOD	FMODIS	SMODIS
SA	***	-	**	-	-	-	-	-
JE	-	-	**	***	-	-	***	*
CH	**	-	*	-	-	-	-	*
AK	-	*	-	-	-	*	*	-
GL	-	-	***	-	-	-	-	-
GM	**	-	-	-	*	-	**	*
RM	-	-	*	**	*	**	-	**
JO	-	-	***	-	*	-	-	*
NR	***	-	***	-	-	-	-	-
SS	-	**	-	-	-	***	-	–
DS	-	-	**	-	-	-	-	-
JT	**	*	***	*	**	-	*	-
ET	***	-	***	***	-	-	-	-
RW	-	-	-	-	-	**	-	-
JW	***	***	-	-	*	**	*	**

Key for variables as for Table 2.1.
Key to *p* value codes as for Table 2.2.

Discriminant analysis

Using the chewing set as the factor for discrimination, the eight variables were assessed for their ability to discriminate between the data from the first and second set. No significant differences were found for any subject (Table 2.4). The degree of difference between the two sets of data can be expressed as the distance between the two pools of data variables, also known as the centroid or Mahalanobis distance

(Armitage and Berry, 1987). A distance of more than 4 indicates reliable differences between groups. The centroid distance between sets of data varied from 0.24 to 1.00 with a mean of 0.48 (Table 2.4).

Table 2.4 Discriminant analysis for each subject, using all variables, and using first *set* and then *side* as the factor. The significance and distance between centroids (C.D.) are given for each factor used.

	Set as factor		Side as factor	
	p value	C.D.	p value	C.D.
SA	0.17	1.00	0.000	2.2
JE	0.86	0.33	0.002	1.4
CH	0.85	0.34	0.001	2.1
AK	0.90	0.30	0.03	1.2
GL	0.40	0.59	0.000	2.3
GM	0.18	1.00	0.001	1.7
RM	0.43	0.57	0.01	1.6
JO	0.89	0.32	0.000	1.8
NR	0.49	0.54	0.000	1.9
SS	0.23	0.97	0.005	1.2
DS	0.95	0.24	0.02	1.4
ET	0.94	0.27	0.000	1.8
JT	0.45	0.56	0.000	3.3
RW	0.88	0.45	0.02	1.3
JT	0.85	0.3	0.000	1.8

When the chewing side was used as the factor for discrimination, there were significant differences between left and right sides for all subjects. If fewer than eight variables were used as variables, it was no longer possible to discriminate between left- and right-side chewing in all subjects. The levels of significance varied but were all greater than a 97% confidence level ($p < 0.03$). The centroid distances had a range from 1.2 to 3.3 with a mean of 1.8 (Table 2.4).

A discriminant analysis was used to determine whether it was possible to classify the data according to the sequence of the chewing trial. A data selection was made of the first and last trial and all the variables were used. No combination of variables was able to discriminate between the first and last trial.

Principal components analysis

When several variables are used to describe an individual it may be useful to combine them into a smaller number of components. The variables in each component are related by a formula consisting of coefficients or weights for each variable. The larger the value for a variable's weight, the greater its influence on the component.

A principal components analysis was applied to the variables in this study to determine which combination of the variables best described chewing displacements. This analysis was done after having pooled the data from each subject. Using all the variables it was found that 87% of the variance of the data could be accounted for by three components (Table 2.5). The weights of the first component indicated that bearing between centres, angle at centre, frontal bimodal distribution, and frontal mode distance were the major variables. The second component had area ratio and mode percent as the dominant variables; the third component had sagittal bimodal distribution and sagittal mode distance as dominant variables (Fig 2.8).

Table 2.5 Weights for variables forming the first three principal components used in this study to describe normal chewing. The weights of dominant variable are underlined.

	Principal components		
	1	2	3
BEAR	0.40	-0.19	-0.01
ANGLE	-0.43	0.14	0.33
AREAR	0.11	0.67	-0.01
MOPER	-0.18	-0.63	0.08
FBIMOD	0.40	-0.09	0.10
SBIMOD	0.37	-0.01	0.54
FMODIS	0.40	-0.20	-0.1
SMODIS	0.36	-0.10	-0.61

Key to variables as for Table 2.1.

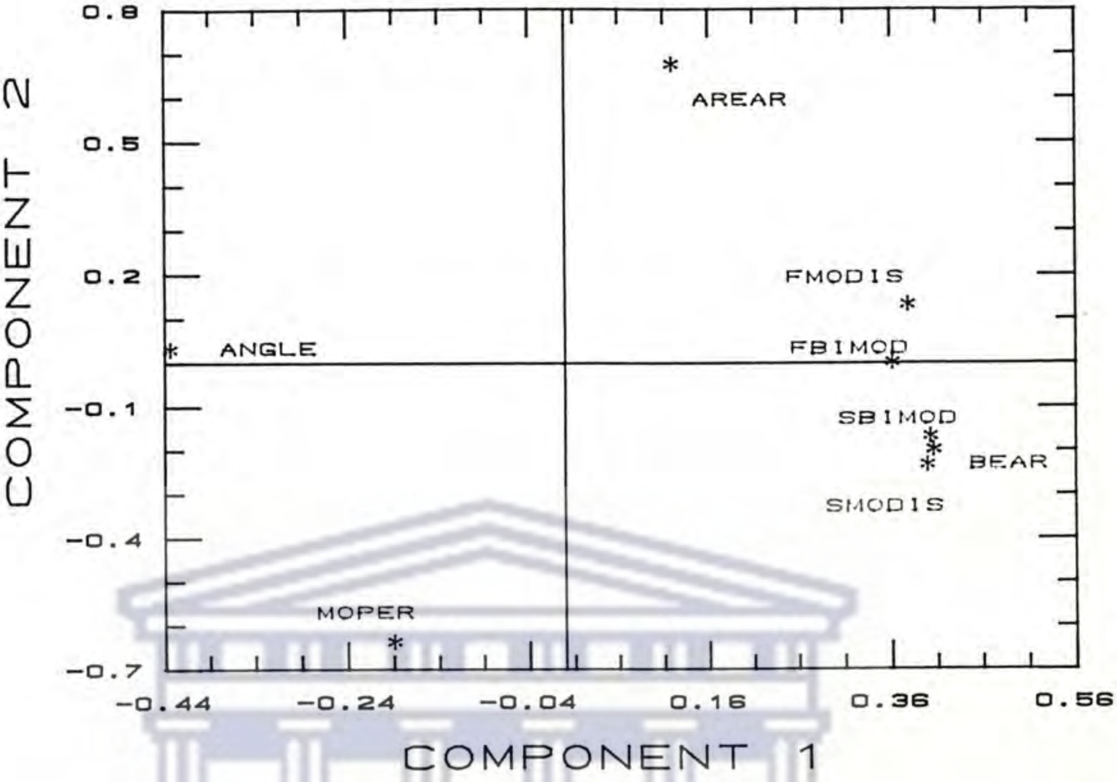

Figure 2.8 A plot of the coefficients of the first two principal components of jaw movement. The further each variable is from the centre of the two intersecting axes, the more powerful is its ability to account for the variance of the data. The further each variable is from adjacent variables the more independent is its contribution to each component.

DISCUSSION

The method used in this study relied on the transformation of spatial co-ordinates on to a 2-dimensional matrix for frontal and sagittal projections. The advantage of this transformation is that it allows filtering of low-frequency values. This may be a crucial procedure to avoid the leverage that the occasional outlying displacements can have on the rest of the displacement values. Michler et al (1987) also found it necessary to exclude extraneous jaw movements, which they achieved by constructing a template that covered most of the tracing area but excluded outlying tracings.

The plot of the number of visitations of the tracking device in each cell provided a useful means of studying the most commonly frequented parts of the chewing cycle (Fig. 2.7). The central core represented a zone in which 33% of the visitations occurred. The presence of a bimodal frequency was revealed by the separation of the core into two parts. Even without further statistical analysis this type of plot provides a more useful visual representation of the chewing cycles than the graphic representation in Fig 2.1. The differences between the left and right sides of the subject J.T. is evident in Fig. 2.7 if the width and position of the central cores from each chewing side are compared.

Difference between sets

The comparison between sets of data recorded on separate occasions showed that measurements made of jaw movement was reproducible within the limits of accuracy of the apparatus. There were, however, occasions when there were significant differences between sets of data. These differences did not appear to be located in one particular variable or within a particular subject. They may behave through failure to ensure that the head frame was properly positioned or from movement of the head during recording, although either of these types of error would presumably have affected other variables at the same time. It is also possible that these differences reflect a normal variation in chewing movements. The computer program that analysed displacements was designed to set certain conditions for accepting data. For example, if displacements did not occur above a certain minimum frequency, they were ignored. It is possible that by altering this minimum, and other conditions like it, the analysis could be even more selective, and hence less sensitive to normal variation.

Differences between sides

The comparison between displacements when chewing on the left and right sides indicates that there were detectable differences in the sample studied. Differences between chewing sides were reported by Gibbs et a. (1981) and Michler et al. (1987). All variables appeared to contribute to this difference, though some were more active than others (Table 2.5). The variables bearing between centres and area ratio were most often found to be different.

There was no single variable that consistently could discriminate between left and right displacements during chewing. Discriminant analysis revealed that differences between right and left chewing were significant for all subjects only when all eight variables were used. The variation between centroids indicated that differences between left- and right-side chewing were more marked in some subjects than in others.

It is important to recognise a limitation of the analysis of jaw movement used in this study. The frequency distribution of the mid-incisor point gives no indication of the sequence of movements recorded. Hence this analysis does not readily distinguish between left and right sided chewing. However a sequential plot of movement in the frontal plane would clearly indicates the side from which the jaw approaches intercuspation.

Components of chewing movements

The number of variables used to describe chewing was reduced by principal component analysis to three main components. The weight (coefficient) for each variable made it possible to identify the contribution it made to each component (Table 2.5). Chewing displacements could not adequately be described by less than three components, each one describing a different characteristic.

The four prominent variables in the first component described the shape of the frontal chewing cycle by a defining the angles and the presence of a bimobal pathway. The weights of three variables were positive (indicating a direct relationship) except for the variable angle at intercuspation which had a negative weight (indicating an inverse relationship). Hence the larger the angle at intercuspation (that is the more nearly vertical the pathway) the smaller would be the bearing between centres and the percentage of bimodal pathways. In summary, the first component describes the shape and dimensions of the core of movement. As the values of the variables increase they describe a progressively flatter, wider, bimodal chewing pathway. They are related to each other but are not dependent. There may be significant differences in one while not in the other.

In the second component, the two prominent variables, area ratio and mode percent, were inversely weighted. A high area ratio describes a unilateral chewing pattern, while a low mode percent indicates a broad pathway on the chewing side. The opposite values for the variables describes a bilateral chewing cycle with a narrow pathway on the chewing side.

The third component is dominated by the sagittal variables: the bimodal distribution and the width between the mode and a second mode. A prominent bimodal pathway in the sagittal plane might suggest that the jaw was not moving laterally, in which case it would be inversely related to the frontal bimodal prevalence. As no interaction with any of the other six variables was noticeable, it would seem that a well-defined and wide bimodal sagittal pathway may not preclude a prominent bimodal pathway in the lateral plane. A chewing cycle whose plane was orientated between the sagittal and frontal planes would account for this observation.

The value of principal component analysis in this study is that it confirms the need for several variables in the measurement of jaw movements. The three components each helped to identify the contribution each variable made to the overall description.

The differences found between chewing movements on separate sides of the jaw could not be accounted for with one variable. This suggests a wide variation in chewing patterns within normal subjects which do not appear to fit any single model. Neill and Howell (1984) devised a classification system based on 16 different shapes of chewing strokes. Similarly, Proschel (1987) found it necessary to use 14 different patterns in his classification; he observed that although the traditional drop shape was one of them, it was seldom found. Proschel and Hofmann (1988) concluded that chewing cannot be characterized by a single pattern.

Gibbs et al. (1981) observed that the width of the chewing cycle was influenced by the consistency of the bolus, and Jempt et al. (1979) has added that as the bolus is altered the vertical height reduces. Our findings failed to confirm any relationship between the variables defined and the assumed reduction in bolus size with successive chewing trials.

CONCLUSIONS

1. Jaw displacement variables can be measured with reliability when a multivariate analysis is used to compare two independent sets of recordings.

2. There are differences in the patterns of displacement between left- and right-sided chewing. In some subjects this difference is more pronounced than in others.

3. It is necessary to use more than one variable of jaw movement to discriminate between chewing sides.

4. Further studies are required to determine optimum values for these variables and optimum interactions between them. The results of the displacement variables in preferred chewing movements and the relationship between occlusal contact area and variables may provide a basis for determining a profile of optimum values.

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Chapter 3

Jaw movements associated with preferred chewing

SUMMARY

Jaw movements during voluntary chewing were recorded from 15 normal subjects with a sirognathograph. A computer program was used to provide a graphic display of the closing strokes in the frontal plane. A record was made of the side from which the jaw approached a central occlusal position. An average of 90 closing strokes was recorded for each subject. In 10 of the subjects, statistical differences were found between the use of the right- and left-hand sides. In these subjects this preference was confirmed by analysis of results from a second set of observations. A model was derived, using multiple regression analysis, which identified a relationship between four jaw-movements variables and an index of preference. A broad chewing pathway, with a bilateral distribution, together with a wide sagittal pathway were characteristics associated with preference. An indication of optimal jaw-movement patterns may be derived from identifying movement variables associated with preferred chewing.

INTRODUCTION

The preference for using either the right or left hand is well documented. The percentage of left-handers varies; the biblical story of the 700 left-handed men in the 26,700 strong army of the children of Benjamin provides an estimate of 2.6% (Judges 20: 15-16). Preference for use of the left hand was found to be 12% by Porac and Coren (1981), who used an index of laterality (R-L)/(R+L) to express handedness, eyedness, footedness and earedness. Preference was found to be most consistent with handedness (77%) and least consistent with footedness (49%). The preference for a particular side tended to prevail, right-footed and 44% had the same side preference for all four activities.

Hoogmartens and Caubergh (1987) added another dimension, that of chewing preference. They observed the side to which the jaw moved to take the first bite of a bolus. From 10 tests an index of laterality was calculated: 45% of patients had a consistent preference for left- or right-side chewing. No association was found between chewing-side preference and handedness, footedness, eyedness or earedness. The investigators concluded that a peripheral mechanism might be responsible for chewing-side preference, unlike the proposed cortical system that may account for other items of preference.

In the previous chapter it was found that eight separate variables of movement were necessary to distinguish between left- and right-sided chewing in 15 normal subjects (Wilding and Lewin, 1991). No attempt was made to determine optimum values for each variable of movement, although it was suggested that a subject's preference might provide some insight into optimum movement variables.

The aims of this study were firstly, to determine what preferences these same subjects had for a chewing side, and secondly whether a model of optimum jaw-movement variables could be derived, based on the subject's choice of a preferred chewing side. The hypothesis was that jaw-movement patterns associated with a preferred chewing side might have consistent characteristics that differed from patterns found on the less preferred side. The characteristics of preferred chewing movements might contribute towards developing a baseline for ideal or optimum chewing movements.

METHOD

Preferred chewing

A sirognathograph was used to capture jaw-movement data, according to the recommendations made by Lewin (1985). Head movement was restrained during all recordings. Fifteen young adults, without signs or symptoms of jaw dysfunction, volunteered for the study. Each was asked to chew a wine-gum, on whatever side of the mouth was most comfortable. Chewing was recorded during five periods, each of 10 s. At a subsequent visit another set of five trials was recorded.

A computer program was written (AL) to make separate plots of the opening and closing strokes of each chewing cycle (Fig. 3.1).

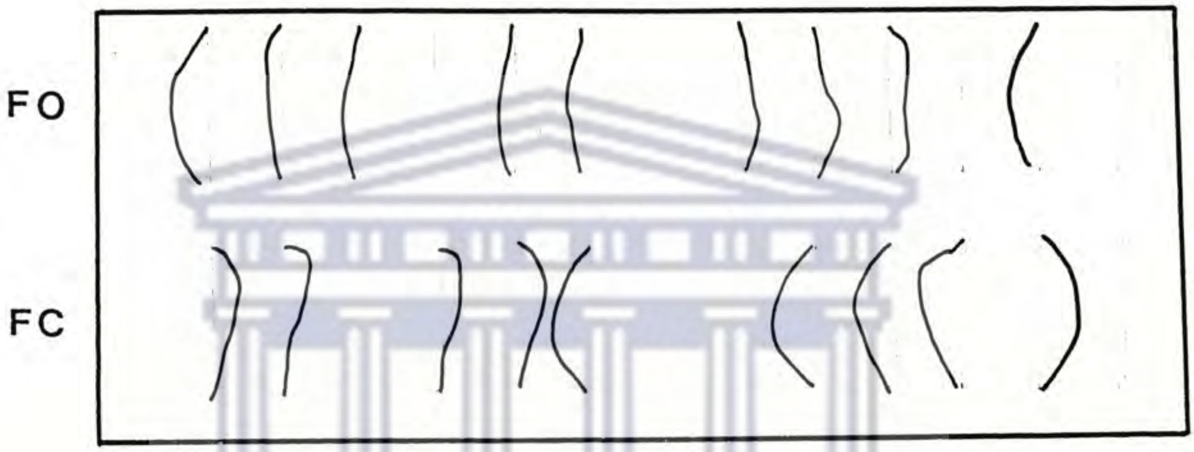

Figure 3.1 The opening (FO) and closing (FC) strokes for each 10s trial were plotted to determine the closing side preferred. The closing strokes viewed in the frontal plane (FC) show four strokes approaching intercuspation from the left and five from the right hand side.

Closing strokes were classified into those approaching from the left- and those approaching from the right-hand side. The number of right- and left-sided closing strokes was counted for each trial. A total of right and left approaches was obtained for each set of recordings. A x_2 test was used to determine whether there were significant differences between the proportion of right- and left-sided closing strokes recorded during the first and second set. A Mann-Whitney test was used to determine whether the right-sided strokes for both sets were significantly different from the left-sided closing strokes.

A preference index for each side was derived by expressing the number of closing strokes on that side as a proportion of the total. Thus,

$$\text{Preference index (left)} = \frac{\text{left count}}{\text{total count}}$$

$$\text{Preference index (right)} = \frac{\text{right count}}{\text{total count}}$$

The values for the preference index (PI) were converted by a standard angular transformation recommended for proportional data by Armitage and Berry (1987) where;

$$\text{Transformed PI} = \sin_{-1} \text{PI}$$

The transformed preference index for each subject was added as an additional variable to each record of the data containing the values for jaw-movement variables of the same subjects (Wilding and Lewin, 1991). A step-wise regression analysis was first used to determine which of the eight variables of chewing on a particular side were associated with the preference index for that side. An attempt was made to derive a regression formula, using the preference index as the dependent variable. The independent variables were those variables of jaw movement selected by the step-wise regression analysis.

RESULTS

The distribution of closing strokes recorded for each 10-s period of observation is given for each subject in Table 3.1. During each set of five recordings an average of 45 closing strokes were recorded. The range was from 39 to 59 closing strokes. When the two separate sets of recordings for each subject were compared, no significant difference was found for 14 of the 15 subjects (Table 3.1). When left and right sides were compared, significant differences were found in 10 of the 15 subjects. Probability values varied from $p < 0.05$ to $p > 0.001$.

A regression formula was derived that expressed the preference index in terms of the following four variables used to describe chewing movements;

1. Mode percent (MOPER; the average of the mode expressed as a percentage of the total frequency for that level).
2. Area ratio (AREAR; the ratio of the areas on the chewing and non-chewing sides of the frontal distribution.
3. Sagittal bimodal distribution (SBIMOD; the percentage of levels in the sagittal frequency matrix in which a significant second mode was calculated).

Table 3.1. The distribution of closing strokes on the left- and right-hand sides during free chewing

Number of chewing strokes

		Set 1					Set 2					p values		
Subject		1	2	3	4	5	1	2	3	4	5	Sets	Sides	Prefer-ence
SA	L	0	0	0	2	1	5	5	0	0	0	-	**	0.14
	R	9	10	9	8	7	5	2	10	10	9			
JE	L	1	6	8	4	5	6	4	8	2	9	-	*	0.65
	R	5	2	2	3	3	2	2	1	6	2			
CH	L	9	5	0	0	10	0	11	10	2	12	-	-	0.53
	R	0	4	13	12	0	14	0	0	10	0	0.47		
AK	L	3	3	0	1	7	1	6	0	6	0	-	*	0.27
	R	4	3	9	8	1	7	6	8	2	9	0.73		
GL	L	8	8	8	8	3	8	8	8	10	7	-	***	0.96
	R	0	0	0	0	0	0	1	1	0	1	0.04		
GM	L	4	3	4	1	4	1	2	1	4	4	-	**	0.38
	R	4	4	4	4	5	5	5	10	7	6	0.62		
RM	L	7	8	0	0	9	4	9	0	8	0	-	-	0.56
	R	0	0	8	7	0	0	0	10	0	11	0.44		
JO	L	0	0	0	0	0	0	0	0	1	0	-	***	0.01
	R	8	8	10	9	10	8	8	8	8	10	0.99		
NR	L	10	9	10	7	6	9	11	5	8	6	-	***	0.98
	R	0	0	0	0	0	2	0	0	0	0	0.2		
SS	L	4	8	7	6	6	5	10	3	5	8	-	*	0.63
	R	3	3	3	5	5	5	0	6	5	1	0.37		
DS	L	8	0	7	10	1	2	1	11	6	8	-	-	0.58
	R	0	11	0	0	9	9	10	0	0	0	0.42		
ET	L	0	0	0	0	1	0	2	0	0	0	-	***	0.03
	R	4	6	9	11	11	11	10	4	10	12	0.97		
JT	L	4	2	0	0	5	0	2	9	7	0	-	*	0.34
	R	3	7	5	10	5	7	8	1	3	8	0.66		
RW	L	3	2	3	1	1	0	0	0	9	10	*	-	0.29
	R	6	7	7	12	11	9	8	11	0	0	0.71		
JW	L	5	7	4	5	5	7	8	8	0	4	-	-	0.61
	R	3	4	4	4	2	2	0	0	9	6	0.39		

Two sets of data, each comprising five recordings of 10 s duration, were obtained for each subject. A $_{x}^{2}$ test was used to test for differences between sets, and a Mann-Whitney test for differences between sides. The probability balues are given for each. The index of preference was expressed as a proportion of strokes counted on each chewing side.

Key to p value codes: -$p > 0.05$;$^{*}p < 0.01$; $^{***}p < 0.001$.

4. Mode distance (SMODIS; the average distance between the first and second modes on the sagittal frequency matrix).

The derived regression formula was;

PI = 319 - 0.04 $(\text{MOPER})_2$ - 66 (LOG AREAR) + 506 (SMODIS/SBIMOD).

The R_2 value (after adjustment) for this regression was 0.42. The residuals ranged from 0.15 to -0.25 with an SE of 0.07. A plot of the predicted and observed values was made to determine whether there were any outlying predictions (Fig 3.2).

DISCUSSION

A preferred chewing side was identified by Christensen and Raude (1985) if a subject was observed using the same side at two successive spot-checks during voluntary chewing. By this definition, 72% of their sample of 25 subjects had a chewing preference. Hoogmartens and Caubergh (1987) observed the first chewing stroke on 10 occasions and if they all occurred on the same side they considered the subject to have a consistent chewing-side preference. They found that 45% of their sample of 128 subjects had a preferred chewing side. In this study, two criteria were used: firstly, that a statistical difference should be found between the number of times the left- and right-hand sides of the dentition were used; and secondly, that any statistical preference should be repeated at a subsequent recording. These criteria were not designed to identify the prevalence of a chewing preference but to quantify preference for each subject. It was assumed that preference is not an all-or-none

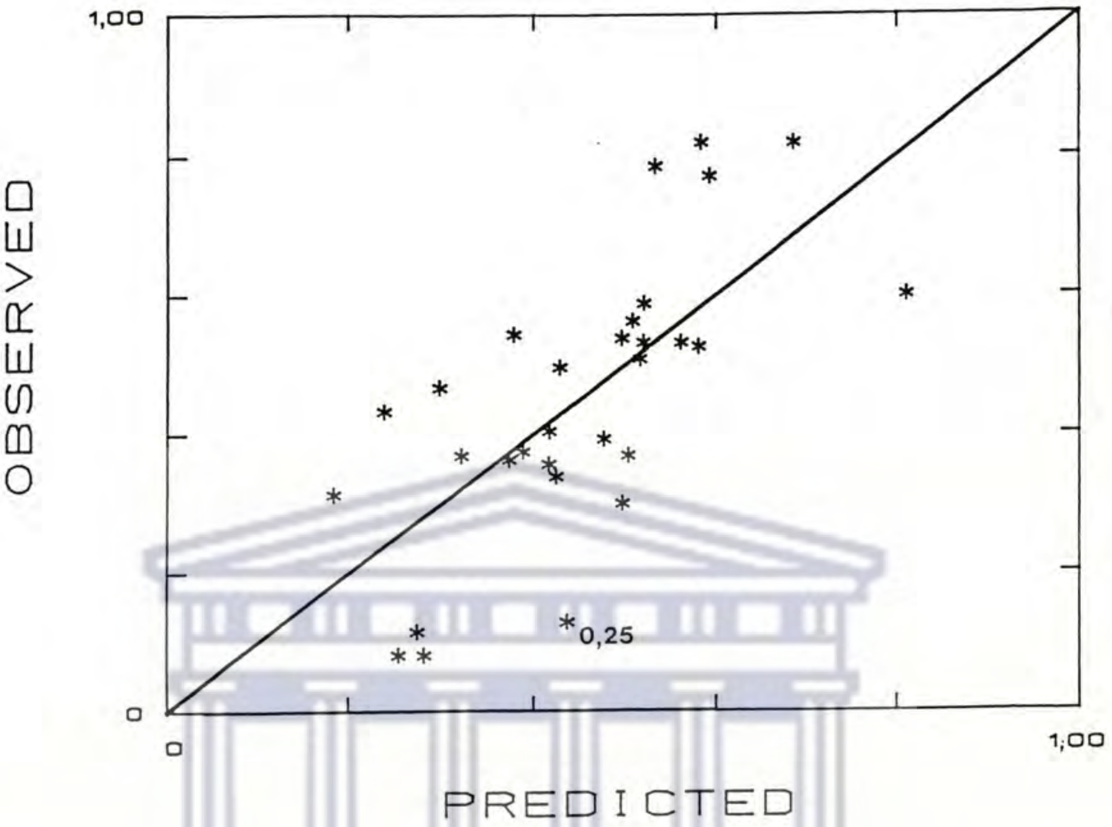

Figure 3.2 The observed preference value was plotted against the value that could be predicted using the regression formula. The worst prediction had a residual value of 0.25 indicating that the prediction differed from the observed preference by 25%. The R^2 value (adjusted) for this model was 0.42.

phenomenon but occurs to a varying extent in most subjects. It would not seem possible to even categorize a subject as having a chewing preference without recording at least an adequate number of closing strokes. Hoogmartens and Caubergh (1987) concluded that there was no association between chewing preference and handedness, although the observed frequencies of their x_2 table showed higher values than expected. It is possible that these trends would have been more substantial if more stringent methods had been used.

In this study the number of chewing strokes recorded for left- and right-hand sides was not identical for each set of recordings, but in only one of the subjects (RW) were they significantly different. In this subject there was not a significant difference between the use of left- and right-hand sides. In all 10 subjects who showed a significant preference for a side, the preference was consistent for both sets of recordings. This suggests that a significant chewing preference was, for these subjects, also a consistent preference.

In a previous study (Wilding and Lewin, 1991), all subjects had been found to be capable of chewing on either side without pain or discomfort, yet in the present study, of the same subjects 10 showed a significant preference for a particular side. Several factors could be responsible for this preference, such as some central cortical factor, similar to handedness, or possibly local occlusal factors. Whatever the reasons it is likely that the choice conferred some benefit to the individual, such as greater efficiency with reduced expenditure of energy and avoidance of fatigue.

The possibility that preferred chewing might be associated with certain types of jaw movements was explored using a multiple regression analysis. The regression formula derived was reasonably accurate in predicting the preference of a subject on the basis of four jaw-movement variables. The SE (0,07) indicated that if preference were predicted on the basis of jaw movement, it would be accurate within a margin of ± 7 chewing strokes for every 100. Each variable provided its own particular contribution to the formula. Excluding any of them reduced the accuracy of the prediction. The variable mode percent (MOPER) is an expression of the density of the jaw-movement pathways; a high value indicated a narrow "one track" pathway, which made a negative contribution to preferred chewing. The association between MOPER and preference can be illustrated by the example given in Fig 3. The variable area ratio (AREAR) is an expression of the relationship between the area on the chewing and non-chewing side; a high value indicates a strongly unilateral chewing cycle and this also made a negative contribution to the formula (Fig 3.3).

The variables sagittal mode distance (SMODIS) and sagittal bimodal distribution (SBIMOD) both refer to the sagittal pathway and express the prevalence of a bimodal frequency distribution and the distance between the two modes. A wide bimodal pathway in the sagittal plane (SMODIS) made a positive contribution to preferred chewing, while a high prevalence of bimodal pathways (SBIMOD) the opposite effect. This appears to be a contradictory influence, as one would expect that the more a sagittal pathway was bimodal, the wider it would be; this expectation was confirmed using a test for correlation between these two variables (coeff = 0.84). This apparent anomaly will require further investigation.

None of these variables on its own could be used to derive a regression formula that had any predictive value; this is consistent with the earlier finding that chewing could not be described without using multiple variables and multiple components (Wilding and Lewin, 1991). It would appear to be invalid to draw any conclusions about jaw movement from a single variable. Hence it could not be argued from this study that bilateral jaw movement was preferred, or the converse, that unilateral movement was avoided.

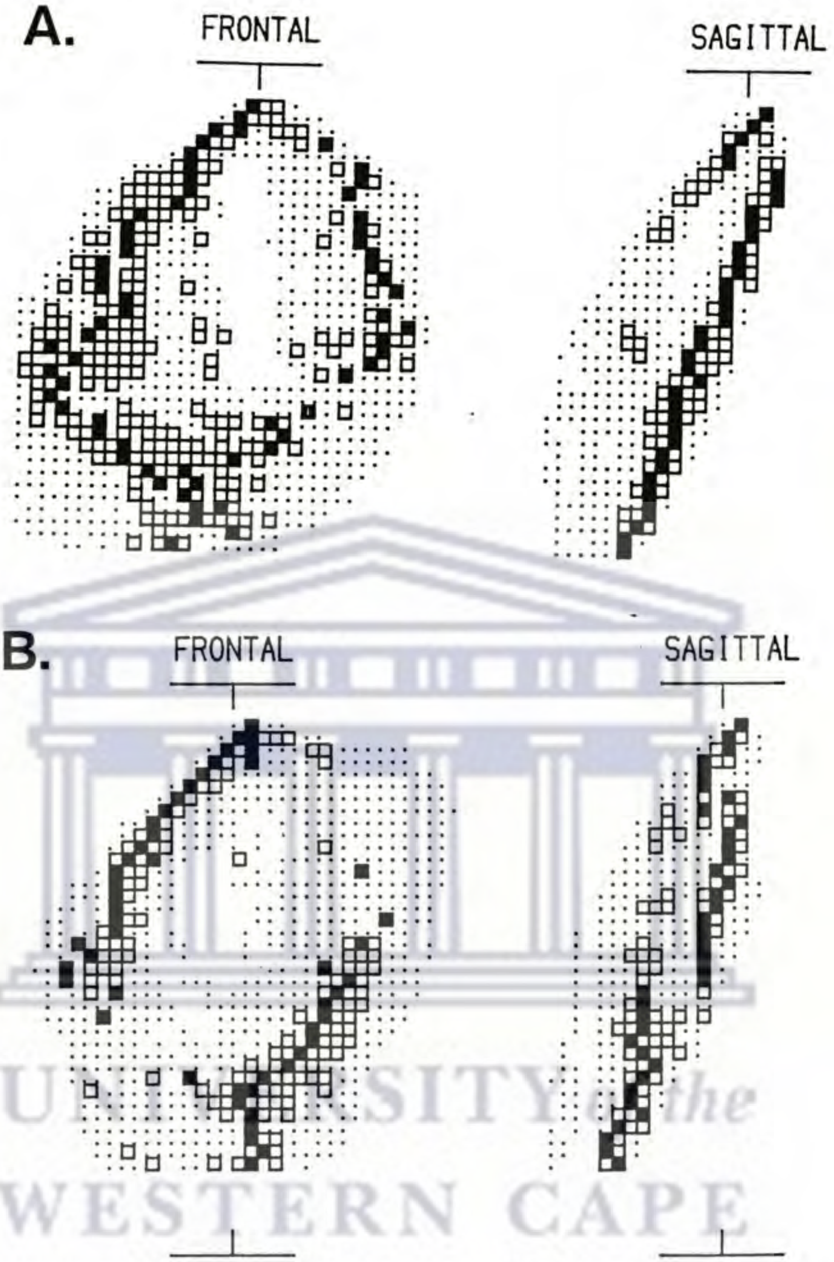

Figure 3.3 The right (A) and left (B) side chewing movements are graphically represented for one of the subjects (JO). The filled boxes represent the position of the mode (highest) frequencies for each level; the empty boxes frequencies greater than 50% of the mode, and the points, all other frequencies greater than zero. The right frontal chewing cycles show a broad pattern of high frequency zones, which represent a pathway with several options (a low mode percent value); the high frequency zones are distributed on both sides of the cycle (a low area ratio value). The right sagittal chewing cycle indicates a bimodal pattern of high frequency zones (high SBIMOD value). The values of these variables are consistent with the model for preferred chewing given by the regression formula. The calculated value for right preference being 84% while the observed preference for this subject was 99%.

The need for a multifactorial analysis in predicting preference may explain the difficulty in distinguishing between jaw-movement variables in health and dysfunction. Feine, Hutchins and Lund (1988) reported that none of the variables of jaw movement, which they recorded with a kinesiograph, was able to distinguish healthy from symptomatic patients. They concluded that the variables tested had no diagnostic value. A similar conclusion was reached in this study when variables were individually tested for association with chewing preference; it was not until multivariate analysis was used that the collective value of variables emerged. If the diagnostic value of jaw-tracking devices is to be fairly evaluated, it appears that multivariate analysis may be necessary.

A preference for chewing on one side was found to be associated with certain ranges in value of four jaw-movement variables. The values of these variables may provide part of the foundation for a baseline of normal or optimal values for chewing movements. This conclusion is based on the assumption that there is some biological advantage in preferred movements. Future studies are planned to investigate the possibility that the same nature of occlusal contacts influences the selection of a preferred chewing side.

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Chapter 4

Functional occlusal contact and chewing side preference

SUMMARY Preference for a particular chewing side may be influenced by several factors, one of which could be the functional contact area on each side of the dentition. In this study, inter occlusal wax records were made for each of the 30 subjects. A digital image of the trans-illuminated wax record was analysed to group grey values into categories of wax thickness. The total area for tight and intermediate tooth contacts was calculated for both the left and right sides of each subject. The chewing side preference was recorded using the method of Wilding and Lewin (1991). No correlation was found between the area of occlusal contact on one side and the preference for chewing on that side. Occlusal contact area does not appear to be a determinant of chewing side preference.

INTRODUCTION

Right or left handedness is usually accompanied by a preference for using the eye, ear and foot of the same side, but the preferred chewing side appears to be independent of handedness and the other preferences (Hoogmartens and Cauebergh 1987). These authors suggest that while handedness, eyedness and earedness appear to be centrally determined, preference for chewing on a particular side may be influenced by some peripheral factor. This suggestion is supported by Wilding and Lewin (1991) who found that certain characteristics of jaw movements are associated with a preference for chewing on one side. If chewing side preference is under peripheral influence, the choice of a particular side may be made because it has some selective advantage over the other, such as improved comfort and chewing efficiency. The quality of occlusal contacts has been shown to influence chewing efficiency (Helkimo, Carlsson and Helkimo, 1977; Omar et al 1989); it is likely that the choice of a favoured chewing side would also be influenced by the quality and quantity of occlusal contacts on that side.

There are a variety of clinical techniques for assessing the position and number of contact points which occur in maximum intercuspation. While this type of examination is suitable for checking the accuracy of restorative procedures it may not be a useful way of assessing the masticatory ability of a dentition. Foods which have to be reduced before swallowing require crushing, shredding or grinding processes (Osborn and Lumsden 1978). The presence of broad opposing surfaces which could be brought into close proximity during chewing could therefor have an equal if not greater contribution in breaking down tough food than discrete contact points. It is also apparent that actual contacts between teeth only occur during the later stages of bolus reduction after much of the food break down has been completed (Woda 1979). A broader interpretation has been used in evaluating occlusal contact area by Gutman et al (1985) who measured the degree of penetration of teeth into stress sensitive material. A qualitative analysis of occlusal contact areas has been achieved by obtaining an image of an interocclusal record produced by transmitted light (Millstein 1984).

In assessing the chewing potential of a dentition it would be necessary to measure not only the areas of actual tooth contact, but in addition, to include the surrounding areas where the opposing teeth are in close proximity. The term functional contact area (FCA) will be used in this study to include both tight contacts and areas of intermediate contact between opposing teeth. The purpose of this study was, firstly, to use digital imaging techniques to develop a reliable method for measuring zones of FCA on each side of the dentition of normal subjects. (A similar technique has simultaneously been developed and described by Tosa et al (1990) The second part of the study was to investigate whether there was any predictable relationship between FCA on each side of the jaw and the preference for chewing on that side. Such a relationship would indicate that the subject could perceive differences in FCA and chose to chew on the better equipped side. Evidence that there was a selective advantage in optimal amounts of FCA could confirm the importance of restoring occlusal contact areas in dental patients.

METHOD

Image Analysis

A series of wax test strips of known thickness was made by compressing warmed wax (Mizzy, Kerr) in a bench press. Steel spacers were inserted between the plates of the press to control the thickness of the wax strips. The strips were trimmed and placed next to one another on a glass slide. A micrometer screw gauge was used to record the thicknesses of each strip (.45m, .30mm .20mm and .10mm). A video image of the wax strips was obtained using transmitted light and the image focused on a monitor screen. The light source was adjusted to give the maximum definition between the different thicknesses of wax. The analogue image was converted to a digital image consisting of 512 x 512 pixels representing 257 shades of grey (Matrox 512 analogue to digital card).

The average of the grey values for each strip of known thickness was calculated. The grey values and wax thickness were used to generate a formula to describe the curve representing their relationship. A logarithmic relationship was found with the formula;

$$Y \text{ (Thickness)} = 2 + .35 \text{ Log}X \text{ (Grey Value)}$$

It was found that an inter-occlusal record (IOR), made using the same wax, produced a clear image of varying shades of grey depending on the degree of penetration of the opposing teeth (Fig 4.1). A window containing the image of the posterior teeth on one side of the dental arch was captured in the same way as the test image and stored in a byte file. A computer program was written (Wilding) to read each pixel value of the image. Each grey value was placed into one of four categories of wax thickness according to the analysis of the test strips (<.45m, <.30mm <.20mm and < .10mm). A pattern code was allocated to each thickness category and the appropriate pattern used to plot each pixel point of the image (Fig 4.2)

As the program proceeded through the image file a cumulative total was kept of the number of datum points in each thickness category. Each total was converted into an area value using the magnification of the image. In order to reduce inaccuracy due to variations in magnification, two small perforations in the wax of the test strip had been made and the distance between them measured with a vernier scaled pair of callipers. The distance in pixels points between the corresponding two bright spots of the image provided a means of estimating the magnification. Each time the test strip was used, the magnification of the image was calculated. In order to avoid errors due to variation in the illumination, an image of the test strip was made each time the imaging equipment was set up. A look-up table was then made using the logarithmic relationship and used to calibrate all the subsequent image data.

Figure 4.1. The wax interocclusal record of the posterior teeth on the left side of one subject.

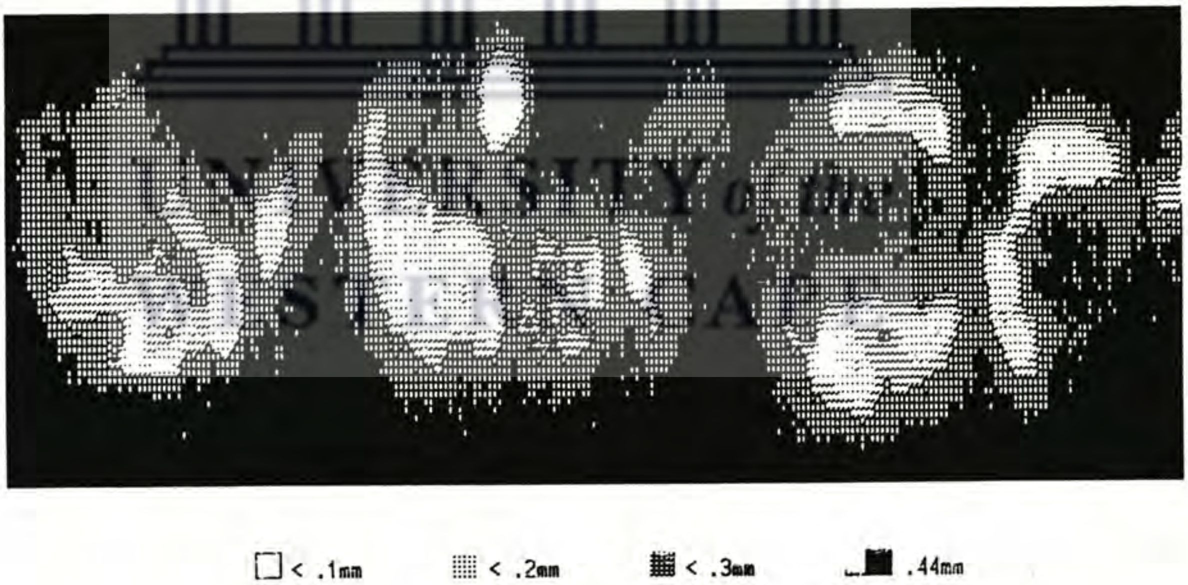

Figure 4.2 A reconstruction of the digital image from the same inter-occlusal record. The different patterns correspond to the four categories of thickness of the test strips.

Clinical Procedures

The sample for the study consisted of 30 young adults with complete dentitions who were free of signs or symptoms of craniomandibular dysfunction. For each subject two sets of IORs were made by closing firmly into a wax sheet which had been warmed uniformly in a water bath to a temperature of 40^{0}C.

The area for each category of wax thickness was determined for each side of the interocclusal record. For each category, the percentage of the FCA contributed by the left side of the dentition was calculated using the formula;

$$\text{Percentage FCA-Left (\%FCA-L)} = \frac{\text{Left Area}}{\text{Left Area + Right Area}} \times 100$$

The data from the first and second IOR of each subject was compared, and the percent error was calculated using the following formula;

$$\text{Percent error} = \frac{(IOR_1 - IOR_2)}{IOR_1} \times 100$$

A rank correlation test was used to discover whether any relationship existed between the various thickness categories of the %FCA-L within the same subject.

A jaw tracking device (Sirognathograph, Siemens, Bensheim Germany) was used to determine the chewing side preference for each subject using the method described in Chapter 3 (Wilding and Lewin (1991). Preference was express as the percentage of closing strokes approaching intercuspation from the left side.

RESULTS

Occlusal contact area

The thickness category < 0.1mm was not found in all IORs and so the < 0.2mm category was selected to represent tight contacts. The thickest category, <.45mm was chosen to represent the intermediate contact areas. The difference between the two IORs was expressed as the percent error for each subject. The mean of the percent error for the FCA (<.45m) was 18% (sd 13%), for the %FCA-L (<.45mm) it was 6.8% (sd 6%) and for the %FCA-L (<.2mm) it was 18% (sd12%).

The average for the total FCA (<0.45mm) of the left side was 39mm^2, with a range from 5.3mm^2 to 94mm^2 (Table 4.1). The FCA was not the same on left and right sides of the dentition in any subject, for either the tight or intermediate categories of tooth contact (Fig 4.3). The mean value for the %FCA-L (<.2mm) was .54% (sd 22%) and for the %FCA-L (<.45mm) was 51%(sd 13%). In 25 of the 30 subjects the difference between the left and right sides was more than 5%. The average for the %FCA-L was 51% indicating an absence of bias in the sample.

Table 4.1 Intermediate contact areas (left) and %FCA-L with preference for chewing on the left side.

	Occlusal Area			
	Total <0.4mm (mm2)	% FCA-L		Chewing Preference
Subject		<0.2mm	<0.45mm	% left
AK	52.56	73	55	27
AN	18.71	62	59	73
BB	34.85	48	50	23
CH	45.68	79	43	53
CJ	7.13	26	40	34
CN	26.99	60	66	28
DS	97.45	69	53	59
EH	40.79	41	58	38
ET	20.56	79	84	3
GF	10.22	21	23	12
GL	59.19	70	51	96
GM	74.40	46	53	38
HG	90.64	42	40	88
JE	47.07	5	41	65
JO	75.32	45	54	10
JT	45.58	57	56	34
JW	37.92	95	57	61
KD	6.44	65	40	23
MK	6.47	50	59	58
NG	29.37	56	55	43
NR	24.09	67	68	98
OL	18.63	30	35	30
RC	7.81	31	29	94
RM	80.55	49	56	56
RN	24.32	55	41	56
RW	47.98	41	67	29
SA	28.29	26	39	14
SN	25.78	56	49	28
SS	81.42	82	59	63
TR	8.47	99	76	1
TV	21.76	50	39	43
Mean	38.59	54.07	51.35	44.45
Std dev	26.98	21.57	13.45	27.19

The %FCA-L for tight contacts was not the same as the %FCA-L for the intermediate contacts in most subjects though there was a significant correlation between the two categories ($P < .01$) (Fig 4.4).

Chewing side preference

The preference for the left side varied from .01% to 98%.(Table 4.1) The average number of strokes observed for each subject was 85 during the 100 second observation. The average cycle time was thus of chewing was .85 cycles / sec. No correlation was found between the preference for chewing on the left side and the %FCA-L in either category of tooth contact. (Fig 4.5).

DISCUSSION

The functional contact area (FCA) does not take into account any contacts which may occur between the teeth during lateral jaw movements. It is possible that FCA and lateral contact areas are unrelated and if this were the case FCA would not represent the tooth surface areas used during chewing. However the importance of the intercuspal position during chewing has been established by Parmeijer (1969) who found that most tooth contacts occurred in intercuspation. Studies of the bite forces generated during chewing have established that the highest forces occur towards the end of the chewing cycle when the teeth are in a central area (Ahlgren and Owall 1970). These finding indicate that tooth contacts in intercuspation are involved in some critical stages of food break down. While there is the little doubt that the FCA measured in this study is relevant to chewing function, the method would be improved if, in addition, eccentric tooth relationships could be determined.

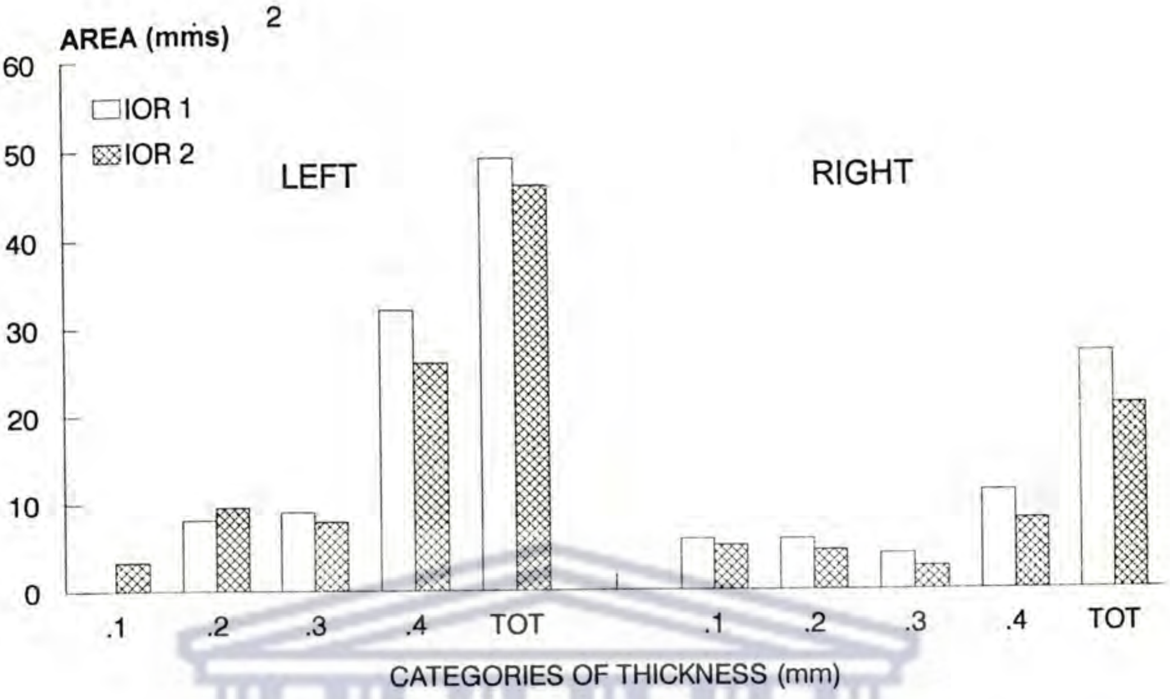

Figure 4.3 A histogram of the areas of each category of thickness for the left and right side of the arch of one subject.

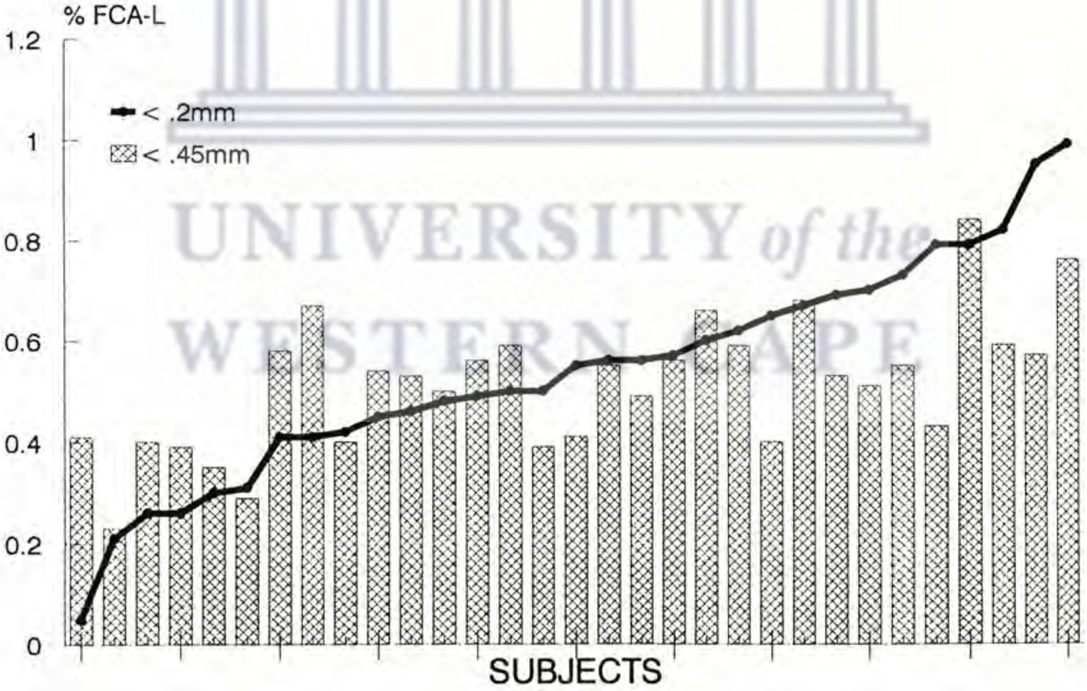

Figure 4.4 The percentage functional contact areas on the left side (%FCA-L) for the tight (<0.2mm) and intermediate (<.45mm) categories. The data for the tight contacts has been ranked.

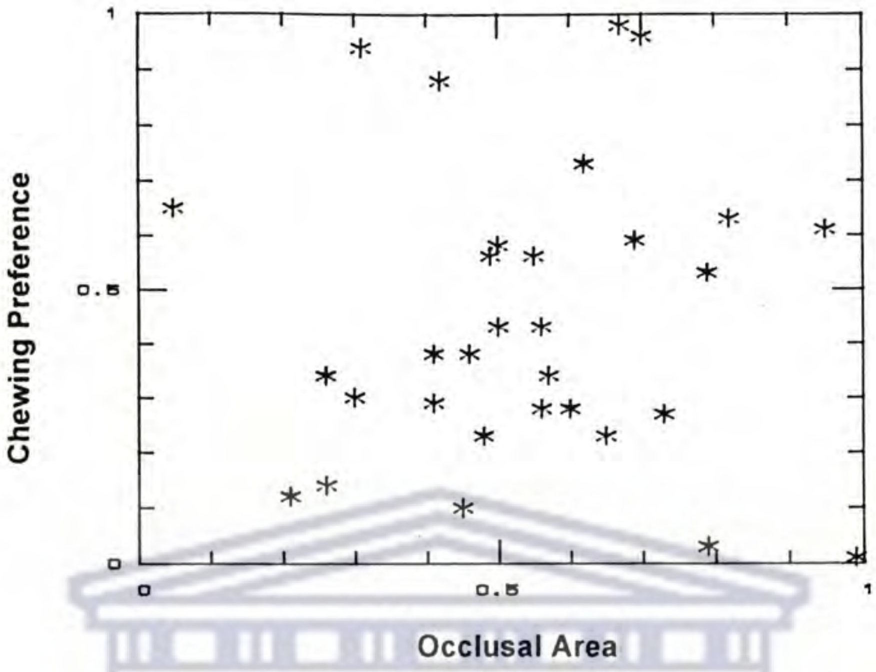

Figure 4.5 Plot of the preference for the use of a particular chewing side and the %FCA-L for each subject.

The pattern of tooth contact areas depends on the force used in closure. Light tapping produces fewer contacts but is preferred by clinicians investigating occlusal interferences (Okeson, 1985). In this study wax was chosen for the IOR in order to present a substantial resistance to closure, such as would occur during active chewing.

The differences between the two IORs made for each subject varied according to the method of comparison. Differences were least noticeable in the %FCA-L category of intermediate contacts (6%). They were more noticeable in the total FCA measured (18%) and in the tight contact category (18%) of %FCA-L. As the consistency of the wax was controlled it is likely that the differences between records were due to variations in the force used during closure. The most accurate combination appears to be the use of use proportional measurements of intermediate occlusal contacts. If absolute FCA values were required it would be necessary to obtain several IORs to provide a reliable mean value for each subject.

The percentage of the FCA on the left (%FCA-L) was not the same for each category but they were directly related. Thus if the %FCA-L for a subject in the category of tight contact (<.2mm) was greater the 50%, the %FCA-L for the intermediate contact (<.45mm) was invariably also in excess of 50%. The standard deviation for the tight contacts(22%) was greater than that of the intermediate contacts(13%). However the percent error between the two IORs for tight contacts(18%) was greater than intermediate contacts (3%). Therefor, while tight contacts may be the more sensitive measure they are subject to greater inaccuracy than the measurement of intermediate contacts. There is no indication from this study as to whether tight or intermediate contacts are a more useful representation of the functional capacity of a dentition, but it would be of considerable clinical importance to determine this.

No correlation was found with the %FCA-L for either of these categories and the preference for chewing on the left side. It is possible that most subjects had more than adequate FCA on both sides of the dentition for efficient and comfortable use. This might apply to those who did not reveal a strong bias in FCA on any side; they could be defined as those whose % FCA-L fell between say 25% and 75%. There were 11 subjects whose %FCA-L for tight contacts fell outside this arbitrary range but only 4 of the 11 whose %FCA-L for intermediate contacts was also strongly biased. This sub group of subjects with more pronounced inequalities in FCA is rather small, but there was still no sign of a relationship between %FCA-L and preference for using the left side.

CONCLUSIONS

1. Digital image analysis appears to be a useful means of analysing an interocclusal record. It provides an opportunity to quantify areas of both tight and intermediate tooth contacts and is accurate enought to detect differences between left and right sides of complete dentitions.

2. The area of tight and intermediate tooth contact does not appear to influence the choice of a favoured chewing side in fully dentate individuals. If peripheral factors are at work in determining chewing preference there must be other more active determinants. At least one possibility is that preference is determined by the side on which chewing is most efficient; this is the subject of a current study.

3. Further investigations will pursue the possibility that young adults with malocclusions do chose the side with a better FCA and in such a study it may be possible to determine what constitutes an optimum FCA. The search for factors which determine optimal chewing function should assist in establishing a baseline of normal data which is necessary in order to

provide goals for orthodontic and prosthodontic treatment and to understand the origins of oral dysfunction.

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Chapter 5

Occlusal contact area and chewing performance

SUMMARY

Chewing is influenced by a number of factors, which include jaw and tongue movements, the activity of circum-oral muscles, bite force, and hard oral surfaces, but it is not clear which of these factors is most crucial to efficiency. The mere presence of surfaces such as the hard palate, or teeth, does not insure that chewing will be efficient. The purpose of this study was to explore the relationship between occlusal contact area, and chewing efficiency and to observe the influence of chewing side preference on efficiency. These variables were recorded for both left and right sides, in a sample of 25 normal young adults. Chewing efficiency was estimated by the size of food particles collected after predetermined number of chewing strokes. The particles were measured using image analysis and the median size calculated using the method described by Olthoff et al (1984). Comparisons were made, firstly within subjects, between the left and right side, and secondly between subjects. Correlations were found between chewing efficiency and occlusal contact area which were more pronounced within, than between subjects. It was concluded that while occlusal contact area influenced chewing efficiency within the same individual, it could not account for the differences in chewing efficiency found between individuals. Differences in the movement of the jaw and in the bite force may have a greater influence on chewing efficiency than occlusal contact area.

INTRODUCTION

Dogs digest meat more rapidly if it is swallowed un-chewed, whereas rats who are deprived of their molars, pass undigested particles of grain (Jenkins 1978). It is not clear to what extent human digestion is dependant on adequate chewing. The study by Farrell (1956), in which human volunteers swallowed small cotton bags containing food, concluded that mastication was of limited importance in digestion. However, the test foods used did not include raw vegetables, fruit, seeds or nuts. In contrast to Farrell's conclusions, Levine and Silvis (1980) found that unless peanuts were well chewed, the available fat was not fully absorbed. It is possible that the contrasting observations made by these studies are both true. Like the rat, and other herbivores, efficient chewing is important for the digestion of raw vegetables, while, like the dog, meat can be digested without chewing. There are options in our modern diet for pre-processed, refined foods which are readily digested without chewing, but it is widely advised that a healthy diet should include fresh fruit and vegetables which do require chewing.

Efficient chewing may be defined as the break down of food with the minimum effort, and maximum rate of particle size reduction. The number of chews before voluntary swallowing (swallowing time) may be a reflection of the efficiency of the chewing process. According to some studies, the swallowing time is greater in individuals whose chewing efficiency is poor or who have few posterior tooth contacts (Luke and Lucas, 1985; Helkimo, Carlsson and Helkimo, 1978). The opposite conclusion was reached by Yurkstas (1965) who concluded that people who cannot chew well do not compensate by chewing their food longer than those with good chewing ability.

A more direct method of measuring chewing efficiency is to collect the chewed food particles and pass them through sieves of various mesh sizes. Deriving an expression for the amount of food trapped by each sieve is not straight forward. The distribution of particle sizes after comminution is not linear, as the large number of very small particles dominates the data, obscuring the relatively few middle and larger sized particles. Edlund and Lamm (1980) used the proportion, by weight, of food trapped by coarse, medium and fine mesh sizes, to derive an index of chewing efficiency for individuals, but were not able to derive a data value relating weight to size. This difficulty was solved by Luke and Lucas (1983a) who determined the theoretical sieve median size (S_{50}) which would retain 50% by weight of the particles. Olthoff et al, (1984) used a particle size distribution function for calculating the value for S_{50} and also calculated the broadness of the distribution, indicating the extent to which the particles were of similar size. The median size is of course reduced the more chewing strokes are used, but again this is not a linear relationship but a power function, which was calculated by Olthoff et al (1984). It has been suggested that chewing efficiency is best determined using this power function to describe the number of chewing strokes needed to halve the initial value of S_{50} (van der Bilt et al, 1987). Changes in particle size during chewing have been calculated using matrix algebra (van der Bilt et al, 1987) and verified experimentally (van der Glas et al, 1985).

There is general agreement that chewing efficiency is related to the state of the dentition. Some authors have evaluated the dentition by counting posterior teeth in contact (Helkimo et al, 1978; Omar, McEwen and Ogston, 1987). The area of functional contact has been measured (Yurkstas and Manly 1949; Lambrecht, 1965), and the area of the occlusal table measured (Luke and Lucas, 1985). The degree of malocclusion has been estimated and found to correlate with the number of teeth in occlusion (Omar et al, 1987). In a study by Yurkstas (1965) it was found that the number of tooth contacts was not related to chewing efficiency, but the area of contact was. All the other studies mentioned have found statistical associations between the state of the dentition and chewing efficiency.

The use of image analysis has allowed for a more precise method for measuring occlusal contact areas than counting teeth or measuring the occlusal table (Wilding Adams and Lewin, 1992). Differences in the occlusal contact area on the left and right sides of normal subjects was found but no association between these difference and the preference for chewing on a particular side. I decided to investigate the chewing efficiency within normal subjects, to determine whether it was improved on the side where there was the larger occlusal contact area, and also whether it might be improved on the preferred chewing side. It would also be possible to pool the left and right side data to determine how influential a variable occlusal contact area would be between subjects.

For this purpose it was decided to develop a technique for measurements of food particle size using image analysis instead of the usual sieving method, and to apply the same analysis successfully developed by previous authors, to describe the distribution of particle sizes (Olthoff et al, 1984).

METHOD

The same subjects were used for the study as participated previously in this work. There were 14 females and 11 males with an average age of 27.3 years. None of the subjects had signs or symptoms of cranio-mandibular disorders.

Clinical Procedures

Each subject was asked to chew an almond on the right side only and to stop chewing after ten closing strokes. The contents of the mouth were rinsed into a beaker containing a small quantity of buffered formalin. The subject then repeated the procedure, but chewed the nut for 20 closing strokes. The same process was followed for chewing on the left side. The swallowing time for each chewing side, was assessed by asking each subject to chew an almond on one side only (starting with the right side) until ready to swallow. The time was recorded from start of chewing until a given sign that the subject was swallowing.

Image Analysis of Food Particles

The particles from each container were transferred into a petri dish and placed on a black background. Incident light was provided by two flexible fibre optic light sources. A digital image of the particles was obtained using an image analysis system (Kontron Elektronik, Munich, Germany). The image was segmented and the minimum dimension *D*, and area *A*, of each particle was measured. Data for the particles were stored in separate computer file for each subject.

A program was written to read each subject's file and to sort the data by minimum dimension, *D*, into 8 size categories between 0.4mm and 2.0 mm. (Table 5.1). The approximate volume for each particle was calculated, assuming a spherical shape. For each size category X, the sum of the particle volumes, Yv, was calculated using the formula,

$$Yv_x = \Sigma_x 4/3 \pi (A^{-2}/2)^3$$

The value Yv was used in all further calculations as though it represented the total volume of particles retained by each sieve size. The following steps in calculating the median particle size were followed according to Partridge (1977). For each size category the percent of the total, $Yv\%$, which was contributed by Yv, was calculated using the formula,

$$Yv\%_x = Yv / \Sigma Yv \quad * 100$$

The cumulative percentage $Yc\%$, of the volume "passing through" each size category was calculated using the formula,

$$Yc\%_x = 100 - \Sigma^1_x Yv\%$$

The cumulative percent of the volume "retained" by each size category was calculated using the formula,

$$Yr\%_x = 100 - Yc_x\%$$

The Rosin-Rammler function, expressed by Allen (1968) in the form,

$$Log\, X = a + b\, Log\, (\, Log\, (100 / Yr\%)\,) \qquad (1)$$

was used to express the relationship between size category and cumulative percent of the volume retained.

The method of least squares was used to determine the characteristics of the best fit straight line that could be drawn through the $Log\ X$ and $Log\ Y$ data points (Fig 5.1). By this method the intercept a on the y axis and slope b of the function was determined. The correlation coefficient R was also calculated. The size category S_{50}

which would theoretically retain 50 percent of the total volume of particles was calculated by substituting in (1) the values for a and b, and 50% for $Yv\%$. The particle size S_{50}, for 10 and 20 chewing strokes was used to determine the rate of size reduction per chewing stroke using the formula derived by Olthoff et al (1984),

$$S_{50} = c \times N^{-d} \tag{2}$$

where c is the fictive particle size at commencement of chewing, d is the rate of size reduction and N is the number of chewing strokes. The values for median particle size after 10 and 20 chewing strokes were used to calculate c and d for each subject. The theoretical value for S_{50} when N was 15 was then calculated from this function, to provide a single representative value of the median particle size for each subject. Chewing efficiency was defined in terms of the reciprocal of the particle size after 15 chewing strokes ($S_{50}15$).

Occlusal contact area and chewing side preference

The functional occlusal contact area and preferred chewing side had been determined for each of the subjects and reported in a chapter 3 and 4. The thickness of wax inter-occlusal records had been measured using and image analysis of light penetration. The preference for the use of each side was expressed as a percentage of the total number of closing strokes. The total number of chewing strokes during the period of observation was used to calculate the duration of the chewing cycle for each subject.

Table 5.1. The treatment of data from one food sample (AKL). The plot of Log X against Log Y is given in Fig 5.1.

X	Log X	Yv	Yv%	Yc%	Yr	Y	Log Y
2	0.693	1256.24	73.7	26.3	73.7	-0.305	-1.189
1.8	0.588	49.51	2.9	23.3	76.7	-0.265	-1.325
1.6	0.47	80.98	4.8	18.6	81.4	-0.206	-1.581
1.4	0.336	49.09	2.9	15.7	84.3	-0.171	-1.767
1.2	0.182	70.91	4.2	11.5	88.5	-0.122	-2.098
1	0	58.18	3.4	8.1	91.9	-0.084	-2.47
0.8	-0.22	61.99	3.6	4.5	95.5	-0.046	-3.08
0.6	-0.51	36.24	2.1	2.4	97.6	-0.024	-3.73
0.4	0	40.28	2.4	0	100	0	0

X = "Mesh" size; Yv = Volume retained; Yv% = Volume % retained ; Yc% = cumulative volume % passing (100 - Yc)
Yr = Cumulative volume % retained (Log 100/Yr); Y = 100/Yr.

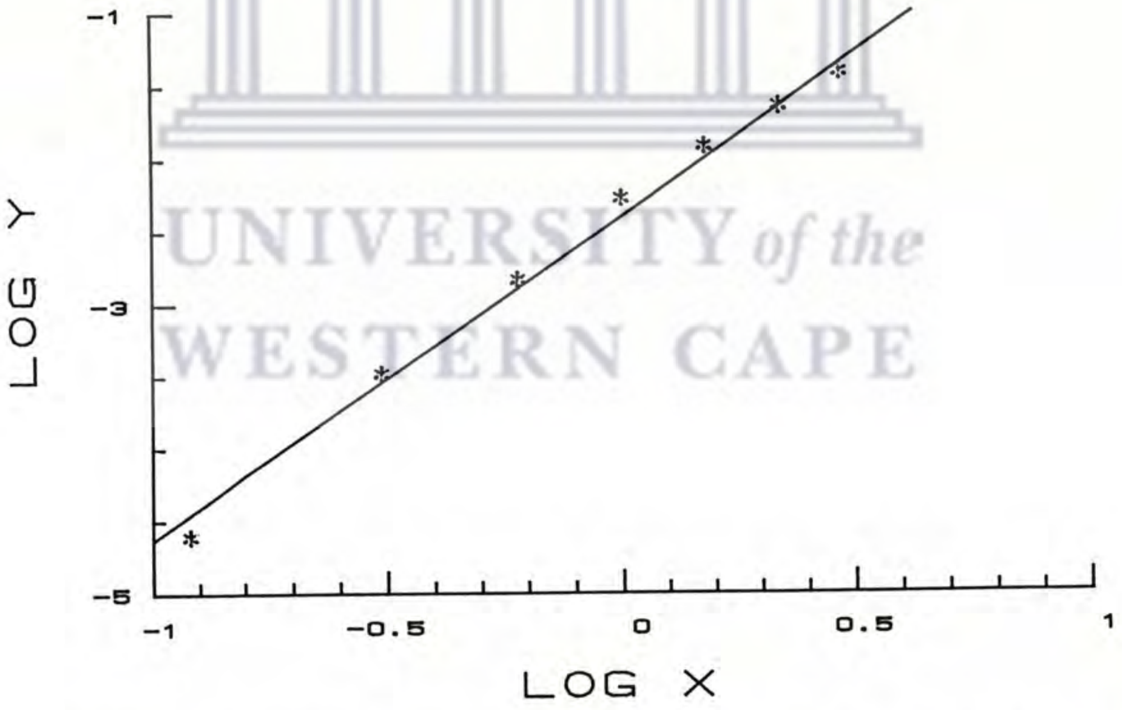

Figure 5.1. A plot of Log X against Log Y of the data given in Table 5.1. Using a least squares method the value for the slope *b* was found to be 2.13. Substituting Yc% = 50%, the value for the median size, S_{50} was 2.80. The R^2 value for the regression was 0.996.

Number of chewing strokes to swallow

For the left and right side of each subject, the number of chewing strokes required before swallowing was calculated as a function of the rate of the chewing time (s) and the swallowing time (s). The number of chewing strokes before swallowing was substituted for *N* in equation [2] to calculate an estimation of the median particle size at the time of first swallowing.

Data Analysis

A set of data was prepared in which the variables for left and right sides of the same subject were paired, so that within-subject associations could be examined (for paired data, n = 25). The paired values were calculated using the general formula;

$$\text{Percentage Left} = \frac{\text{Left} \times 100}{(\text{Left} + \text{Right})}$$

A second data set including both left and right side values was used to investigate associations between variables (for un-paired data, n=50). Non-parametric tests were used to investigate differences, and correlation between variables. A stepwise selection of variables was used to examine the combined effects of occlusal contact area, chewing side preference and swallowing time on the median particle size.

RESULTS

The sample mean for the median particle size after 10 chewing strokes, was 2.58mm (sd 0.61); after 20 chewing strokes it was 1.82 mm (0.45). The mean slope *b* of the Rosin Rammler function was 2.43(0.44) for 10 chewing strokes and 2.92

(0.51) for 20 chewing strokes. The difference in the slope between 10 and 20 chewing strokes was significant ($P < .001$). The mean of the correlation coefficients *R,* of the least squares method for line fitting to the Rosin-Rammler function was 0.994.

From equation (2), the mean value for the rate of particle size reduction, *d* was - 0.52 (0.22), and for the fictive original particle size *c*, was 10.08mm (6.62). The mean value for the particle size calculated after 15 chewing strokes ($S_{50}15$) was 2.08mm (0.48).

The mean time to swallow was 11.4 seconds with a range from 4 to 25 seconds. The mean cycle time was 0.86 (0.11)s. The mean value for the median particle size at swallowing was 2.74 mm (1.05). The average area of tight occlusal contact was 4.5 mm^2 and for intermediate contacts was 25.7 mm^2 (Table 5.2).

Table 5.2. Summary statistics of unpaired data derived from left and right sides of each subject.

	OCCLUSAL AREA		PARTICLE SIZES				SWALLOWING		CHEWING
Variable:	tight	inter	size10	size20	size15	sizesw	time	cycsw	pref
Sample	52	52	52	52	52	52	52	52	52
Average	5.32	27.74	2.60	1.80	2.10	2.74	11.57	9.98	50
Std dev	6.25	20.75	0.61	0.43	0.48	1.04	4.00	3.69	28
Minimum	0	2.68	1.3	1.06	1.16	1.35	4	3.48	1
Maximum	31.33	91.39	4.21	3	3.45	7.26	25	20.5	99
Range	31.33	88.71	2.91	1.94	2.29	5.91	21	17.02	98

Paired Data - within subject: left right ratios

The mean values for the left right ratios of each variable were all close to 50% (Table 5.3). The standard deviations varied from 4.71% for $S_{50}15$, to 25.45% for tight occlusal contacts.

Negative correlations (P<.001) were found between intermediate occlusal contact areas and the median particle size, after 15 chewing strokes (coeff -0.59) and at swallowing (coeff -0.58) (Table 5.4, Fig. 5.2). A weaker correlation was found between occlusal contact area and the rate *d* of particle size reduction (coeff - .31, P = .06). A positive correlation was found between swallowing time and the median particle size calculated for 15 chewing strokes (coeff .43, P <.05).

Table 5.3. Summary statistics of paired data derived from the values for each subject, expressed as a percentage of the ratio of the left to the right chewing side.

	OCCLUSAL AREA		PARTICLES SIZES				SWALLOWING		CHEWING
Variable:	tight	inter	size10	size20	size15	sizesw	time	cycsw	pref
Sample size	26	26	26	26	26	26	26	26	26
Average	55.18	51.20	49.09	49.09	49.13	48.74	52.16	52.54	50
Std dev	22.63	14.40	5.43	4.93	4.62	7.75	7.67	7.81	28
Minimum	4.85	23.82	39.57	36.67	37.85	32.69	37.5	37.5	1
Maximum	100	83.66	61.02	58.69	59.26	72.35	66.67	66.67	99
Range	95.15	59.84	21.45	22.02	21.41	39.66	29.17	29.17	98

Table 5.4. Spearman rank correlations for paired data, N = 25.

	tight	inter	size15	pref	time	sizesw
tight	.	.	.	.	.	.
inter	0.40	.	.	.	.	.
size15	-0.32	-0.59	.	.	.	.
pref	-0.01	-0.00	-0.29	.	.	.
time	-0.10	-0.14	0.42	-0.22	.	.
sizesw	-0.14	-0.57	0.54	-0.26	-0.15	.
cycsw	-0.17	-0.16	0.43	-0.28	0.96	-0.14

tight = tight occlusal contact areas
inter = intermediate occlusal contact areas
size15 = median particle size after 15 chews
pref = preference for chewing on the left side
time = number of seconds of chewing required before swallowing

Unpaired data- between subject

A similar pattern of associations were found between the variables in the unpaired data set but the coefficients and levels of significance were all reduced (Table 5.5, Fig. 5.3). No significant correlations was found between occlusal contact areas, nor the chewing side preference and any other variable expressing chewing efficiency (Table 5.5). Correlations between variables such as the median size at swallowing and the number of chewing cycles at swallowing were expected as they were interpolated from the common variable, swallowing time.

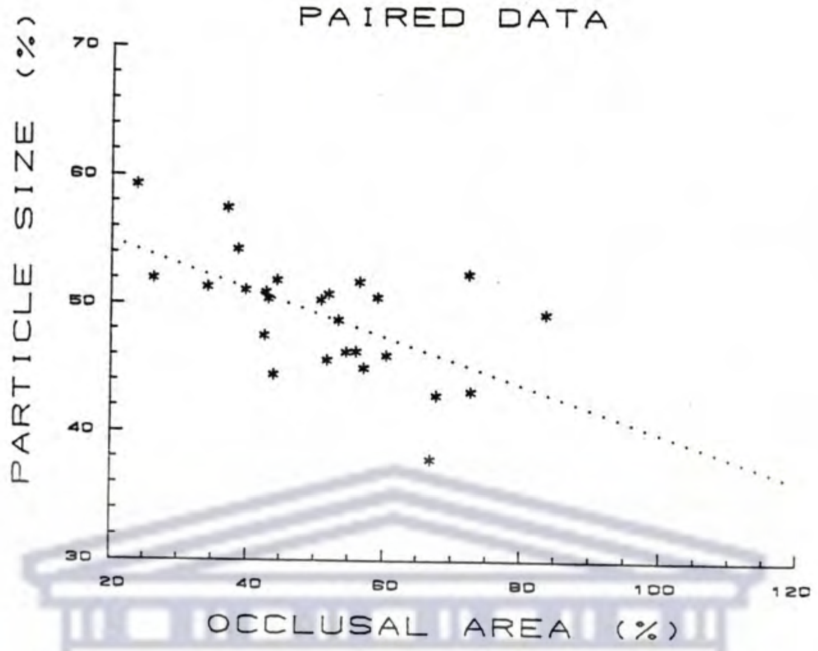

Figure 5.2. A plot of the paired data for functional occlusal contact area and the particle size, both expressed as percentages of the left to right ratio. The correlation coefficient was - .59 (P < .001).

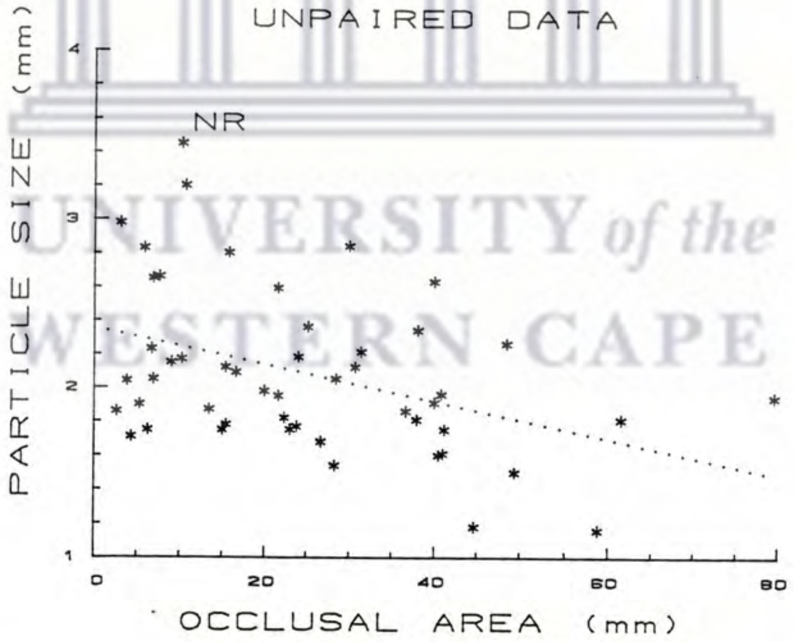

Figure 5.3. A plot of the functional occlusal contact area and particle size after 15 chewing strokes for the unpaired data set. The correlation coefficient was -.35 (P <.01). One of the outlier plots was of the subject NR.

In view of the apparent association between more than two independent variables, a stepwise selection was used to develop a model which would express the relationship between particle size, chewing time, occlusal area and chewing side preference. The independent variable chosen first was the median size, calculated for 15 chewing strokes ($S_{50}15$). The regression model with best predictive value had the following function;

$$S_{50}15 = 60 + 0.13(time) - 0.22(inter) -.17\ Log(pref)$$

where *time* was the swallowing time, *inter*, the intermediate occlusal contact area and *pref*, the chewing side preference. The R^2 (adjusted) value for this regression was 0.54 for the paired data and 0.21 for the unpaired data (Fig. 5.4).

Table 5.5. Spearman rank correlations for unpaired data , N = 50

	tight	inter	size15	pref	time	sizesw
tight	.	.	.	.	.	.
inter	0.41	.	.	.	.	.
size15	0.04	-0.20	.	.	.	.
pref	0.00	-0.04	-0.07	.	.	.
time	-0.10	0.01	0.27	-0.17	.	.
sizesw	0.12	-0.26	0.65	-0.04	-0.39	.
cycsw	-0.05	0.10	0.14	-0.15	0.90	-0.49

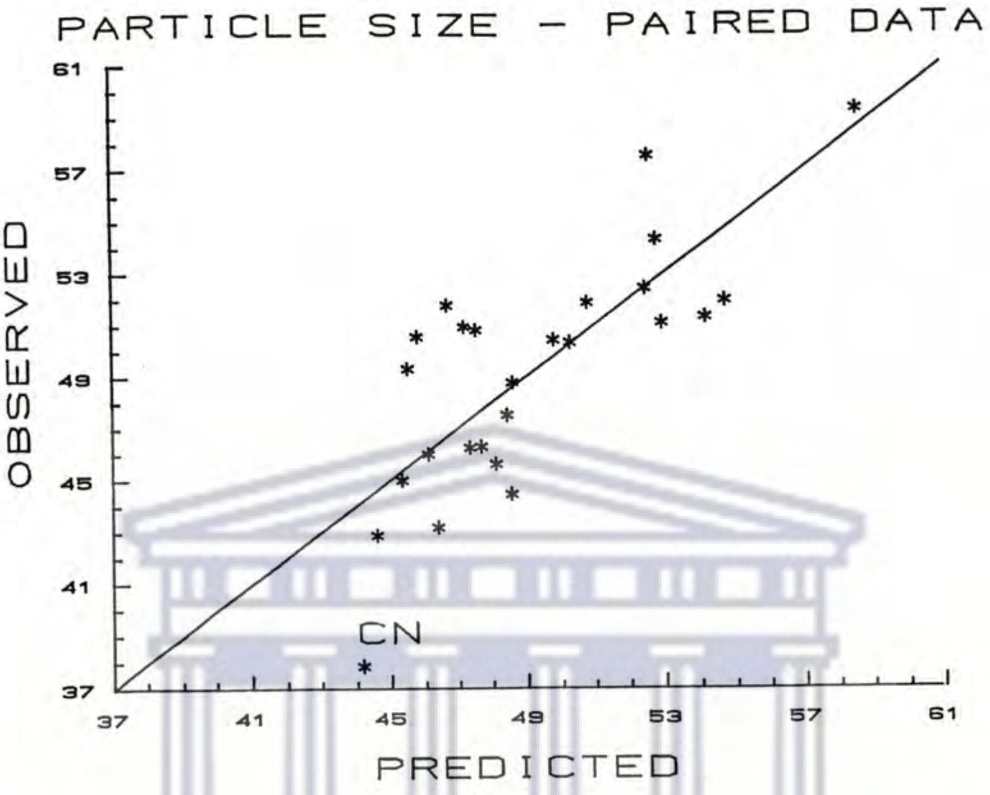

Figure 5.4. The predicted and observed values from a regression model for the paired data. Particle size was the dependent variable and occlusal area, swallowing time and chewing side preference were independent variables. The adjusted R^2 value for the regression was 0.54.

DISCUSSION

Method

The texture of natural foods such as carrots, peanuts and almonds cannot be standardised. Edlund and Lamm (1980) proposed using pellets made from a silicon impression material, and this material was successfully used in several subsequent studies by other authors. During the last ten years the tear strength of silicon impression materials has improved to the extent that current impression materials are too tough to be used as a test food unless their properties are altered by the addition of certain additives (Slagter et al, 1993). Almonds were therefore chosen for this study, by default, and preferred to other foods for the clear outline of the fractured particles.

The assumption made in the calculation of the particle volume, that particles were all spherical, is clearly unfounded but for practical purposes it appeared to satisfy the basic premise of the Rosin-Rammler function. The plot (Fig 5.1) showing the relationship between "sieve" size and particles "volume" is a straight line with a good fit, and was typical of the sample. It therefore seems that it may not be necessary to weigh food particles in the determination of particle size, if two dimensional measurements can be made using image analysis. A recently published study by van der Bilt et al (1993a) establishes the reliability of the imaging technique in comparison to sieving methods.

Accuracy in measuring chewing efficiency is best assured by making several observations from each individual with a range of chewing strokes. In this study only two observations for each individual were made, after 10 and 20 chewing strokes. It appears however that this procedure was accurate enough to reveal differences in particle size between the left and right chewing sides of the same individual; when these differences were expressed as a ratio, a strong negative correlation was found with the ratio of intermediate occlusal contact area (Table 5.4).

The calculated value for the median particle size after 15 chewing strokes appeared to be more representative than the two variables from which it was derived. This confirms the validity of the observation of Olthoff et al (1984) that particle size reduction during chewing can be expressed as a power function of the number of chewing strokes [2]. The gradient of this function, that is, the rate of particle size reduction, did not in this study, emerge as a reliable measure of chewing efficiency, judging from the lack of association with other variables. This finding was also the experience of Lucas and Luke (1985) and van der Bilt et al (1993b).

The mean rate of particle size reduction calculated from equation [2] was 0.52, which is comparable to other studies using a silicon test food. The mean value in the study by Olthoff et al (1984) was 0.56, and 0.63 was the value calculated by van der Bilt et al (1987). The disadvantage of using natural food in this study was evident in the large standard deviations, both for median size and rate of reduction (Table 5.3). Olthoff et al (1984) found that the standard deviation of the particle size reduction rate for nuts was higher than the artificial test food and therefore confirmed the limitations of natural test foods. However, in the two studies previously mentioned in which an artificial test food was used, the sample size was in both cases less than 10 subjects. It may be that there is in fact a wide variation in chewing efficiency between individuals who have complete dentitions.

Swallowing time

Swallowing time was associated with particle size in both the paired and in the unpaired data set. A possible interpretation is that subjects whose chewing efficiency is poor, chew for longer before swallowing. This process does not appear to compensate entirely for their reduced efficiency as the estimated particle size at swallowing did not approach a common value for the sample, the standard deviation being 1.0mm. This finding resolves some apparent contradictions between previous studies. One conclusion has been that individuals with reduced dentitions compensate by chewing for longer (Luke and Lucas 1985, and Helkimo et al 1978). Another conclusion is that such individuals do not compensate, but swallow larger particles (Yurkstas 1965). The results of this study indicate that both findings are true. Subjects with reduced occlusal area, do chew for longer before swallowing, but not long enough to completely compensate for their reduced efficiency. The swallowing time presumably depends on factors other than particle size, such as the consistency and water content of the food, saliva flow and lubricative quality, habit and level of hunger.

Occlusal Contact Area

The paired data compared one side with the other in each subject. Correlation between occlusal contact area and particle size indicated that chewing was more efficient on the side where there was a greater occlusal area. This is consistent with general statements relating the state of the dentition to chewing efficiency which were made by Yurkstas and Manly (1949) and subsequently confirmed in many other more recent studies.

A significant correlation with particle size was found with the intermediate occlusal contact area (between 0.2mm and .45mm inter-occlusal distance) and not with the tight occlusal contact areas (less than 0.2mm inter-occlusal distance). There is evidence that the masticatory apparatus of mammals, only fulfils its functional requirements after the enamel cusps have worn off (Osborn and Lumsden 1978). Such occlusal wear tends to increase the broad areas of tooth contact. The present study tends to support the superior value of broad intermediate tooth contact areas over smaller areas of tight intercuspation, and thus indirectly confirms the advantages of tooth wear. This information contributes to the weight of evidence, which is beginning to challenge the traditional assumptions that "ideal" cusp morphology should reflect the features of an unworn dentition (Owen, 1985).

The subjects in this study were without signs or symptoms of dysfunction and had not lost any teeth. However the data for one subject (NR) showed that on the right side there appeared to be some difficulty in chewing (Fig. 5.3). The right side was usually avoided (preference was 2%), the chewing time before swallowing was 25 seconds and the median particle size, was 4.21mm after 10 chewing strokes; these latter variables being maxima for the entire sample. The occlusal contact area on the right side was 10.3 mm^2, lower than the mean but still within a standard deviation of the sample mean. Many other subjects had smaller occlusal contact areas but better chewing efficiency. In such a comparison occlusal contact area does not seem to be a decisive factor. However NR clearly performed better on the left side, when compared to the right, perhaps with the assistance of approximately double the occlusal contact area.

This subject illustrates that when the left and right sides in the same subject are compared, occlusal contact area is strongly associated with chewing efficiency. Yet when subjects are compared, occlusal contact area is not a good predictor of chewing efficiency. There may be other, even more decisive factors which are perhaps constant within an individual but emerge as decisive differences between the chewing efficiency of individuals.

There is evidence which points to the identity of these other factors which were controlled for in paired data sets but uncontrolled in the unpaired data set. Luke and Lucas (1983a) identified two different processes in chewing, selection and breakage. Selection involves the movement of a food particle onto the occlusal table and its exposure to opposing tooth surfaces. The chances of any food particle being selected decrease as the particle becomes smaller, but the probability remains constant within an individual; there is however considerable variation between individuals, and this has been attributed to at least two factors, the movement of particles, and occlusal area (van der Glas et al 1985, van der Bilt et al 1987). The skill in moving food particles would be reasonably constant within an individual, and not influenced by chewing side. But the availability of accessible areas of tooth surface does vary from one side of a subject to the other. Within individuals then, differences in occlusal contact area produce noticeable differences in the chewing efficiency. Lambrecht (1965) showed that the chewing efficiency of a patient's denture could be improved by increasing the occlusal contact area. But if chewing efficiency between denture wearers is compared, it varies even though each patient has the same occlusal contact area, and is noticeably reduced in comparison with dentate individuals (Yurkstas 1965). When the chewing efficiency of individuals is compared, differences in food manipulation may be more powerful determinants of selection than occlusal area.

Breakage involves the fracture of food particles and is thought to depend on tooth morphology, chewing force and mandibular movement (van der Bilt et al, 1987). These factors may be reasonably similar when comparing left and right sides of the same individual. However it is clear that between individuals there is considerable variation in bite force and jaw movement. Denture wearers cannot exert the same bite force as dentate subjects and this may then diminish their ability to break up food particles and account for their comparative inefficiency when compared to dentate subjects (Haraldson, Karlsson and Carlsson, 1979).

It may be possible to measure breakage directly by recording the rate of particle fragmentation in a subject (van der Bilt et al 1987). The rate of fragmentation may be independent of particle size, in which case mathematical simulations of chewing may be valid (Lucas and Luke, 1983b; van der Bilt et al, 1987). If it is not the variable becomes a complex one which must be made for several sizes of particles (van der Glas et al, 1985;1987).

The significance of occlusal area in chewing efficiency will only be determined when a model for chewing efficiency can be constructed which incorporates factors which determine both selection and breakage of the food. It appears that these factors would include tooth morphology, jaw movement and bite force. This study may not have been able to place occlusal contact area in its proper perspective, because although the subjects had a wide range of occlusal contact areas, they may have all been adequate for efficient chewing. The importance of occlusal contact area may emerge in its true perspective when the sample contains patients with malocclusions or reduced dentitions (Omar et al, 1987; van der Bilt et al, 1993c).

There is little evidence available about the chewing efficiency of subjects who are completely edentate, although in a deprived society there are many people, who are edentulous but unable to afford dentures (Wilding and Osman, 1990). My impression, of such patients has been that they have claimed to manage most prepared foods quite well but had difficulty with nuts and raw vegetables. In such circumstances it seems likely that the hard palate and tongue are recruited into a more active role in mastication.

Chewing side preference

The lack of association between occlusal contact area and the preferred chewing side was reported in a chapter 4. The correlation between particle size and chewing side preference was not significant although preference was selected as a component of the model for predicting particle size. The negative coefficient indicated that particle size tended to be smaller on the preferred side. While the influence of preference on chewing efficiency is therefore inconclusive, it may be a reflection of some more decisive variable in chewing. Chewing side preference is associated with certain characteristic types of jaw movements (Wilding and Lewin, 1991). It is therefore possible that there is some association between chewing efficiency and jaw movements. According to the predictions of both van der Glas et al (1987) and van der Bilt et al (1987) particle breakage may well be a function of bite force and mandibular movement. These possibilities are pursued in the next chapter.

CONCLUSIONS

1. Image analysis appears to be a suitable means of measuring particle size.
2. Subjects with reduced chewing efficiency spend longer chewing, but still swallow larger particles.
3. Broad areas of intermediate occlusal contact appear to contribute to chewing efficiency more than few tight contact points.
4. Occlusal contact area is a good predictor of chewing efficiency in an individual but cannot account for differences in chewing efficiency between individuals.

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Chapter 6

Optimal jaw movements based on chewing performance.

SUMMARY - Chewing performance is an expression of the functional capacity of the jaws and teeth. In the previous chapter, the variation in chewing performance could not be explained by differences in occlusal contact area. I therefore decided to investigate the possibility that chewing performance might be associated with certain patterns of jaw movement. Data from the two previous studies using the same subjects, were analyzed using a stepwise regression to select variables of jaw movement which could predict chewing performance. A multivariate model with an R^2 value of 0.79 ($p < 0.000$) was generated with particle size and as the dependant variable. Eight components of jaw movement made up the independent variables. Some of the more dominant variables in the model were those which describe a wide, bilateral chewing cycle with a predominantly lateral path of closure. Another powerful predictor of efficient chewing was a smooth flowing movement with minimal changes in velocity. The inclusion of occlusal contact area into the model did not enhance its predictive capability. It was concluded that selected jaw movement variables were significant determinants of chewing performance, and therefore could contribute to developing a baseline for normal masticatory function.

INTRODUCTION

The masticatory system has been assessed by measuring jaw movement, muscle activity, occlusal contact and chewing performance (Ahlgren, 1966, and 1976; Gibbs *et al.*, 1981; Lewin, 1985; De Boever and Adriaens, 1983; Woda, 1979; Yurkstas, 1965). However, when the masticatory system fails to function without pain, it is difficult to identify the extent to which structural or functional deficiencies may be active in the etiology. This may be because existing diagnostic systems lack specificity; they tend to include many false positives in the diagnosis which can lead to unnecessary treatment of the patient (Feine, Hutchins and Lund, 1988; Lund and Widmar, 1989). Poor specificity in diagnosis may occur because the accepted norms are not broad enough to allow for normal variation. A wide range of values for jaw movement, representations of occlusal contact and chewing performance was found in subjects without a complaint, but it has not been possible to determine a range for each of the variables which is compatible with either minimal or optimal function (Wilding and Lewin, 1991a; Wilding Adams and Lewin, 1992; Wilding, 1993). As the jaws and teeth are intimately involved in the function of chewing, it seemed worthwhile to determine a range of values for jaw movement and occlusion, within which effective chewing was possible. The values which contribute to the greatest performance should be the most optimal for the system. I therefore decided to use chewing performance as a determinant of optimal values for jaw movement so as to develop baseline data necessary for the diagnosis of masticatory dysfunction.

MATERIALS AND METHOD

The same subjects were used for the study as participated previously. The sample comprised 15 females and 11 males with an average age of 27.3 years. None of the subjects had signs or symptoms of cranio-mandibular disorders.

Jaw Movement, side preference, occlusal contact and chewing performance,

The method for determining jaw movements, chewing side preference, occlusal contact area and particle size and has been described in chapters 2 through chapter 5. A graphical representation of the frequency distribution was used in addition to the computer analysis of jaw movement variables to examine the jaw movement data (Fig 6.1). Statistical analysis of the frequency distribution was used to describe the characteristics of the most frequented pathways during chewing (Fig. 6.2). The following variables were selected from the original 8 used to describe jaw movement in chapter 2.

Angle was the angle between the most frequented approach to the region of maximal intercuspation and the horizontal; the higher the angle near intercuspation, the flatter the chewing cycle would appear to be in the frontal plane.

Bimode was the percentage of rows in which a bimodal pattern in the frequency distribution was found; the higher the percentage the more separated would be the opening and closing pathways.

Mode percent was derived as a percentage of the total frequencies which was contributed by the highest frequency (the mode) for each level of the matrix;

; the higher the mode percent the narrower the movement pathway.

Area was the total area between the locations of the first and third quartiles for each row of the frequency matrix. It thus described the area, centred around the position of the median frequency, in which fifty percent of total the frequencies were found; the higher the area the more spread out the chewing pathway is.

Opening was the mean value for each cycle of the maximum degree of opening from initial intercuspation.

Sagittal area was the core area (inner 50 percentile) of the sagittal pathways; the higher the sagittal area the more protrusive is the chewing cycle.

Acceleration was the mean, of changes of velocity between successive grid positions of the matrix and was calculated using a program written by A. Lewin (Lewin *et al.*, 1991). The greater the standard deviation of acceleration, the more erratic or wandering the movement.

Cycle time was the mean duration in seconds of a subjects chewing cycles.

Data Analysis

A Spearman's rank correlation test was used to investigate association between the variables. A stepwise selection of variables was used to examine the combined effects of jaw movement variables on the dependent variable, particle size. By further trial and error a multiple regression model was developed to describe the relationship between chewing performance and jaw movement (SG Plus, Statistical Graphics Corporation, USA).

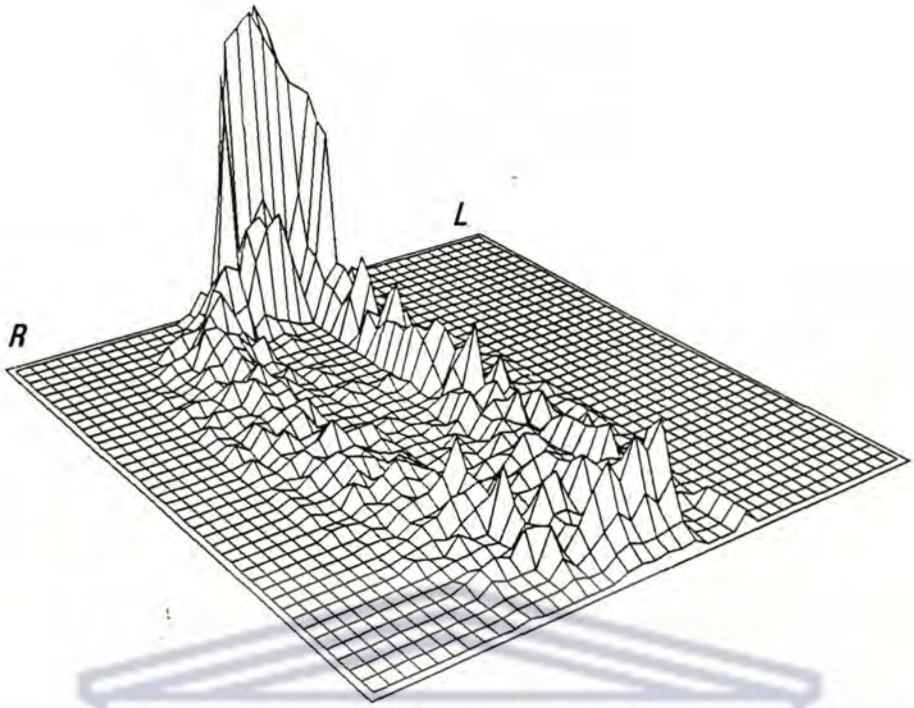

Figure 6.1 Chewing cycles viewed in the frontal plane. Time frequencies in each cell of the 40 x 40 matrix are represented by this histogram. The data were derived from 50 seconds of chewing on the right side. The highest peaks are in and around maximum intercuspation where the tracking device was recorded most frequently. The ridges represent well frequented movement pathways. The chewing performance of this subject (CH) was one of the most efficient in the sample (Table 6.4).

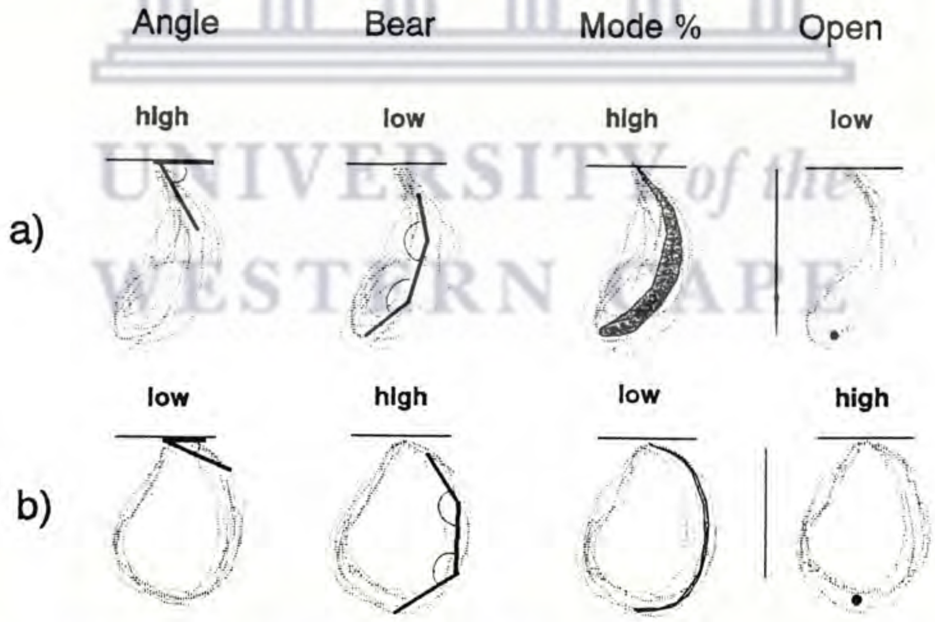

Figure 6.2. Diagrammatic representation of four variables which describe patterns of jaw movement. The a) series shows features which reflect the jaw movements of Fig. 6.1. and are associated with high chewing performance. The b) series of diagrams illustrates opposite values for the four jaw movement variables and reflect the jaw movements in Fig. 6.6.

RESULTS

The mean particle size after 15 chewing strokes (*size*) was 2.10 mm (sd=0.47). A significant difference was found between the mean particle size of male subjects (1.88 mm, sd 0.39) and female subjects (2.24 mm, sd 0.47; $p < 0.01$). A correlation was found between particle size and time before swallowing (coeff 0.28 $p < 0.05$; Table 6.1). Hence subjects with poor performance (larger particles) tended to chew longer before swallowing than those with better performance.

There was a significant difference in jaw *opening* between males (11.4 mm) and females (9.4 mm, $p < .001$), and in *cycle time* (male, 0.92s, female 0.82s; $p < .01$). A weak association was found between *size* and *int-contact* (0.23, $p = .06$), but not with tight contact areas. Stronger associations were found between *size* and jaw movement variables, such as *angle*, (0.29, $p < .01$) and between *time* and *opening* (-.35, <.01) (Table 6.1). Many of the jaw movement variables were related to each other, notably those which describe the shape of the chewing cycle. Significant associations were found between *int-contact* and the *sagittal area*, (0.47, $p < .001$) and between *acceleration* and both *angle* and *bimode* (0.45; -0.41, $p < .001$).

A stepwise multivariate analysis helped to construct a model to describe the interactions between jaw movement variables and chewing performance (Table 6.2). The model comprised 9 independent variables, including an indicator variable, and had an adjusted R^2 value of 0.79 ($p < 0.000$). The predicted values for chewing performance were plotted against the observed values (Fig. 6.3). An analysis of variance test for the regression showed that some variables had a greater influence than others (Table 6.3).

Table 6.1. Correlation coefficients between variables used to describe chewing performance and jaw movement.

	Size	Time	Accel	Cycle	Angle	Bimode	Area	Mode%	Open	S-area
Time	0.28^{*}	–	–	–	–	–	–	–	–	–
Accel	0.23	0.18	–	–	–	–	–	–	–	–
Cycles	-0.26	-0.02	0.23	–	–	–	–	–	–	–
Angle	0.29^{*}	0.34^{*}	0.45^{***}	0.07	–	–	–	–	–	–
Bimode	-0.35^{**}	-0.20	-0.41^{***}	0.08	-0.34^{*}	–	–	–	–	–
Area	0.00	-0.18	-0.26	-0.01	-0.29^{*}	0.50^{***}	–	–	–	–
Mode%	0.00	0.04	0.01	-0.00	0.29^{*}	-0.25	-0.55^{***}	–	–	–
Open	-0.09	-0.35^{**}	0.01	0.07	0.09	0.27^{*}	0.39^{**}	-0.29^{*}	–	–
S-area	-0.02	-0.15	-0.17	-0.01	-0.24	0.53^{***}	0.65^{***}	-0.48^{***}	0.46^{***}	–
Int-contact	0.23	0.02	-0.28^{*}	0.13	-0.17	0.22	0.24	-0.08	0.23	0.47^{***}

Size, median particle size after 15 chewing strokes; Time, time taken in chewing before swallowing; Accel, mean change in velocity; Cycle, mean duration of the chewing cycle; Angle, angle between the pathway to centric and the horizontal; Bimode, double pathway of the chewing cycle; Area, area of the chewing pathway; Mode%, the breadth of the movement pathway; Open, the mean value for maximum opening; S-Area, the core area of the sagittal pathway; Int-contact, total area between 0.2mm and 0.45mm inter contact distance.

* $= p < .05$; ** $= p < .01$; *** $= p < .001$

Table 6.2. Structure of the model relating chewing performance to jaw movements.

Dependent variable		
LOG PARTICLE SIZE		
Independent variables	**Coeff.**	**Std. error**
CONSTANT	0.205	0.317
OPENING	-0.626	0.245
ANGLE/OPENING	0.040	0.025
MODE PERCENT	-0.008	0.002
BIMODAL PATHWAY/PATHWAY AREA	-0.054	0.024
CYCLE * OPENING	0.782	0.292
ACCELERATION / CYCLE	-.0003	0.017
PREFERENCE	-0.001	0.000
Independent Dummy		
SUBJECT		
Result R^2 (adjusted) = 0.79;	SE = 0.9	

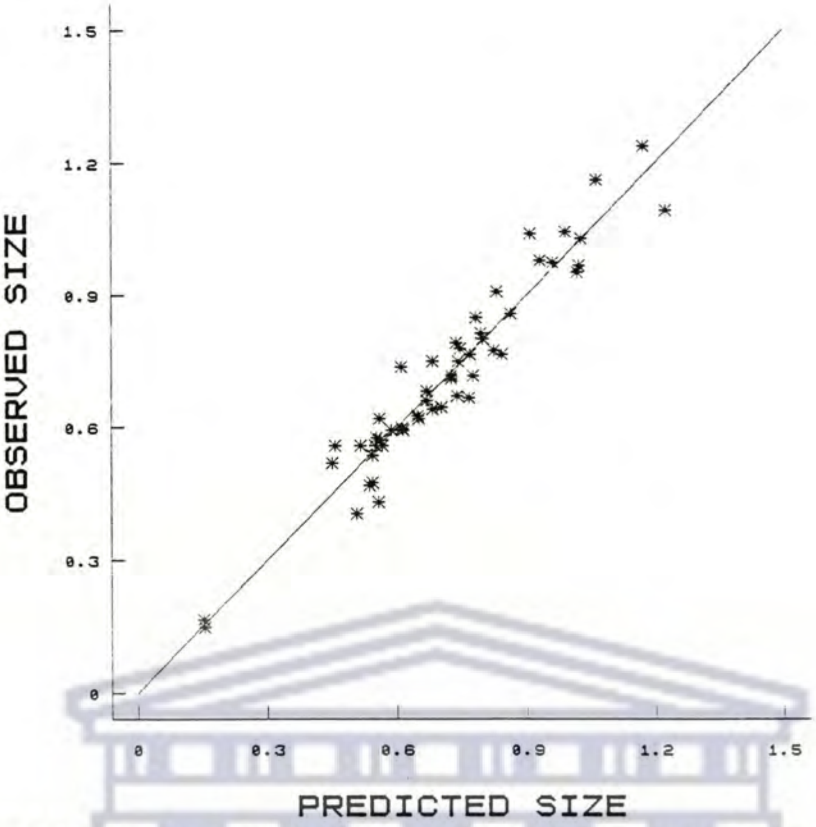

Figure 6.3. Plot of the predicted and observed values for chewing performance for each subject. The R^2 value for the regression was 0.79.

Table 6.3. Summary of the effect of increase in regression model variables on chewing performance. The level of influence was estimated from the F ratio of an ANOVA for the regression.

JAW MOVEMENT	AFFECT ON CHEWING PERFORMANCE	LEVEL OF INFLUENCE
Angle	decrease	- - -
Bimodal pathway	increase	+ + +
Area pathway	decrease	- - -
Mode percent	increase	+
Opening	increase	+ + +
Acceleration	decrease	- - - -
Cycle time	decrease	- - - -
Preference	increase	+ +

The difference between the predicted values and the observed values for chewing performance were calculated and these residuals plotted in order to study the performance of the model for each subject and to identify some of the outlying predictors (Fig. 6.4, Table 6.4).

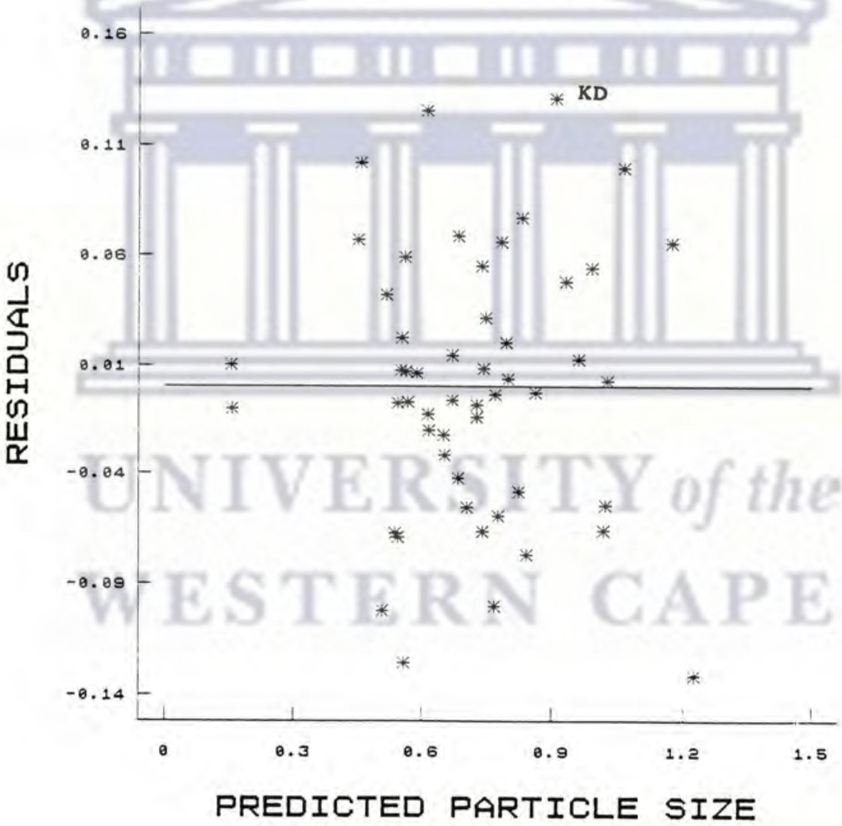

Figure 6.4. Plot of the residuals and the predicted values for chewing performance. Large residuals such as KD indicate failure of the model to predict chewing performance with the same accuracy for all subjects (Table 6.4).

Table 6.4. Selection of jaw movement data, chewing on the right side, for subjects who represented a range of chewing performance. The mean, standard deviation an median is for the entire data set (n = 52).

NAME	RESID.	TIME	SIZE	OPEN	ANGLE	BIMODE	AREA	MODE	S.AREA	CYC/S	PREF	ACCEL
CH	-.01	8	1.23	11.7	35.6	75.6	26.1	23.6	13.7	1.10	47	5.8
JT	-.05	10	2.24	12.6	33.1	21.6	49.6	13.2	26.1	0.82	66	4.8
KD	.13	10	2.83	10.4	44.8	75.6	34.3	22.7	12.0	0.52	77	3.1
BH	.03	18	2.07	5.1	24.7	8.1	16.9	33.3	5.7	0.79	62	3.7
HG	.07	19	2.37	9.9	73.0	1.0	15.0	20.8	11.4	0.91	12	9.1
Avg	.00	11.5	2.1	10.3	57.0	34.2	66.2	24.7	11.7	0.87	50.0	5.2
Std	-	4.1	47	1.8	15.6	18.9	21.9	8.8	6.4	0.12	28.8	1.9
Med	-	10.1	1.9	10.1	57.6	28.5	67.4	23.5	9.7	0.87	44	4.9

Resid; the mean difference between the predicted and observed chewing performance. See Table 6.1 for other legends.

A significant contribution to the accuracy of the model was made by the indicator variable, *subject*, without which the R^2 value for the regression fell to 0.40. This variable was derived by allocating the same numerical code to the data from both left and right sides of each subject. Indicator variables help to show the main effects of a grouping of data in a regression model (Armitage and Berry, 1987). Differences between subjects therefore accounted for some of the variation in chewing performance. No improvement in the predictive accuracy of the model occurred by using the sex of the subject as an indicator variable.

The predictive accuracy of the model was not improved by including occlusal contact area as an independent variable, in spite of its weak correlation with particle size (Table 6.1).

DISCUSSION

The test food used to study jaw movement was a rather tough variety of wine gum. A tough food was chosen so as to make the chewing task challenging enough to bring out characteristics of movement which might not emerge if a test food were used which required little effort, such as chewing gum. The test food chosen to measure chewing performance was almonds. This choice was made because nuts fracture cleanly into particles whose size can be measured. Unfortunately neither test food is ideal for both purposes; it is likely that some variables of jaw movements observed during chewing nuts are not the same as those used for chewing tougher foods (Chew *et al.*, 1988). However, in a previous study significant differences in jaw movements were not found as bolus consistency changed during progressive chewing on the same food, which is an indication that certain characteristics of jaw movement are quite consistent for an individual (Wilding and Lewin, 1991).

The dependent variable

The association between particle size and swallowing time was observed by Yurkstas (1965) and confirmed by Wilding (1993) who reported that subjects with reduced performance compensate partly by chewing for longer but still swallow larger particles than those whose chewing is more efficient. The uncertain relationship between swallowing time and particle size makes it an unreliable indicator of chewing performance. Its correlation with several variables of jaw movement may be explained by the influence of fast moving well coordinated movement on the duration of the chewing cycle, and therefore indirectly, on the swallowing time. Swallowing time might provide a rapid and uncomplicated way of assessing chewing ability in a clinical situation where the necessary technology for determining particle size is either not available or not cost effective.

It has been suggested that the rate of particle size reduction is the most accurate single expression of chewing performance (van der Bilt et al., 1987; van der Glas *et al.*, 1987). However this calculation is a power function of both particle size and number of chewing strokes, expressed as a gradient, and is therefore particularly sensitive to less than three plotting points (Wilding, 1993). My calculation of this variable was made from only two observations, so is not as accurate as the calculation made by van der Bilt *et al.* (1987). This inaccuracy may explain the absence of any significant correlation between rate of particle size reduction and variables of jaw movement.

The independent variables

Several variables of jaw movement were associated with chewing performance. Almost all these associations have been described in the literature on mastication, at least in qualitative terms. Ahlgren (1975) observed that the angle of contact glide is smaller in individuals with a normal occlusion. In this study the good predictors of chewing performance which describe the shape of the chewing cycle were the variables *angle*, *bimode, opening* and *area*. *Angle* describes the approach pathway to and from the intercuspal area, or angle of contact glide; when *angle* is low there is a lateral approach to intercuspation. This variable was not on its own, a reliable predictor of chewing performance. For example, both CH and JT had equally low values for *angle* but CH had a far better chewing performance (Table 6.4). There was a significant inverse correlation between *angle* and the variable *bimode* which reflects the frequency of two separate pathways of opening and closing. When the angle of contact glide was low there was a tendency for there to be two separate pathways to the cycle (Table 6.1). This was not always the case as is illustrated by the subjects CH and JT. Both of these subjects had low values for angle, but CH had a particularly high value for bimode while JT did not (Table 6.4). This difference was associated with the improved chewing performance of CH.

There was a significant correlation between *bimode* and *area* and between *area* and *mode%*. JT had a high value for *area* and a low value for *mode%*. This represents a large area of the chewing cycle and a lack of any well frequented pathway. The values for each of these four variables reflect the actual appearance of the chewing cycle of both these subjects. The plot of the frequency distribution of CH reveals a circular pathway which follows a similar path on each cycle (Fig. 6.1). The plot for JT (Fig. 6.5) reveals a large area in which there are a variety of pathways.

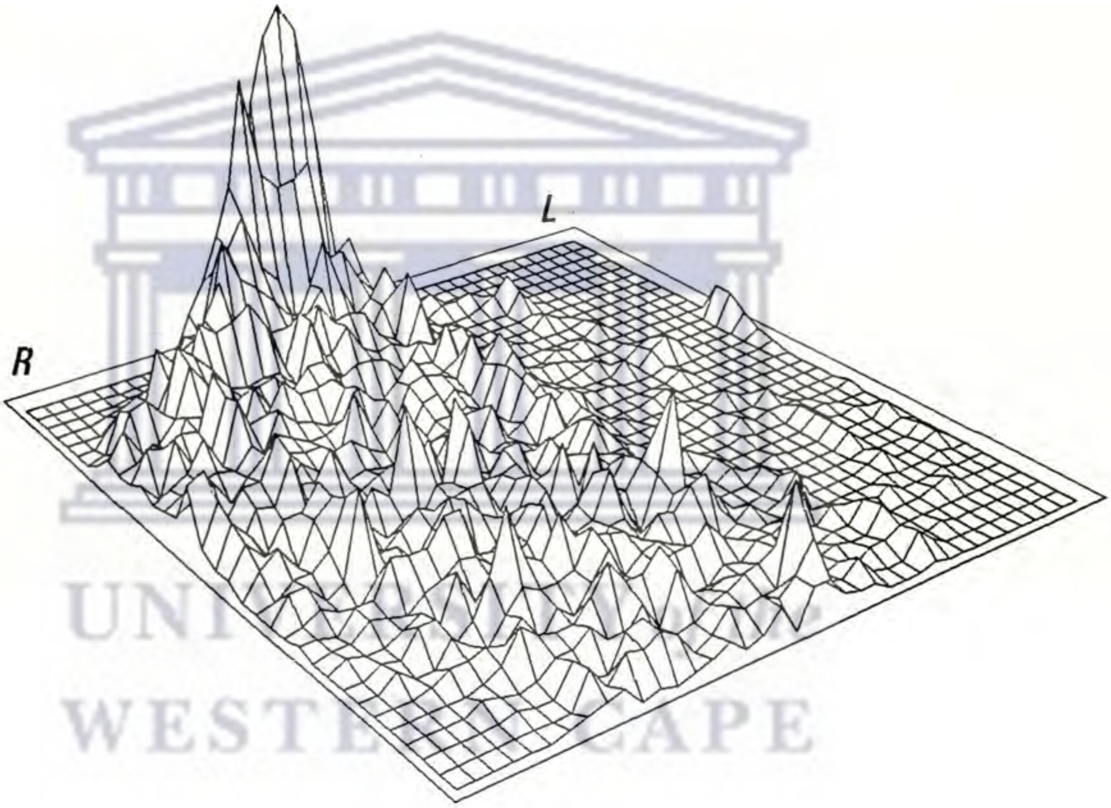

Figure 6.5. Chewing cycles (right side) of a subject, JT with average chewing performance in spite of a low mode% value (13.2%) and a low bimode value (21.6%). The low value for these two variables is a reflection of the wide chewing pathway with litle evidence of a bimodal frequency distribution (Table 6.4).

The appearance of both these subject's cycles fits the tear drop description often used to characterise the normal chewing cycle. Ahlgren (1966) classified this as Class I, while Pröschel and Hofmann (1988) classify this shape as type A, B and C, and Lewin (1985) as quadriphasic, having four main directional changes. Pröschel and Hofmann (1988) found this shape to be the dominant pattern in 193 patients. It is important to note however that the chewing performance of these two subjects was quite different, and that this difference was predictable on the basis of measurable features in the chewing cycle which are not easily detected by qualitative description and categorisation.

Subject BH (Fig. 6.6) had a low value for *angle* (Table 6.4), but was less than average in performance. The low performance of BH was accurately predicted, which indicates that other variables characteristic of poor performance such as the limited amount of *opening,* and the low *bimode* value were able to influence the final prediction towards a true reflection of chewing performance.

Several authors have suggested that a smooth, fast chewing movement may be desirable (Lewin, 1985; Evans and Lewin, 1986; Mongini and Tempia-Valenta 1984; Pröschel, 1987). In a sample of San, who are hunter gatherers in the Kalahari desert, Evans and Lewin (1986) found their mean cycle time was less than 0.5s per cycles, less than half that of the subjects in this study. In a recent analysis of their jaw movements using the model described here, it was predicted that the San's chewing performance would have been at least double that of this sample (Wilding R.J.C. Evans W. and Lewin A., unpublished).

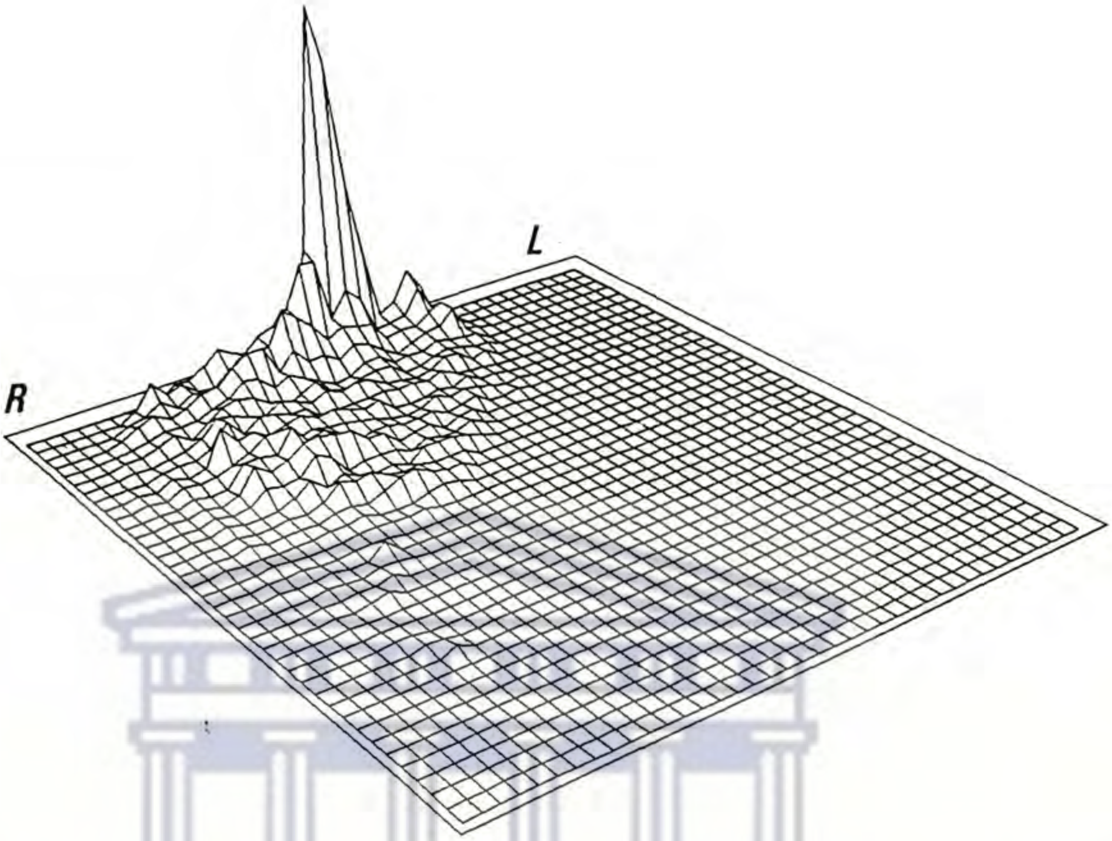

Figure 6.6. Chewing movement of subject BH, with poor performance but some of the qualities which would indicate better performance such as a very low angle (Table 6.4). A factor which may have been responsible for the accurate prediction (residual 0.04) is the reduced opening. This subject illustrates the need for a multi-variable model to express optimal jaw movement.

In this study, the smaller the *acceleration*, and the longer the durtation of the chewing *cycle*, the more efficient was the chewing. The subject HG had a particularly high value for *acceleration* and poor chewing performance which was accurately predicted (residual 0.07) (Table 6.4). The plot of the frequency distribution for HG (Fig. 6.7) shows an area in the chewing cycle where the incisors appeared to hesitate before continuing. This pause in mid-cycle may have contributed to the high value for acceleration in this subject whose rate of chewing was average.

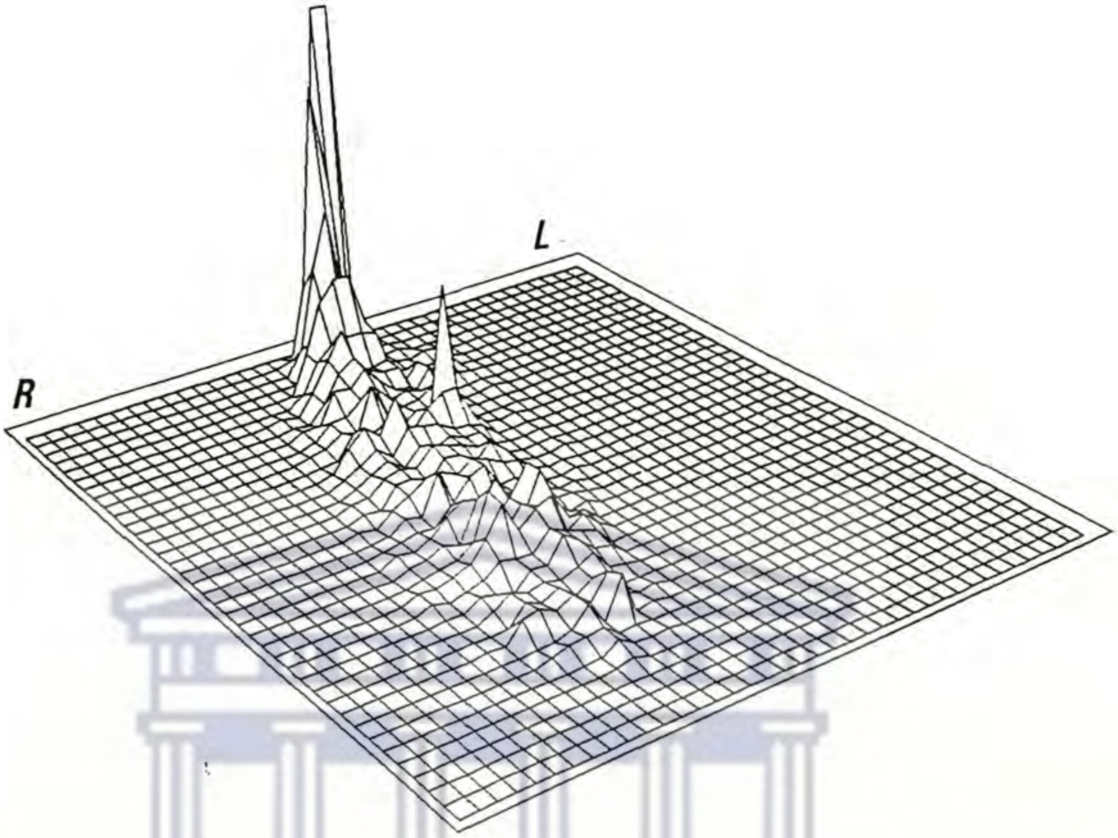

Figure 6.7. Chewing cycles of a subject, with a poor chewing performance on the right side (HG). The acceleration in this subject was particularly high, indicating erratic and jerky movement. The small peak to one side, indicate a particular position during movement where there appeared to be repeated hesitation, and may represent some mechanical derangement of the joint movement which was subclinical.

The association of a large sagittal area of movement with broad tooth contact area was predicted by Mills (1955). He described a mesiolingual movement on opening which he termed the lingual phase of occlusion, the effect of which was to extend the phase of tooth contact thereby increasing the triturating effect of the chewing cycle. A strong correlation was found between *sagittal area* and *int-contact* (coeff. 0.48, $p < .001$), which may reflect the need for a broad area of tooth contact in order to extend the phase of grinding in a mesiolingual direction. Interestingly, neither of these variables had a predictive influence on chewing performance. A significant relationship between occlusal contact area and chewing performance has been found by several authors (Yurkstas,1965; Helkimo, Carlsson and Helkimo, 1977; Luke and Lucas, 1985; Omar, McEwen and Ogston, 1987; van der Bilt et al. 1993) The absence of occlusal contact area in the model derived in this study may be because every subject had at least some useable opposing occlusal surfaces. However there was a considerable variation in contact area, both within and between subjects (mean 38.6 mm^2, sd 26.9 mm^2) and a weak correlation was found with particle size, so its failure to emerge as a contributor to the model is perhaps unusual (Table 4). The occlusal contacts measured in this study were derived from an inter-occlusal record of an afunctional jaw posture. Since there is no way of knowing whether the sets of contacts registered are indeed those used during the comminution of the test food it can only be assumed that they may represent areas of potential contact of opposing occlusal surfaces. Hence these occlusal contact areas are more correctly described as "potential occlusal contacts." These representations may be so far from the actual tooth approximations during chewing that they are ineffectual and irrelevant to the chewing process. The role of occlusal contact area is clearly of vital importance when it is significantly diminished, but it does not seem of any benefit to have the maximum possible occlusal contact area in the posture where maximum intercuspation occurs.

Variations in skeletal or occlusal morphology were not recorded in this study, both of which might have influenced masticatory ability. However, Ahlgren (1966) wrote ".. although a case with "normal" occlusion usually has a more regular chewing pattern than a case with malocclusion of the teeth, there is no direct relationship between movement pattern of the mandible in mastication and occlusion of the teeth. Many other factors such as personality, temperament, social environment and food selection are probably more decisive in the formation of the individual chewing pattern than the occlusion of the teeth." Further studies are necessary to determine the degree of malocclusion, at which, chewing performance becomes dependent on occlusal contact area. It will also be necessary to devise means of evaluating the extent to which individuals exploit potential tooth contacts as they are required, when these contacts are not represented by an analysis of maximum intercuspation.

The model was able to predict 79 % of the variance between subjects but for some subjects it was clearly less accurate. The difference between the observed and predicted chewing performance for KD was one of the highest in the sample (Table 6.4). Most of the values for KD's jaw movements were within a standard deviation of the mean, and hence an average chewing performance was predicted, but in fact, KD's chewing performance was one of the worst in the sample. KD's values for *cycle*, were unusually low, indicating a fast rate of chewing. The coefficient given to cycles in the model had insufficient weight to predict a poor chewing performance for KD. It is possible that if the sample size was larger there would have been more individuals like KD and the coefficient for *cycles* would have been larger. It is also possible that an important variable in determining chewing performance is missing from the model, which then would not improve however large the sample. There were several areas in the chewing cycle where pauses were common. These pauses are noticeable in the plot of the frequency distribution for KD (Fig. 6.8). They are similar to the pause seen in the subject HG (Fig. 6.7) although high values for *acceleration* were not a feature of KD's chewing (Table 6.4).

The indicator variable

The improved chewIng performance of males, in comparison to female subjects may have resulted from at least two factors. Firstly it has been shown that for similar levels of EMG activity, males generate a higher bite force than females (Visser and Ruke, 1974). An increased bite force may contribute to an increased rate of breakage of food particles. However, there is evidence that the forces generated during muscle contraction are well in excess of those required to break up the food (Slagter *et al*, 1993); these authors note that peak forces generated during mastication are poorly related to the reduction in particle size during chewing, and suggest that muscle force not used in food breakage may be available for maintaining an un-interrupted chewing rhythm. Males were found to have a wider jaw *opening* and shorter cycle time than females, which would require the application of increased muscle power throughout the entire cycle and not necessarily involve the use of greater maximum force. Gender differences in the sample to did not contribute to the regression model and this could have been because they were already expressed in the variables *opening* and *cycles*.

A second possibility which might explain sex differences in chewing performance is that females chew more slowly with more limited opening than males because of social conditioning. Some Eastern cultures encourage females to adopt a quite spoken voice, restrained laughter and a composed facial expression. Wide vigourous chewing, such as males may be comfortable with, is not commonly observed in females of such cultural background.

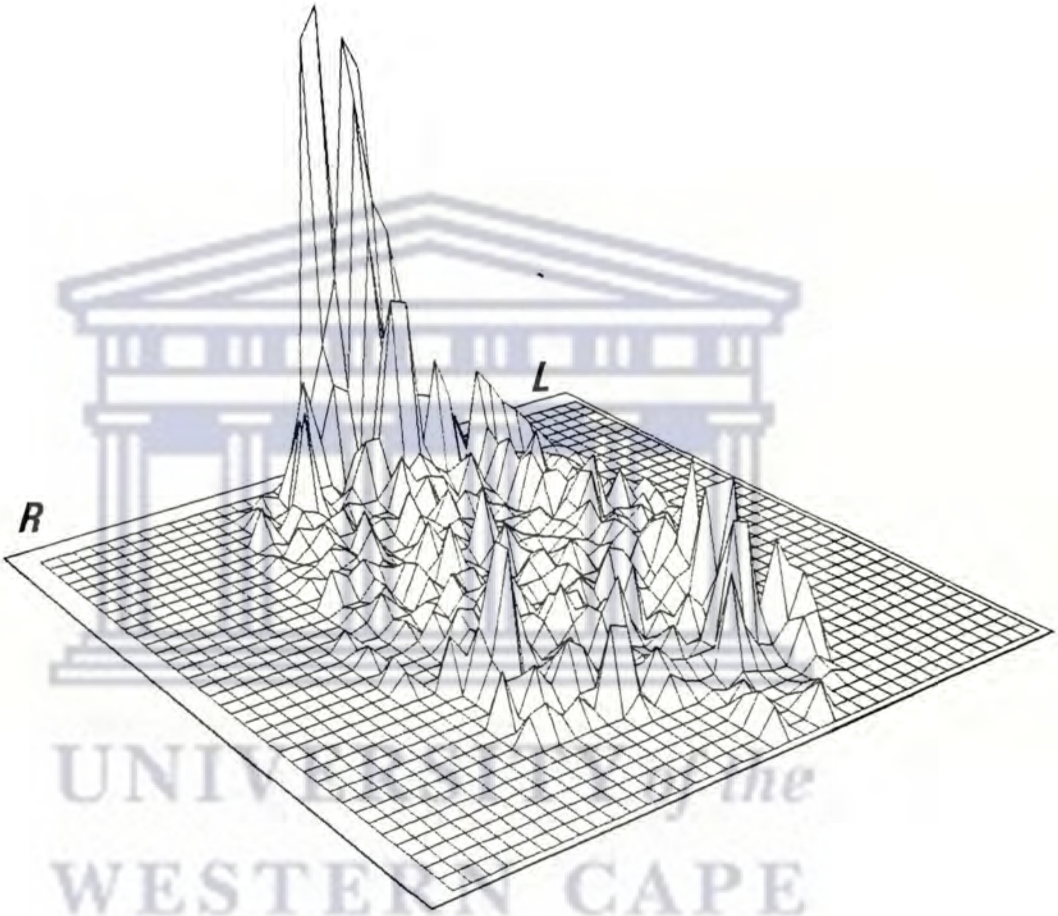

Figure 6.8. Chewing cycles (right side) of a subject KD with an average value for most variables except cycle, but a poor chewing performance which the model did not predict with the same accuracy as other subjects (Table 6.4). An unusual feature is several zones of high frequency far from the intercuspal position indicating a repeated hesitation during each chewing cycle at similar jaw positions.

The role of the indicator variable *subject*, provides some clue as to the influence of the individual in the model. In a previous study of chewing performance and occlusal contact area, a set of data was prepared which expressed all variables as a proportion of left and right sides of each subject (Wilding, 1993). Only when this was done was an association found between the ratios of left to right chewing performance and left to right occlusal contact area. It was concluded that there was some factor, common to both chewing sides, which was controlled when the data was paired. The role of the indicator variable in this study seems to confirm the existence of an unidentified variable, common to both chewing sides of an individual. It has been shown in previous chapters that jaw movements, chewing performance, occlusal contact area and chewing side preference are not side similar. Each of these variables therefore has a separate interaction with others in a set of data in which left and right sides are pooled. It is therefore possible that a variable which is common to both left and right sides of the individual is the missing factor in the model of this study, expressed by the indicator variable *subject*. There is great variation in the muscle power (integrated EMG) used by individuals during chewing, although little difference between left and right chewing sides or between males and females for submaximal levels of effort (Ahlgren, 1966; Visser and Ruke, 1974). During clenching, the muscle power and bite force are asymmetrical, although clenching involves greater power than chewing and thus may reveal side differences which are not found during chewing (Pruim 1979; Naeije, McCarrol and Weijs, 1989). Muscle power may be found to explain the weight of the indicator variable *subject*, and to replace it in a model of chewing performance which will bring outlying predictions like those of KD closer into the model. Ahlgren (1966) reported that greater muscle activity is developed in "grinders" than in "choppers". In view of the strong association in this study between "grinders" and performance, the next chapter will investigate the possibility of determining optimal values for muscle activity based on chewing performance.

Optimal jaw movements

Efficiency in a system may be described in engineering terms as an inverse function of the useful output and the input, so efficiency improves as the useful output increases or as the input decrease (French, 1988). Efficiency is thus a ratio and not an absolute quantity of work done. The commonly used term "chewing efficiency" is therefore inappropriate because it makes no reference to the input of the system but refers only to the useful output, more accurately described as chewing performance. Chewing performance is dependent on two processes, food selection and breakage (Lucas and Luke, 1983). If it were possible to measure the glucose utilisation of the masticatory muscles during chewing, and thus the chemical energy expended in the chewing process, the ratio between input and useful output could be calculated. Energy wasted in non-useful output would occur in the form of heat generated during muscle activity (French, 1988). Energy would also be lost in non-useful work done overcoming the inertia of the jaws, and the resistance of soft tissues to movement, and in bracing the jaw against the temporomandibular joint surfaces while biting. This non-useful mechanical work of chewing could be reduced by well coordinated movement, and skill in selection and breakage of food.

In contrast to this concept of efficiency, chewing performance is a measure of useful work done. This is clearly dependent on both the amount of energy available and the efficiency with which it is converted into useful work. Well coordinated jaw movement would enhance performance because there is an efficient use of muscle energy. The importance of efficiency in achieving high performance is clearly illustrated by the distance achieved in the tee shot of top class female golfers. It is likely therefore that chewing performance is determined by several factors, the level of biting force available, some critical amount of occlusal contact area, and the efficiency of the processes of selection and breakage of the food.

I believe that the characteristic of jaw movement which improve chewing performance must be the most efficient and therefore optimal. By this definition, optimal masticatory movements are characterised by a smooth-flowing, fast chewing cycle which moves in an open loop following the same pathway on each cycle, with a lateral approach to and from positions of tooth contact (Fig 6.2a). It must be stressed that there is a wide range of values for jaw movement variables compatible with health; no single jaw movement variable on its own is a determinant of optimal function.

CONCLUSIONS

1. Chewing performance may be predicted by a model consisting of several jaw movement variables.
2. Jaw movements which contribute to a high chewing performance may be more efficient than those which do not. On this basis, certain characteristics of jaw

movement may be defined as optimal.

3. The minimal requirements for occlusal contact area and muscle power still have to be determined.

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Chapter 7

EMG activity and chewing performance

SUMMARY

In this study, the relationship between chewing performance (test food particle size), derived from the same subjects in a previous study, and EMG activity was investigated with a view to developing optimal values of EMG variables, based on their ability to predict chewing performance. Electrognathograph (EGN) and EMG recordings from surface electrodes over the masseter muscles, digastric and anterior temporalis muscles, were made from 24 subjects while they chewed a hard fruit gum.

A negative correlation was found between the food particle size and masseter RMS (-0.48 $p<0.01$). Positive correlations were found between particle size and the asynchrony of ipsilateral and contralateral anterior temporalis muscles (0.36 $p<0.05$). A multiple regression model of EMG and EGN variables was able to predict chewing performance with an R^2 value of 0.66. If chewing performance is used as an output measure of masticatory function, it is possible to determine optimal ranges for EMG variables and jaw movements.

INTRODUCTION

Chewing requires two main processes, selection and breakage (Lucas and Luke, 1983). Selection involves the manipulation of unreduced food particles onto occluding tooth surfaces by movements of the tongue, jaws, lips and cheeks. In monkeys, movement of the tongue and lips not only help select food but also influence the shape of the chewing cycle (Hiiemae, Hayenga and Reese 1994). Some aspects of jaw movement in humans, are fair predictors of chewing performance (Wilding and Lewin, 1994). Jaw movement is not produced by any single muscle, but is effected by a variety of synergistic combinations of functioning units within several jaw muscles (Thexton and McGarrick, 1994). For any particular bite force and direction there are certain combinations of muscles which generate the force most efficiently (Osborn and Baragar, 1985). The relation between muscle activity and jaw movement is therefore complicated by the large number of distinct units in each masticatory muscle, which can function independently of one another (Schumann *et al* 1994). While the bite force vector generated at a particular tooth by even the smallest physiological unit can be theoretically determined, the number of possible interactions with other units makes it difficult to predict jaw movement on the basis of EMG activity recorded with a few surface electrodes. In spite of this complexity, associations have been found, for example between lateral grinding movements and contralateral jaw muscle activity (Hannam and Wood, 1981; Wood, Takada and Hannam, 1986; Hylander, Johnson and Crompton 1987).

Claims have been made for the value of EMG recordings in the diagnosis of dysfunctional movements and activity in TMD (Cooper and Rabuzzi, 1984; Ash,1986; Naeje and Hansson, 1986). In a review of this literature, Lund and Widmar (1989) concluded that as yet there was not adequate normal data to support the use of EMG recording in the diagnosis of dysfunction. Diagnostic tests require a substantial baseline of both normal data, and a reliable gold standard of disease, to allow predictions to be made with acceptable levels of accuracy, precision, sensitivity and specificity (Douglas 1993). The purpose of this study was to determine whether chewing performance could be used to identify an optimal range of muscle activity. This data might define a useful baseline against which putative muscle dysfunction could be compared. In addition it was hoped to find evidence of an association between optimal muscle activity and optimal jaw movements derived from a previous study (Wilding and Lewin 1994).

METHOD

Sample

The same subjects were used for the study as participated in previous studies of jaw movement, and chewing performance (Chapters 5 & 6). The sample comprised 12 females and 12 males with an average age of 27.3 years. None of the subjects had signs or symptoms of cranio-mandibular disorders.

Data Capture

EMG recordings were made using surface electrodes over the posterior and anterior aspects of the ramus of the mandible, the region of the anterior temporal muscle and under the chin over the region of the anterior belly of the digastric muscles on each side of the jaws. Although these regions of sampling may not represent the activity of muscle defined in anatomical terms, the electrical activity sampled from these regions will be referred to for convenience as EMG of anterior and posterior masseter, anterior temporalis and digastric muscles. The subjects chewed on a hard fruit gum for 15 seconds on first the left and then the right sides. Incisal movements were simultaneously recorded in three planes using a Sirognathograph (Siemens, Benheim, Germany). The signals were digitised at 300 Hz and converted to ASCII files using Bio-Pak equipment (Bio-Research, Milwaukee, USA).

The data for vertical displacement were used to separate the EMG data into a series of chewing cycles. The mean duration for each chewing cycle was calculated and will be referred to as the cycle time.

Electromyography

A moving average of 20 data points was used to rectify and smooth each value using a root mean square calculation (RMS). For each contraction phase the RMS and peak value was calculated, and the mean values for all cycles found. The period during active contraction (burst time) was calculated for each closing cycle for the masseter and temporalis muscles. For each of the adductors, the integrated EMG (iEMG) was calculated for each closing cycle, and the mean found for the total period of recording. The iEMG was also calculated for the digastric data during jaw opening.

The difference between the iEMG for ipsilateral and contralateral adductors, was calculated for each closing phases and the mean calculated (Fig. 7.1a). This variable will be referred to as iEMGipco. A point along the time axis during each muscle burst was found, which equally divided the area under the smoothed and rectified curve. This point was used to define the midpoint of the burst. The difference between the midpoints of ipsilateral and contra lateral adductors was used to express the phase lag between contractions of the chewing and non-chewing sides, and will be referred to as LAGipco. From the manner in which the phase lag was calculated it follows that a negative value indicated that the ipsilateral mid-burst point, occurred earlier (lower time value) than the contralateral mid-burst point.

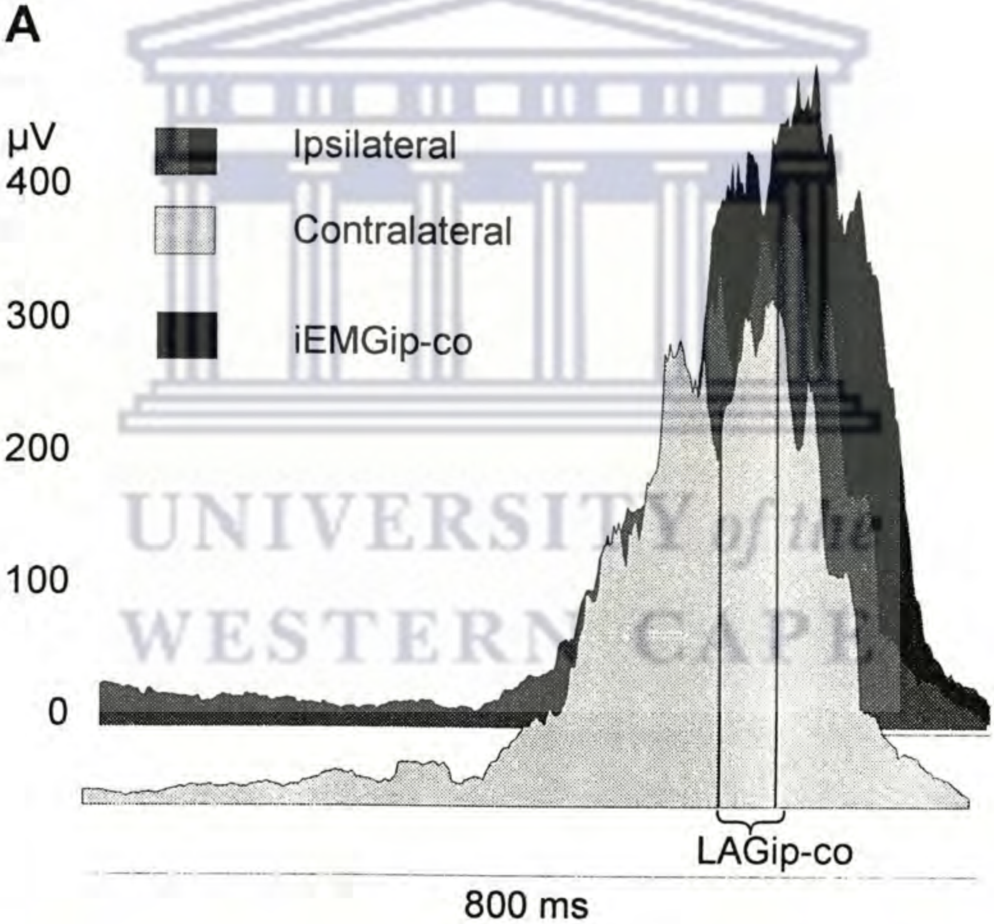

Figure 7.1 a). Rectified and smoothed EMG signals for one chewing cycle. The areas under the curve for the contra-lateral masseter (light shading) are superimposed over the ipsilateral masseter EMG. The variable iEMGipco represents the difference between these two areas. The time difference between the centre of each area is represented by the variable LAGipco.

The difference between the integral of each adductor and the abductor (digastric) of the same side, during the adductor burst period was calculated. The result represented the nett adductor iEMG available for that muscle during closing (Fig. 7.1b). This variable will be referred to as iEMGnett.

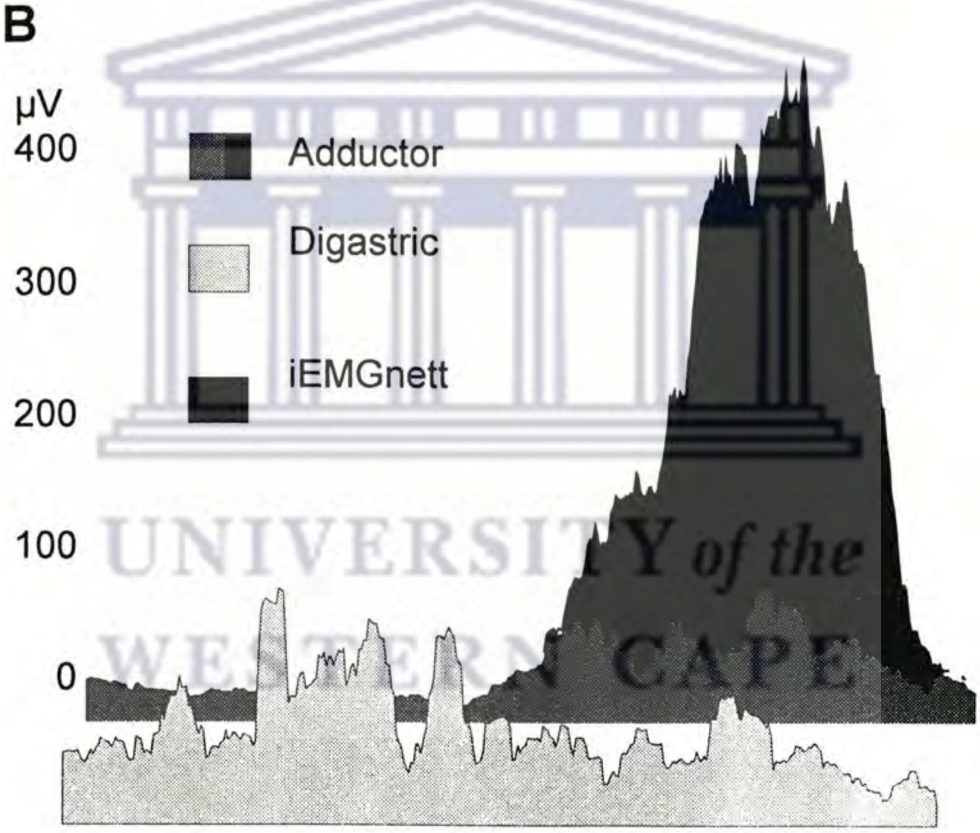

Figure 7.1b) The area between the adductor (masseter and temporalis) and abductors (digastric) curves, during the closing phase reflects the nett adductor EMG and is represented by the variable iEMGnett.

In view of the potential for voltage reversals to describe some of the characteristics of an EMG wave form, the number of turns and the mean turn interval was calculated after the method described by Junge and Clark (1993).

Statistical Analysis

Non-parametric tests were used in investigate differences between ipsilateral and contralateral chewing sides, gender differences and correlations between variables. A stepwise multiple regression was used to develop a model to predict particle size, using firstly variables derived from EMG data. A second model was derived using EGN in addition to EMG derived variables. All data were analyzed using Statgraphics Plus (USA) software.

RESULTS

The sample mean for the masseter EMG (RMS) during its active burst was 145.4 μV (sd 60.8), and for the temporalis anterior it was 133.6 μV (sd 55.7). The average value for the digastric RMS during the opening phase of movement was 53.8 μV (sd 21.3). No significant difference was found between the anterior and posterior masseter RMS and these values were combined for future analysis.

The integrated EMG (iEMG) for ipsilateral and contralateral chewing sides were compared and a significant difference was found between their sample means for the masseter muscles ($p<.001$) but not for the temporalis or digastric muscles (Table 7.1).

The sample mean for the phase lag between ipsilateral and contralateral masseters mid-burst was 20.38 ms (sd 37.65) which indicates that the masseter burst on the contralateral side usually occurred before the ipsilateral side. The sample mean for the phase lag for the temporalis muscle (-32.5ms sd 42.6) indicated that for temporalis, the ipsilateral mid-burst usually occurred before the contralateral side. A pattern similar to that of temporalis muscles was found for the digastrics muscles with a lag between the ipsilateral and contralateral sides of -15.6ms (sd 26.3).

The sample mean for iEMGnett (the nett adductor integrated EMG) for the masseter muscle was 27.0 µV.sec (sd 24.2) and for the temporalis was 21.4µV.sec (sd 20.5). The mean duration of the burst period for the masseters was 149.2 ms (sd 100.9) and for the temporalis was 133.1 ms (sd 77.5). The sample mean for the average turn interval was 160.9µV (sd 45.1) for the masseter muscles and 155.9µV (sd 45.4) for the temporalis muscles.

Table 7.1. The mean integrated EMG (µV) and standard deviation (SD) for ipsilateral and contralateral adductors during closing and the mean difference in integrated EMG (iEMGipco) and phase lag (LAGipco) for masseter and temporalis muscles. A negative value for LAGipco reflects an early contraction of the ipsilateral adductor.

	Masseter (µV.sec)		Temporalis (µV.s)		Digastric (µV.s)		LAGipco (ms)		
	Ipsi	Contra	Ipsi	Contra	Ipsi	Contra	Mass	Temp	Dig
Mean	48.5	34.1**	42.9	36.0	21.5	19.8	20.3	-32.5	-15.6
S.D.	29.8	24.8	25.0	24.7	8.87	8.48	37.6	42.6	26.2

* = $p<0.05$, ** = $p<0.01$, *** = $p< 0.001$ for data in column to left.

Gender differences

The mean iEMG for temporalis was higher in females (51.1µV.s, sd 22.2) than males (34.8µV.s ;sd 25.4) ($p< 0.02$). The mean for iEMGnett (temporalis) for females (98.0µV sd 30.7) was higher than for males (72.9µV sd 37.2&, $p<0.02$) (Table 7.2).

Table 7.2. Sample means and standard deviations() for iEMG in males and females during chewing.

	Males (12)	Females (12)	
Mean iEMG	34.8µV.s (25.4)	51.1µV (22.2)	*
Mean iEMGnett (temporalis)	72.9µV (37.2)	98.0 µV (30.7)	*

Asterisks indicate significant differences as for Table 7.1.

Correlations between variables

Several EMG variables were found to correlate negatively with particle size. These included the RMS values for the masseter, temporalis and digastric muscles, and the masseter turns frequency. The highest correlation was found for masseter RMS (coeff -0.48, $p<0.01$). The variable iEMGipco for masseters also had a negative correlation with particle size (Table 7.3). A positive correlation with particle size was found with the LAGipco for temporalis muscles (coeff 0.36, $p<0.05$). The sample mean value for this phase lag was negative, indicating that the ipsilateral temporalis burst usually occurred before the contralateral burst.

Table 7.3 Correlation coefficients for particle size, EGN and EMG variables.

	Particle size	Mass RMS	Mass iEMG	Mass iEMGnett	Mass iEMGipco	Temp LAGipco	Dig iEMG	Bimode	Angle	Cycle time
Particle size		***	*	*	*	*	*	*	**	*
Mass RMS	-0.48		****	****	***	*	**		*	**
Mass iEMG	-0.33	0.94		****	***	**	****		**	*
Mass iEMGnett	-0.30	0.92	0.91		***	**	**	*	*	*
Mass iEMGipco	-0.31	0.53	0.54	0.49		*	**			
Temp LAGipco	0.36	-0.38	-0.44	-0.42	-0.36		*		****	
Dig iEMG	-0.32	0.62	0.71	0.42	0.45	-0.33			*	*
Bimode	-0.41	0.27	-0.22	-0.32	0.04	-0.26	0.03		*	
Angle	0.46	-0.42	-0.44	-0.43	-0.17	0.53	-0.33	-0.48		
Cycle time	-0.34	0.39	0.37	0.33	0.24	0.00	0.32	0.11	0.04	

Asterisks indicate significant of correlations as for Table 7.1

A negative correlation with particle size was found with the cycle time (-0.34 $p<0.01$). A positive correlation was found with ANGLE and particle size (0.46, $p<0.001$). Correlations were found between ANGLE and several EMG variables; the most significant being with LAGipco for temporalis (0.53 $p<0.002$; Table 7.3).

No correlations were found between the RMS peak values for adductors and particle size. A strong correlation of 0.91 ($p<0.001$) was found between the turns interval for masseter and masseter RMS.

Multivariate models

A stepwise multiple regression was used to generate a number of models using EMG data as the dependent variables. It was possible to predict 44% of the variance of the vertical dimension of jaw opening from EMG variables (Table 7.4). The masseter iEMG and iEMGnett had powerful influences in the model . A model constructed to predict chewing cycle time had an adjusted R^2 value of 0.48 and was dominated by masseter iEMG and the duration of the temporalis burst.

The relationship between EMG variables and jaw movement patterns was revealed in a model in which ANGLE was the dependent variable. The components of the model for ANGLE were dominated by variables representing temporalis muscle activity.

The logarithm of the particle size was predicted with an adjusted R^2 value of 0.51 using EMG variables. The Masseter RMS, and iEMG and temporalis LAGipco were the dominant adductor variables. The model also included the digastric iEMG. (Fig. 7.5).

Table 7.4 The components of multivariate models with EMG data as independent variables. For each model the influence of each component is indicated by either + or - signs. The number of signs reflects the F-factor for adding or removing the variable from the model (one sign = 4 F-factor units).

	Opening max.	Cycle time	Angle	Log Particle Size
R- squared (adjusted)	0.44	0.48	0.46	0.51
Mass. RMS mean	+ +			- - -
Mass. iEMG	+ + + +	+ + + +	-	- - -
Mass. iEMGnett	- - - -			-
Temp. RMS mean			- -	
Temp. iEMG		+ +		
Temp LAGipco			+ +	+ + + +
Temp. burst time		— — —	- -	
Temp. iEMGnett	+	— —		
Dig. iEMG	- - - -	- -		- -

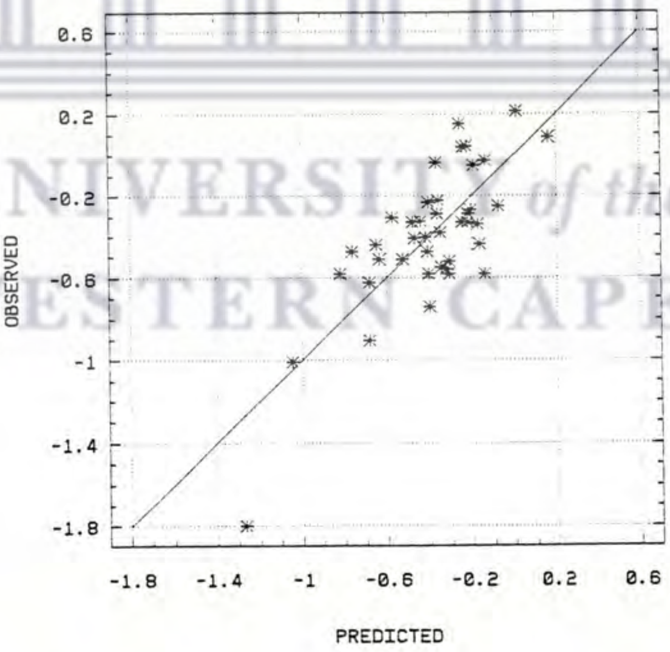

Figure 7.2. A plot of the predicted values for particle size calculated from the EMG model (Table 7.4) and the observed values for particle size. Both scales are logarithmic. The R^2 value of the multivariate model was 0.51.

A model containing both EGN data and EMG variables provided a more accurate prediction of particle size than either group on its own. This combined model had an adjusted R^2 value of 0.66 (Table 7.5, Fig. 7.3) The EMG components of the model included most of those selected for EMG alone and listed in Table 7.4. The EGN variables all had high coefficients in the model. A model consisting of just the three EGN variables, ANGLE, BIMODE and chewing time had adjusted R^2 value of 0.53

The addition of gender as an indicator variable raised the predictive accuracy of the combined EGN/EMG model to an adjusted R^2 value of 0.75. Indicator variables help to show the main effects of a grouping of data in a regression model (Armitage and Berry 1987).

Table 7.5 The components of a multivariate model with both EMG and EGN data as dependent variables with the logarithm of particle size as the dependent variable. The influence of each variable is denoted by plus and minus signs as for Table 7.4.

Independent variables	Influence
ANGLE	+ +
BIMODE	- - -
Cycle Time	- - -
Mass RMS	- - -
Mass iEMG (log)	+ +
Mass iEMGnett	+
Temp LAGipco	+ +
INDICATOR gender	

R^2 adjusted = 0.66
R^2 adjusted = 0.75 including INDICATOR variable

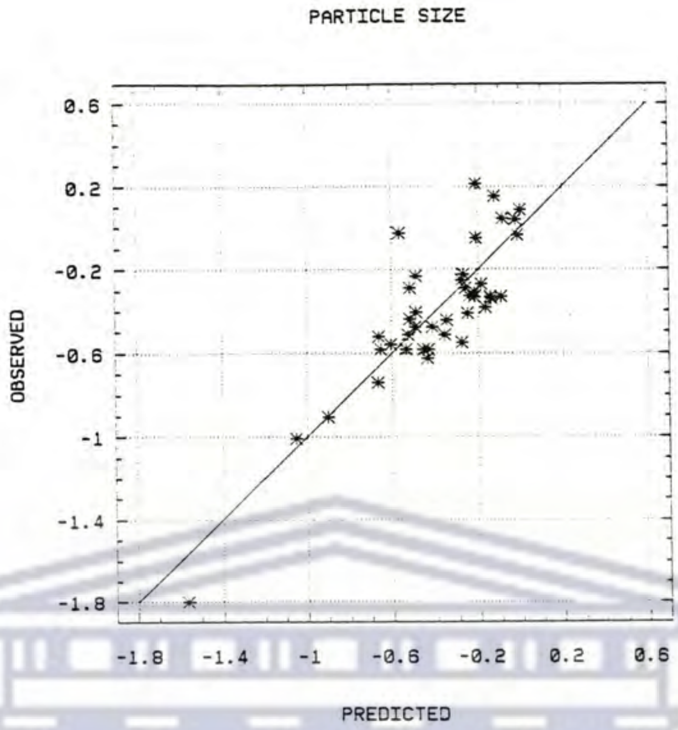

Figure 7.3. A plot of the observed values for particle size and those calculated from the EMG and EGN model excluding the indicator variable, gender (Table 7.5). The R^2 value of this model was 0.66.

DISCUSSION

A tough test food was chosen so as to make the chewing task challenging enough to bring out characteristics of muscle activity which might not emerge if a test food were used which required little effort, such as chewing gum. The test food which was used to measure chewing performance in a previous study of the same subjects was almonds. This choice was made because nuts fracture cleanly into particles whose size can be measured. Unfortunately neither fruit gums nor nuts are ideal for both purposes. Some variables of jaw movements, particularly vertical dimension, are reduced when chewing nuts in comparison to tougher food (Chew *et al*, 1988). However chewing patterns and muscle activity were found to be similar when chewing either hard or soft gum provided the chewing rate remained constant (Bishop Plesh and McCall 1990). In a previous study significant differences in jaw movements were not found as bolus consistency changed during progressive chewing on the same food, which may be an indication that certain characteristics of jaw movement are quite consistent for an individual (Throckmorton and Dean 1994).

The masticatory muscles have different functional and electrophysical regions (Wood, Takada and Hannam 1986). The placement of just one pair of surface electrodes does not therefore represent more than the surface activity of a region. It therefore cannot be assumed that the electrodes used in this study were representative of the muscle name used to describe their position. Therefore the individual data from each electrode placed, represents only part of that muscle's activity, which could vary according to several factors. These include the size of the muscle, the site of electrode, the position, direction and magnitude of the bite, and the activity of other muscles (Moller 1970).

Two pairs of electrodes were placed over the area of the masseter muscle. No significant difference was found in the RMS, or integrated EMG between the two electrodes.

Asymmetry between ipsilateral and contralateral sides

Differences in the EMG activity between chewing and non-chewing sides have been reported by a number of authors (Ahlgren and Owall, 1970; Moller, 1970;

Stohler, 1986; Hannam and Wood 1981; Hylander, Johnson and Crompton, 1987).

A positive correlation was found between the variable iEMGipco for masseters and particle size (Table 7.3). Thus small differences in integrated EMG of ipsilateral and contralateral muscles were associated with small particle size. These differences were expressed as a working/balancing ratio by Hylander, Johnson and Crompton (1987) who found that as the ratio approached 1.0 the amount of overall masticatory force during chewing increased.

Asynchrony between ipsilateral and contralateral sides

Differences in the mid-burst time of the ipsilateral and contralateral adductors have been reported (Moller,1970; Hannam and Wood, 1981; Hylander, Johnson and Crompton, 1992). Our results confirm that the contralateral masseter reaches its mid burst point usually before the ipsilateral muscle (LAGipco is negative)(Table 7.1). On the other hand the mid burst point of the ipsilateral temporalis muscle usually occurred before the contralateral side (LAGipco positive), an asynchrony also observed by Moller (1970) and reported in posterior temporalis by Takada, Miyawaki and Tatsuta (1994). A negative correlation was found between the asymmetry of masseter muscles (iEMGipco) and the asynchrony of temporalis muscles (LAGipco) (Table 7.3). It is necessary to recall that LAGipco values were mostly negative; the lowest values therefore represent a long lag period between the ipsilateral and contralateral bursts. The subject CH, who had the highest chewing performance in the sample, illustrates symmetry of masseter and asynchrony of temporalis muscle contractions (Fig. 4a). These variables contributed to making an accurate prediction of particle size, with a residual of 0.09mm (Table 7.4).

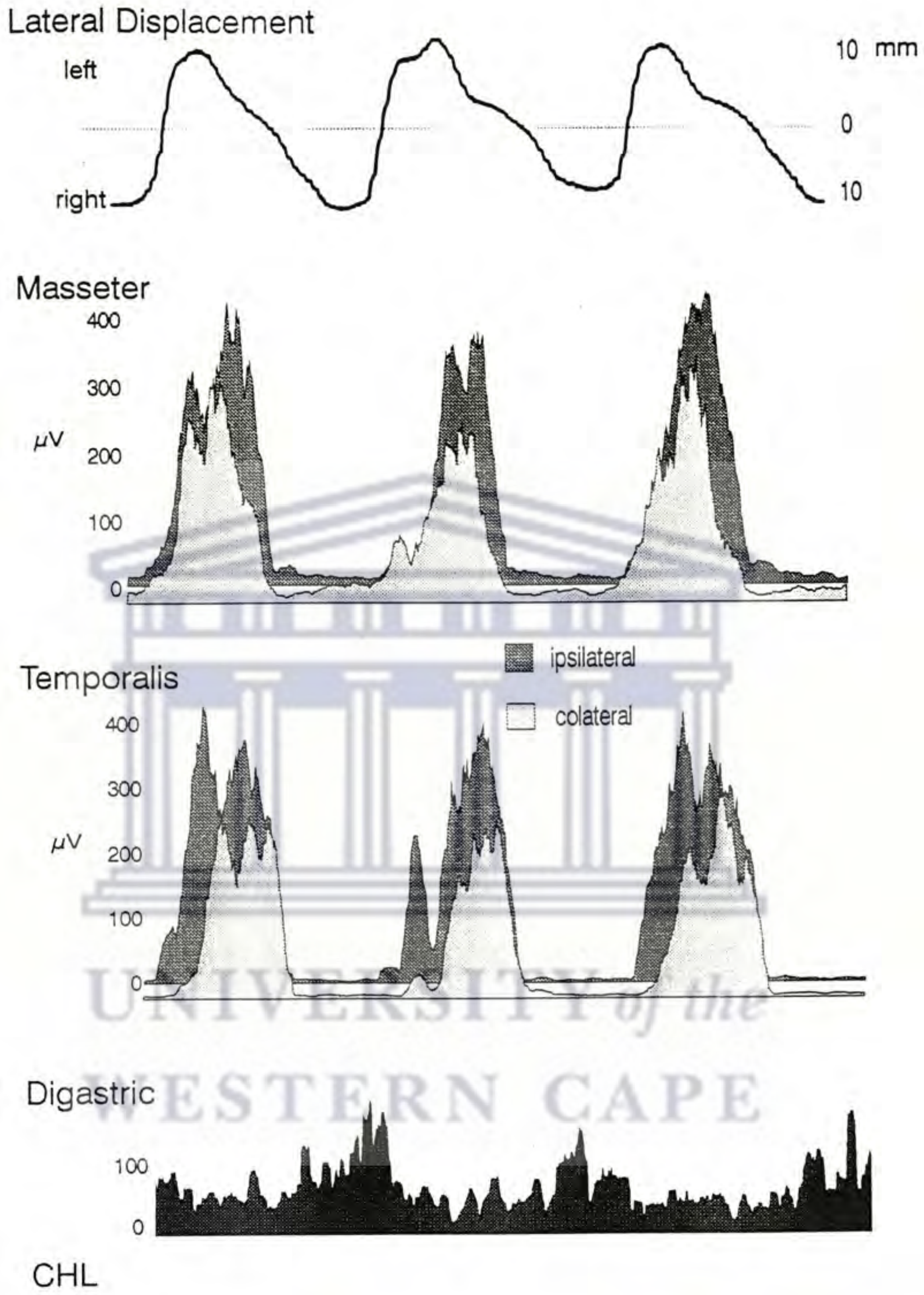

Figure 7.4a: The rectified and smoothed EMG signals for the ipsilateral (dark shade) and contralateral (light shade) adductor muscles during three chewing strokes on the left side. The displacements in the frontal plane of the mid-incisor point are traced above. a) The subject CH. The difference between ipsilateral and contralateral masseter curves (iEMGipco = 112μV.s), and the phase lag between ipsilateral and contralateral temporalis muscles (LAGipco = -17.2ms) contributed to accurately predicting the superior chewing performance of this subject (Table 7.6).

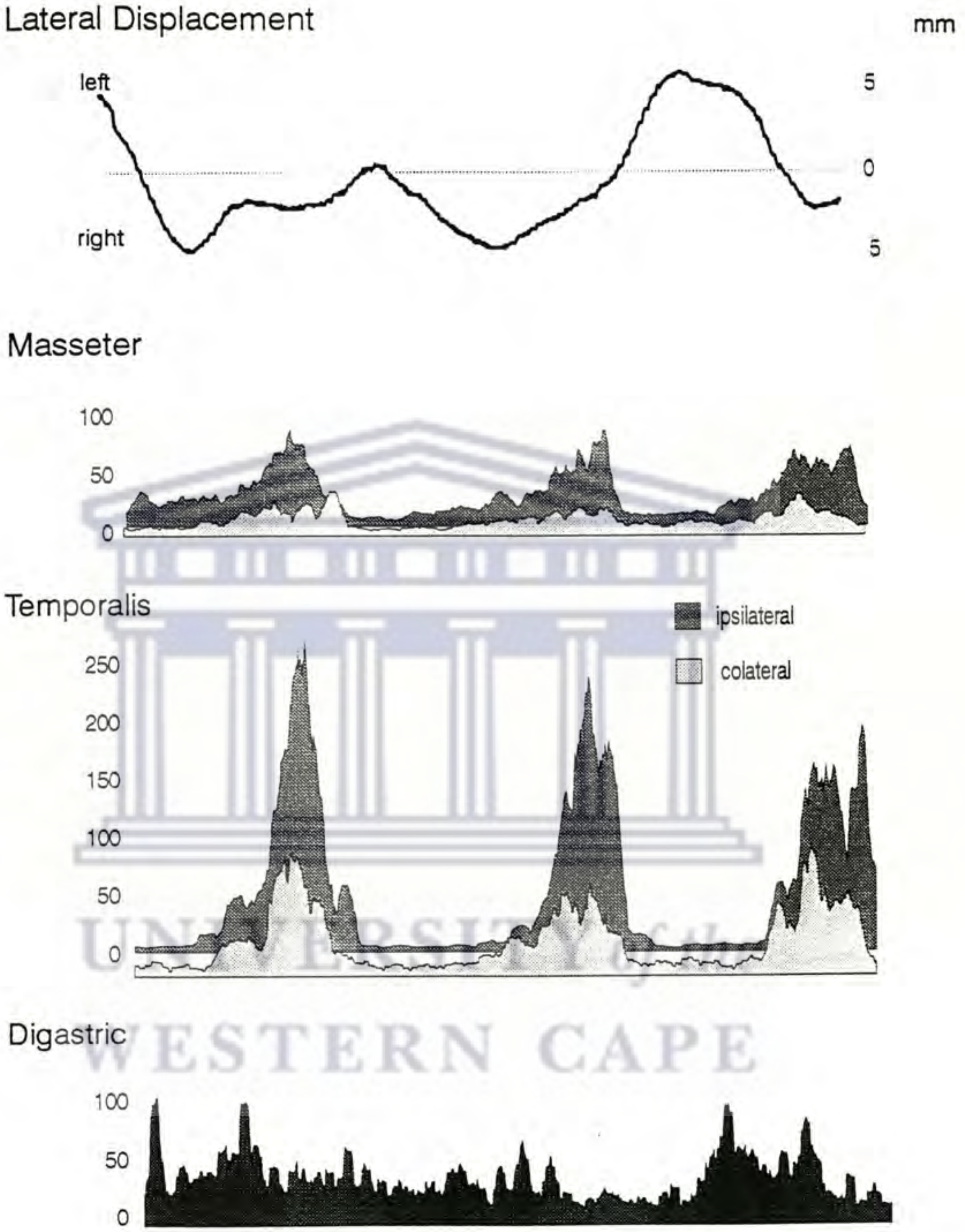

Figure 7.4b: The subject KD. This figure is not drawn to the same scale as Fig 7.4a). The low mean RMS (65.0μV), the co-activation of digastric (low iEMGnett), and the reverse synchrony of temporalis muscles (LAGipco = 9.8 ms), contributed to accurately predicting the inferior chewing performance of this subject (Table 7.6). The reversed sequence of the first two chewing cycles which approach intercuspation from the non-chewing side were reflected by a more vertical approach to intercuspation (ANGLE =75 degrees) .

Early activity of the contralateral pterygoid muscles and the deep fibres of masseter during chewing have been related in monkeys and humans to a relative increase in laterally directed movement during the intercuspal phase of chewing (Wood Takada and Hannam,1986; Hylander Johnson and Crompton 1987).

In most subjects the contralateral masseter burst preceded the ipsilateral burst (Table 7.1), but no correlation was detected between laterally directed movement (ANGLE) and LAGipco for masseter. However a relationship was found between ANGLE and the LAGipco of temporalis (Table 7.3). This positive correlation (0.53) indicated that lower angles of approach to intercuspation (ANGLE) were associated with an early ipsilateral contraction of the temporalis muscle. An additional predictor of ANGLE was the ipsilateral temporalis burst time (Table 7.4). In a previous study by Wilding and Lewin, ANGLE was found to be a strong predictor of chewing performance (Wilding and Lewin, 1994), it remained an influence in the statistical model containing both EMG and EGN variables (Table 7.5). These results suggest that asynchronous contraction of the anterior temporalis muscle contributes to a longer intercuspal period with improved chewing performance (Fig. 7.4).

The relative significance of temporalis activity as a determinant of chewing performance is suggested by Thexton and McGarrick (1994) who found that the temporalis muscles in the cat, were particularly active late in jaw closure after tooth contact with the bolus. Takada, Miyawaki and Tatsuta (1994) found that a longer duration of the posterior temporalis was a feature of chewing harder food. These observations, together with our findings confirm the suggestion made by Moller (1970) that a primary role of asynchronous temporalis contraction is to move the jaws through the intercuspal zone without necessarily exerting a high bite force. When high bite forces are required the masseter muscles become more active than temporalis muscles (Naeje, McCarrol and Weijs, 1989). In this role they may be contributing to food particle selection and placement, while adductors with greater mechanical advantage such as masseter and medial pterygoid provide the necessary breaking forces. The roles of adductor muscles are however clearly not circumscribed and are able to take over a secondary role when necessary. If one muscle is "knocked out" others are recruited to do the work (Miles and Madigan 1983).

Digastric co-activation

The adductor muscle activities were characterised by well defined bursts of activity during the closing phases of chewing cycles and relaxation during opening. While the activity of the digastric muscles peaked during opening there was considerable sustained activity throughout the cycle (Fig. 7.4). Miles and Madigan (1983) found that co-activation of the digastric muscle always occurred during isometric biting, but was modified by the level of force being generated by the adductors or by the expectation that the resistance to jaw closing may suddenly yield. It has been suggested that the co-activation of digastric during closing is the result of a separate pool of motor neuron activity concerned with control, rather than primary opening[5]. The digastric iEMG was found to be negatively correlated with particle size, indicating that digastric activity during opening, had a primary effect on particle size. Digastric iEMG also appeared in the various multivariate models, in particular in the prediction of maximum opening (Table 7.4).

Table 7.6 Averages and standard deviations for the sample data and values for two subjects selected from the top and bottom of the range of chewing performance. The residual is the difference between the observed particle size and the size predicted by the multivariate model. CHL has a large negative value for LAGipco indicating an early contraction of the ipsilateral temporalis muscle during closing.

	Particle Size (mm)	Residual (mm)	Cycle time (s)	Angle (deg)	Bimode (%)	Mass RMS µV	Dig RMS µV	Mass iEMGnett µV	Mass iEMGipco µV	Temp RMS µV	Temp LAGipco ms
Avg	2.10	0.00	0.81	54.8	28.6	145.5	53.9	88.4	2.7	133.6	-5.4
SD	0.53	0.00	0.12	15.8	21.2	60.9	21.3	39.0	6.8	55.8	7.4
CHL	1.18	+0.09	1.10	53.9	67.6	262.1	82.1	164.1	9.4	274.1	-17.2
KDL	2.98	+0.53	0.52	75.1	51.4	65.7	39.4	56.4	4.2	157.6	9.8

The variable iEMGnett would have been influenced by the degree of relaxation of the digastric and the activity of the adductors. This variable correlated with particle size and appears as a components in the statistical model developed to predict particle size (Tables 7.4 & 7.5). Co-activation of digastric muscle provides some stiffness to the jaw movement which is protective (Miles and Madigan 1983). Our results suggest that if this protection is more than optimal, it is inhibitory to chewing performance. The subject KD who had a high mean particle size (poor chewing performance), and a low value for iEMGnett may reflect the influence of excessive co-activation (Table 7.6, Fig. 7.4b). Multivariate models for maximum opening and cycle time are both influenced by the nett adductor EMG of temporalis muscle (Table 7.5).

Gender Differences

No gender differences in the variables of masseter muscle were found, but the iEMG value for temporalis was significantly higher in females; this may have accounted for the increase value for temporalis iEMGnett in females (Table 7.2). This increase in activity is consistent with the observations made that females use more muscle power in order to achieve the same bite force as males (Visser and De Ruke 1974; Throckmorton and Dean, 1994). Gender differences in chewing performance were reported in a previous study (Wilding and Lewin, 1994; the mean particle size after 15 chewing strokes being significantly larger in females than in males. This appears to be in spite of significant increases in the temporalis muscle activity of the same females who volunteered for this study. However maximum bite forces are well in excess of those required to chew even hard test foods and so it is likely that the bite forces available to females are more than adequate to achieve food breakage (Slagter *et al*, 1993). These authors suggested that a smooth uninterrupted chewing cycle may make greater demands on muscle power than food breakage. There is some evidence in this and other studies to suggest that the temporalis muscle plays a greater role in directing lateral jaw movement than the masseter (see Angle, Table 7.4) Hannam and Wood,1981; Hylander, Johnson and Crompton, 1992; Huang, Zhang and Herring, 1993; Miles and Madigan, 1983). The gender differences found in temporalis, rather than masseter muscle suggest that it may be movement rather than bite force for which females use greater muscle activity. These data still do not account for the observed gender differences in chewing performance.

It has been suggested that gender differences in chewing performance may be influenced by specific cultural patterns which inhibit oral activity in females [4]. The results of this study do not contribute any further understanding of gender differences in chewing, though the presence of some factor associated with gender is clearly evident from the effect gender had as an indicator variable added to the EGN/EMG model (Table 7.4).

Multivariate models

The model selected to predict chewing performance from multiple EMG variables was moderately accurate ($R^2 = 0.51$, Table 7.4, Fig. 7.2). When both EMG and EGN variables were used to predict chewing performance, the accuracy of the model was better than with either factor alone. Wilding and Lewin (1994) described a model to predict chewing performance based only on jaw movement. In that model an indicator variable was found to increase the accuracy of prediction from a R^2 value of 0.40 to 0.79. It was suggested that this missing variable, which was subject dependent, might be related to muscle activity. This prediction appears to have been partly correct as the accuracy of our model, without any indicator variable, now accounts for 66% of the variance in the observed level of chewing performance. In this study the inclusion of an indicator variable gender, further improved the predictive accuracy of the model. There appears to be some gender related characteristic which influences chewing performance which requires further investigation.

Optimal values

It is likely that those characteristics of muscle activity and jaw movement which are associated with improved chewing performance are more effective and perhaps more efficient than patterns of muscle activity associated with poor chewing performance. Such effective patterns of movement and muscle activity may therefore be described as optimal, or most likely to produce the desired effect. By this definition, optimal masticatory movements are characterised by a prolonged chewing cycle time which moves in an open loop, with a lateral approach to and from positions of tooth contact. Optimal muscle activity would be characterised by adequate masseter activity, minimal co-activation between opening and closing muscles and asynchrony of the anterior temporalis muscles. Non of these observations is new to the literature on mastication; their collective presence in this study merely serves to validate their role. They are naturally quite restricted observations, confined by the limited movement and EMG data recorded in this study, and therefore do not exclude a host of other aspects of chewing which promote optimal performance. It must be stressed that all these data are derived from clinically normal subjects and so there appears to be a wide range of values for jaw movement and EMG which is compatible with health. Further studies may determine whether there is a wide overlap between these suggested optimum patterns and subjects with diagnosed mandibular dysfunction.

The combination of muscle activity and incisal displacement suggest that an investigation into the acceleration of the mid-incisal area might reflect both movement and muscle activity. Acceleration data not only reflects forces acting on the mandible but reveals the rhythmic oscillations of physiological tremor. In view of the association between tremor and efficient skilled tasks such as handwriting, the role of jaw tremor as a predictor of chewing performance will be investigated (Van Galen *et al* 1993).

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Chapter 8

Jaw movement tremor

Summary Forces applied to a bolus during chewing may be inferred from EMG activity of jaw muscles, but their magnitude and direction would be a complex estimation as many separate muscle units contribute to generating bite forces. The resultant bite force is also affected by the resistance of the bolus and the reaction at both joints. Accelerometers have been used to determine transient loads during dynamic limb movement and to calculate movement tremor. Tremor is a feature of limb movement and has its origins in neuromotor output and feedback. The purpose of this study was to investigate physiological tremor in jaw movement as a factor which might influence chewing performance more directly than either muscle activity or jaw displacements. Data on chewing particle size and EMG activity was available for 24 normal young adults from a previous study. Jaw movements during chewing were recorded using electrognathography (EGN) and the velocity and acceleration in three planes determined. The power spectrum for acceleration was calculated during opening and closing phases of the chewing cycle. A multivariate model was able to predict chewing performance with an adjusted R^2 value of 0.78. The coefficients of variables in this model indicate that acceleration had a more direct influence on chewing performance than muscle activity or patterns of jaw displacement.

INTRODUCTION

The chewing process requires selection and placement of appropriate sized food particles and breakage of the particles between opposing teeth (Luke and Lucas 1983). The forces necessary to break some test foods have been estimated by Slagter *et al* (1993).

These authors concluded that maximum bite forces are not required for breakage, even when the available maximum force is much reduced, as it is in denture wearers. The reduced chewing performance of denture wearers has been attributed to inability to sustain a chewing rhythm rather than an absolute reduction in available bite force (Slagter *et al*, 1993). This view is supported by data which indicates that chewing performance is associated with co-ordination and timing of muscle contraction rather than the peak levels reached during muscle bursts (Wilding and Shaikh, 1995). However the reduced chewing performance of females, in comparison to men could not be explained by gender differences in muscle activity (Wilding and Shaikh, 1995)

Forces developed during biting are the resultants of reaction at the joint and a combination of tensile forces generated in masticatory muscles (Osborn and Baragar (1985). These authors predicted that in order to produce a bite force at the teeth of a particular direction and magnitude, a combination of muscle groups would be recruited which collectively produced the resultant bite force most efficiently. Recent studies using multiple electrodes have revealed that within each muscle group there are sub units which can function independently (Schumann *et al*, (1994). These authors confirm the predictions made by Osborn and Baragar's computer model that units are recruited selectively in patterns which are related to the magnitude and direction of bite forces.

While it is clearly desirable to record the activity of independent functioning units, estimation of the resultant force at the teeth becomes challenging. In view of the association between jaw movement patterns and chewing performance (Wilding and Lewin 1994) and the duel role of food selection and breakage in chewing (van der Glas, *et al* 1987) it would be useful to estimate the forces on the mandible during all phases of the cycle. Changes in acceleration of the mandible during chewing may provide information about the collective result of complex patterns of muscle contractions.

Acceleration data may also be used to estimate the degree of physiological tremor during movement. If a limb, such as the arm is held outstretched against gravity, an invisible tremor occurs (Stiles 1976). The frequency of this tremor can be calculated by recording the acceleration of the limb, at least 50 times a second, using a sufficiently sensitive device attached to the hand. The wave form of the recorded acceleration is then analyzed, using a Fourier transform, to determine the main frequency components of the wave. Peaks have been found between 8 and 12 Hz which have an amplitude several orders of magnitude higher than other frequencies. This band width constitute the frequency range of normal physiological tremor. The frequency range decreases, as the hand is held outstretched for over 15 minutes or if weights are added to the hand (Stiles 1976, Burne, Lippold and Prior 1983). The frequency of normal tremor is also altered by the nature of resistance to isometric contractions (Viitasalo, Gajewski and Wit 1994).

The purpose of this study was threefold; firstly to measure the acceleration of the jaw during the chewing cycle in order to compare acceleration and tremor at opening and closing phases of the chewing cycle; and secondly to determine whether there were characteristic tremor frequencies associated with the output of the masticatory activity as reflected by chewing performance; and lastly to pursue an investigation of gender differences with a view to have a better understanding of the determinants of chewing performance.

METHOD

Velocity and acceleration

The data for velocity and acceleration analysis comprised two sets derived by joining all opening sets together into a single set of opening data, and all closing sets together into a single set of closing data.

The velocity, *v* and acceleration, *a* were calculated in three dimensional space using the data for vertical, lateral and protrusive displacements of the mid incisors. Calculations for both these vectors were made at each consecutive data point *x*, using a distance *x+40* equal to a time interval of 0.1s. This interval of was found suitable to be a suitable time scale for observing the acceleration due to the grosser movements of the jaws and for eliminating signal noise.

$$vx_n = (x_n - x_{n+40}) / s$$

$$vxyz_n = sqr[\ (x_n - x_{n+40})^2 + (y_n - y_{n+40})^2 + (z_n - z_{n+40})^2\ ] / s$$

$$ax_n = (\ vx_n - vx_{n+40}\ ) / s^2$$

$$axyz_n = sqr[\ (ax_n^2 + ay_n^2 + az_n^2)$$

The mean velocity during the opening and closing phases of chewing were separately calculated. The mean acceleration during opening and closing was calculated after rectifying the data to positive values.

For the purpose of examining the frequency distribution of the unrectified acceleration data, trains of 2048 consecutive data points were made by joining all opening data into one set and all closing data into another. A Fast Fourier analysis (Morrison, 1994) was used to investigate the frequency distribution of the acceleration for each opening and closing set. The median power frequency and the power frequency of the two highest amplitude peaks within a band width from 1 to 30 hz was found (Fig 8.1).

The raw, unrectified data of the masseter EMG during opening was joined into trains of 2048 data items. A Fast Fourier analysis was performed and the spectrum analysed in a band width between 1 and 150 Hz. The median power frequecny was found.

Statistical Analysis

A two-tailed student t test was used to investigate differences in velocity, acceleration, tremor frequency and amplitude between opening and closing phases of the chewing cycle, and between male and female subjects. A linear regression was used to establish correlations between these variables and the logarithm of the chewing particle size of the same subjects.

A stepwise multiple regression was used to develop a model to predict particle size, using variables derived from the velocity and acceleration data. A second model was derived using additional variables derived from EMG and EGN data.

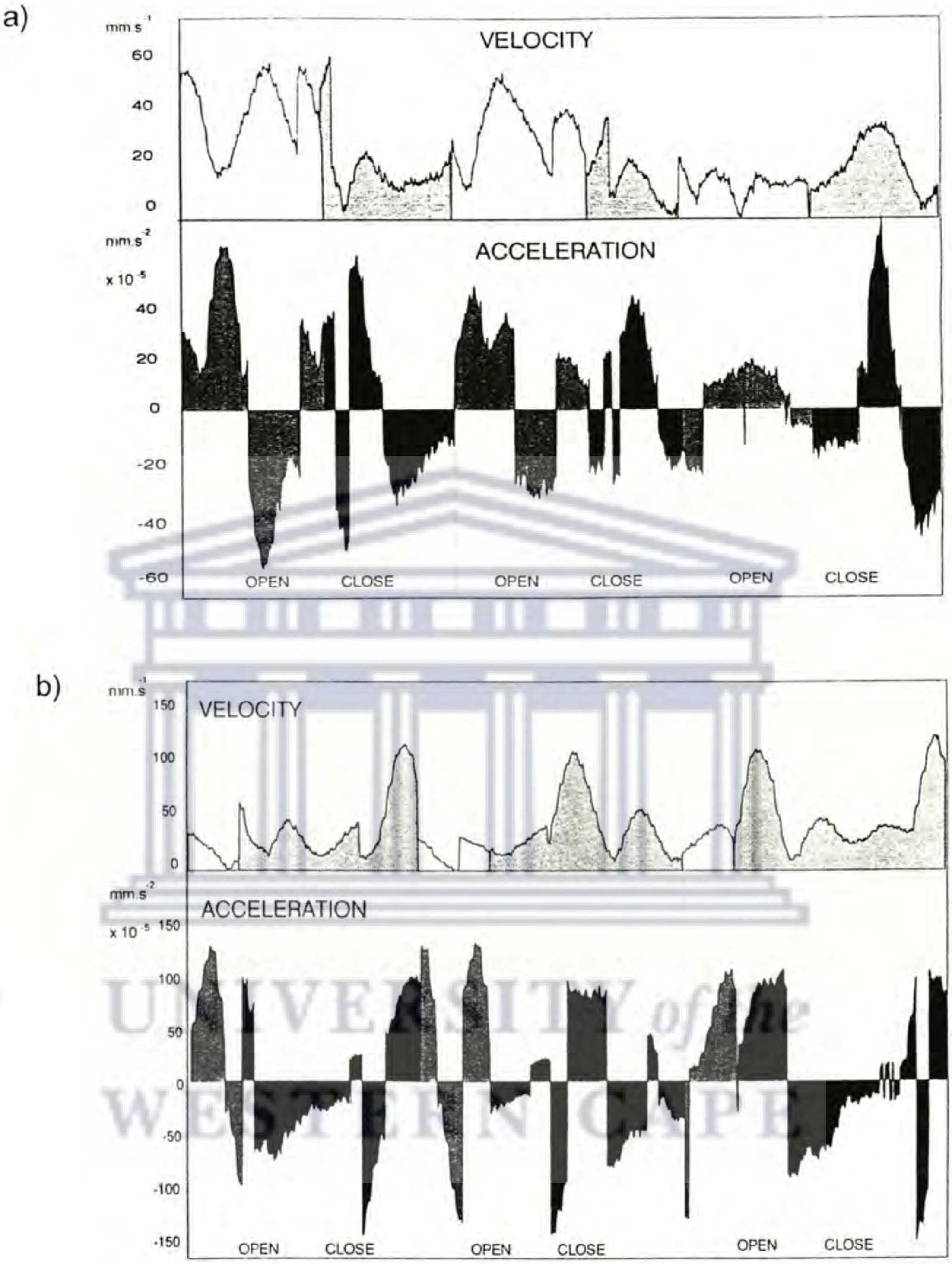

Figure 8.1. The velocity and acceleration of the jaw tracking point during three chewing cycles. The opening phase of each cycle is represented by lighter shading than the closing phase. Variations in acceleration and velocity during both opening and closing phases did not permit simple sub division into a fast and a slow phases. **a)** The subject KDL had a faster mean opening velocity than closing velocity, a tendency found in the rest of the sample. The actual mean closing velocity was low as was the amplitude for acceleration (Table 8.5). **b)** The subject CHL shows high peaks of closing velocity, which are greater than opening velocity (Note Fig 8.1a and 8.1b are not to scale). CHL had the highest chewing performance of the sample.

The effect of gender, as an indicator variable was added to both models. Indicator variables help to show the main effects of a grouping of data in a regression model (Armitage and Berry, 1987). All data were analyzed using Statgraphics Plus (USA).

RESULTS

Acceleration and Velocity

The mean velocity for the sample during opening ($22.19 mm.s^{-1}$, sd 9.68) was significantly greater than during closing (17.97 $mm.s^{-1}$ sd 8.08; $p<0.01$) though in several subjects the reverse was found (Table 8.1, Fig 8.1). No significant difference was found between the mean acceleration during opening and closing. Correlations were found between closing velocity and both opening and closing acceleration (coeff, 0.63 and 0.68, $p<0.001$).

The power spectrum analysis of acceleration showed a series of peaks between 2 and 15 Hz. The amplitude and frequency of the two highest peaks for each data set was recorded (Fig 8.2). The mean for the sample of the peak amplitude (Peak 1) during opening was $15.30mm.s^{-2} \times 10^{-5}$ (sd 6.85) and during closing was $13.82mm.s^{-2} \times 10^{-5}$ (sd 8.13).

The mean value for the amplitude of the second highest peak (Peak 2) was $6.49mm.s^{-2} \times 10^{-5}$ (sd 3.04) during opening and $7.08mm.s^{-2} \times 10^{-5}$ (sd 3.85) during closing. The mean amplitude of Peak1 was 67% of the combined amplitudes of Peak1 and Peak 2 during opening and 67% during closing. This indicates that during both opening and closing there was a well defined peak amplitude tremor (Fig 8.2).

The sample mean of the tremor frequency for Peak1 was higher during opening (8.04Hz, sd 2.83) than closing (6.29Hz, sd 2.33 ;$p<0.01$) (Table 8.1, Fig 8.3).

Significant differences ($p<0.001$) were found between the Peak1 frequency and Peak2 frequency for both opening and closing tremor.

Table 8.1. Sample means and standards deviations () for velocity, acceleration and the amplitudes of the highest two peaks of the power spectrum, with their relative frequencies, for opening and closing jaw movements during chewing.

	Opening	Closing	
Velocity	22.19 (9.68) ¶	17.97 (8.08) ¶	*
Acceleration	33.13 (14.13) #	30.87 (15.50)#	
Tremor amplitude			
Peak 1	15.30 (6.85) #	13.82 (8.13) #	
Peak 2	6.49 (3.04) #	7.08 (3.87) #	
Tremor frequency			
Peak 1	8.04 (2.83) §	6.29 (2.33) §	**
Peak2	10.17 (4.62) §	9.56 (3.56) §	
Median	11.26 (2.72) §	10.74 (1.87) §	
EMG masseter frequency			
Peak1		6.08 (2.57) §	
Peak2		8.17 (3.96) §	

¶ units are $mm.s^{-1}$; # units are $mm.s^{-2}$ $x10^{-5}$; § units are Hz.
* = $p<0.05$; ** = $p<0.01$

This indicates that there were two distinct tremor frequencies, each with its own band width, for both opening and closing movements. The median frequency was calculated by finding the frequency at 50% of the total power spectrum. No differences were found between the median frequency of opening and closing power spectra.

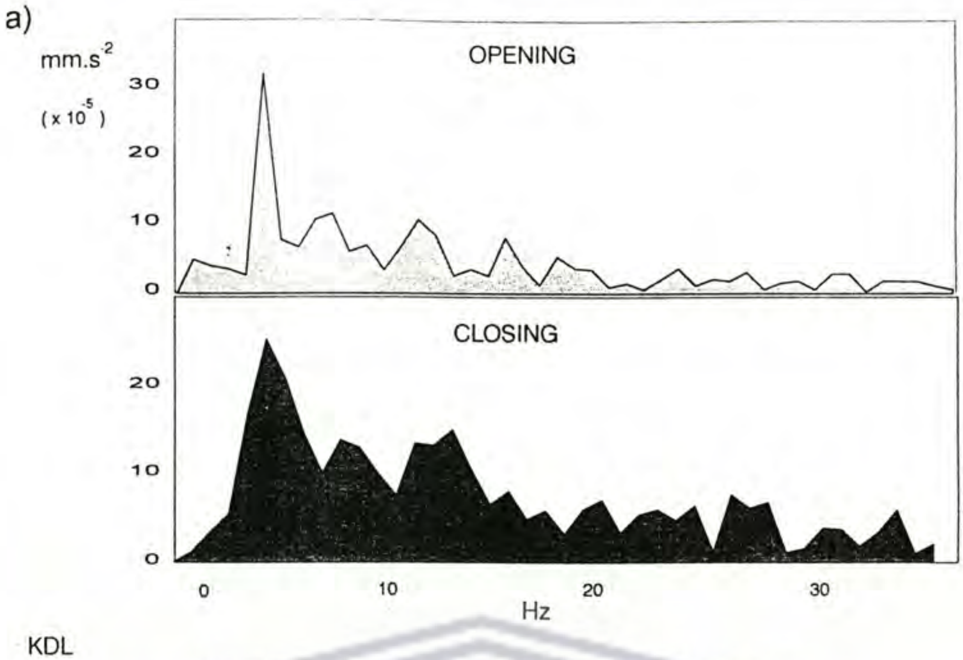

Figure 8.2 The power spectrum between 1 and 30 Hz for the acceleration measured at the mid-incisal point during opening and closing. The three highest amplitude peaks were identified and their respective frequencies recorded. a) The low frequency of all three peaks during opening contributed to the predicted poor chewing performance for this subject KDL (Table 8.5).

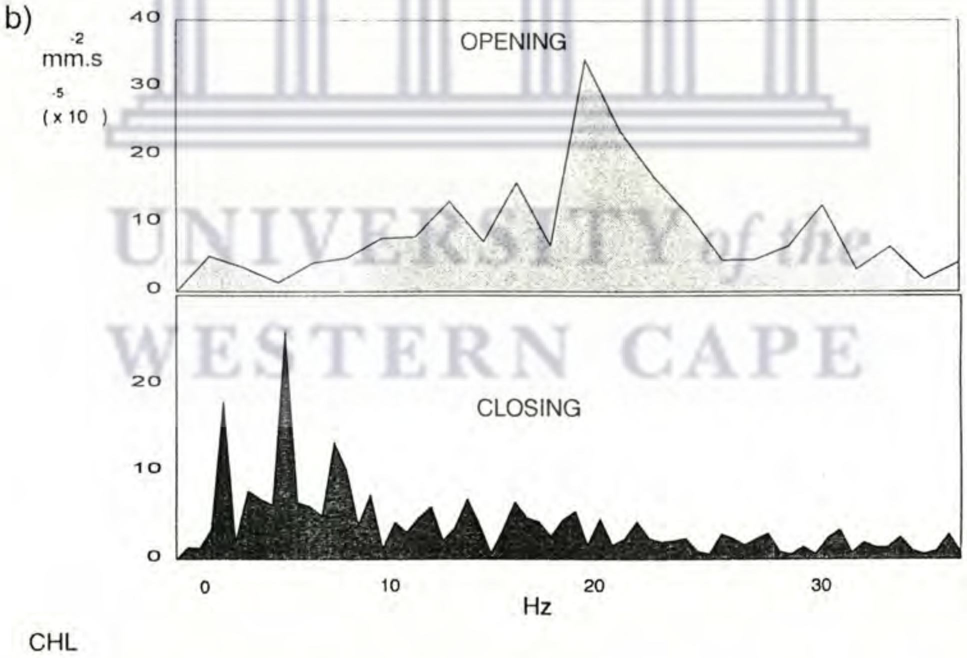

Figure 8.2 b) The subject CHL illustrates the difference found in most subjects, between tremor amplitudes and frequencies during opening and closing. The high peak frequency during opening, contributed to accurately predicting a high chewing performance for this subject. (Table 8.4 & Table 8.5).

A correlation was found between the amplitude of Peak1 and its frequency for both opening and closing sets of data (coeff. closing 0.55, opening 0.41; $p<0.001$) (Fig 8.4). This indicates that higher energy tremors were associated with higher frequencies.

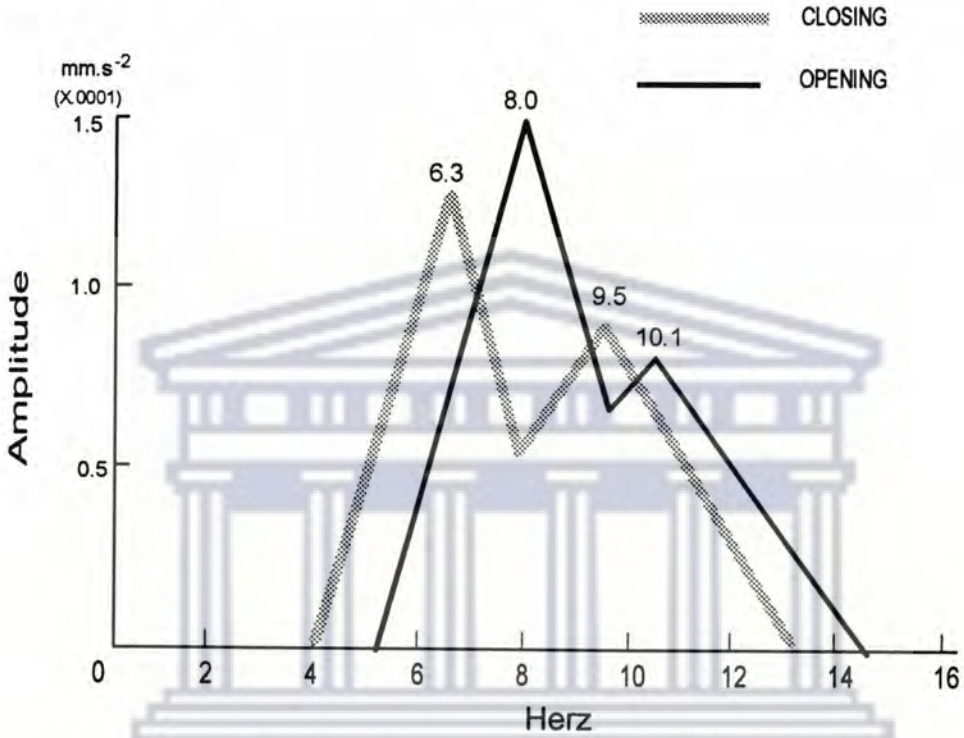

Figure 8.3 The mean frequencies of the highest two amplitudes of the power spectrum are illustrated. The mean tremor frequencies are represented as peaks, and their standard deviations projected to the base line. Statistical differences between the frequencies of the first and second peak amplitudes were found for both the tremor frequencies and oscillations in the EMG signal (Table 1).

Electromyography data

A correlation was found between temporalis RMS and both closing velocity (0.38) and acceleration (0.33 $p<0.05$).

The mean frequency of the Peak1 amplitude for masseter EMG power spectrum was 6.08Hz (sd 2.57) and the mean frequency for Peak2 was 8.17Hz (sd 3.96) (Table

8.1). The difference between these two frequencies was significant ($p<0.01$). Equivalent data for temporalis muscle was 6.13Hz (sd 2.49) for the Peak1 frequency and 10.09Hz (sd 7.04) for the peak2 mean frequency ($p<0.01$). These data suggest that there were at least two discrete sets of oscillation in the EMG signal, which appear to correspond with the two highest amplitude tremor frequencies in acceleration at the mid-incisor point. Significant correlations were found between the Peak1 tremor frequency during closing and the Peak1 frequency of both masseter (coeff 0.85) and temporalis (coeff 0.88) muscles (Fig 8.4b). This suggests an association between oscillations in the electrical activity of the closing muscles, and the tremor frequencies detected in jaw movement.

No differences were found between the frequencies of the first and second highest amplitude peaks of the power spectrum for the digastric muscle during opening. A correlation was found between the peak amplitude of the digastric power spectrum and the tremor frequency of Peak1 amplitude during opening ((0.62, $p< .001$).

Gender differences

The mean acceleration during opening was also higher in males ($37.64 mm.s^{-2} \times 10^{-5}$, sd 12.38) than for females ($28.80 mm.s^{-2} \times 10^{-5}$, sd 10.41; $p<0.05$). The Peak1 amplitude during opening was higher in males ($17.40 mm.s^{-2} \times 10^{-5}$, sd 7.74) than females ($13.30 mm.s^{-2} \times 10^{-5}$, sd 5.30; $p<0.05$) (Table 8.2). The Peak2 amplitude during closing was also higher in males ($8.30 mm.s^{-2} \times 10^{-5}$, sd 4.55) than females ($5.91 mm.s^{-2} \times 10^{-5}$, sd 2.69 $p<0.05$).

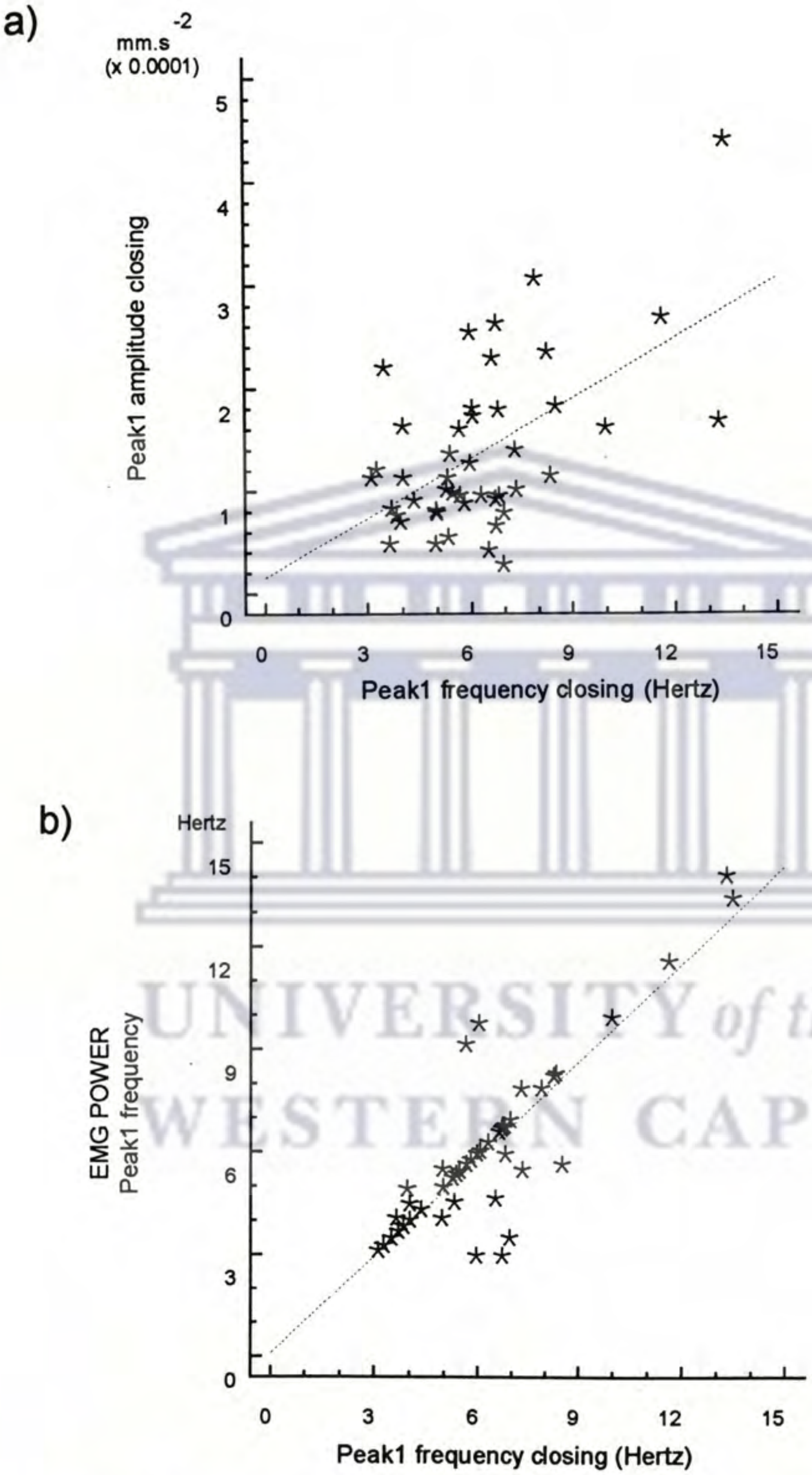

Figure 8.4 Plots of the regression between the frequency of Peak1 closing with a) the amplitude of of Peak1 (Coeff 0.55, $P < 0.001$). b) the frequency of the peak amplitude between 1-30Hz of the power spectrum of masseter EMG ($R = 0.85$, $p< 0.0001$).

Table 8.2. Sample means for velocity, acceleration and tremor amplitude and frequency for males and females during chewing.

	Males (12)	Females (12)	Sign. level
Acceleration Opening	37.64 (11.32) #	28.80 (10.41) #	*
Tremor amplitude Peak1 Opening	17.40 (7.74) #	13.30 (5.30) #	*
Tremor amplitude Peak2 Closing	8.30 (4.55) #	5.91 (2.69) #	*

units as for Table 8.1
Asterisks indicate significant differences as in Table 8.1.

Correlations between particle size, velocity and acceleration

A negative correlation was found between the logarithm of particle size and the closing velocity of each subject (-0.46 $p<0.01$) (Table 8.3). No correlation was found with the opening velocity, but there was a correlation between mean opening acceleration and particle size (-0.38, $p< 0.05$). Negative correlations with the logarithm of particle size were found with the Peak1 frequency during opening (-.51, $p<0.01$), the median tremor frequency during opening (-0.64, $p< 0.001$) and with the amplitude of Peak2 during closing (-0.63, $p< 0.001$). This indicates that higher frequency tremors during opening and higher amplitude tremor during closing were associated with small particle size, or improved chewing performance.

The acceleration during closing was associated with the asynchrony of ipsilateral and contralateral temporalis contraction LAGipco (0.36 $p<0.05$), and the jaw movement variable, BIMODE (0.37 $p<0.01$).

Table 8.3. Correlation coefficients for particle size, jaw movement and EMG variables.

	Particle size	Velocity Cl.	Accel. Op.	Accel. Close.	Trem. Freq. median	Trem. Ampl. Peak2 Open.	Trem. Ampl. Peak2 Close.	Mass. RMS	Temp. RMS	Temp. LAGipco	Bimode	Cycle time
Log Particle size		**	**	**	****		****	**	**	**	*	*
Velocity closing	-.46		****	****	**	**	****		*		**	
Acceleration Opening	-.38	.63		****	***	****	****		*	*		
Acceleration Closing	-.41	.68	.82			***	****		*	*	*	
Tremor freq. median open	-.64	.41	.49	.19		**	**		**		**	*
Tremor ampl. Peak2 open	-.26	.48	.76	.67	.42		***			*		
Tremor ampl. Peak2 close	-.63	.76	.71	.80	.42	.62						
Masseter RMS	-.48	.01	-.05	.10	.24	-.07	.13		**	*		*
Temporalis RMS	-.41	.37	.08	.33	.41	.26	.32	.45		*		*
Temporalis LAGipco	.42	.21	.36	.39	-.28	.30	.18	-.37	.01			
Bimodal pathway	-.35	.50	.37	.39	.44	.26	.40	-.00	.31	.10		
Cycle time	-.40	.16	.03	.12	.30	.22	.22	.37	.39	-.04	.17	

* = p<0.05; ** = p<0.01; *** = p<0.001; **** = p<0.0001

Multivariate models

A model was derived from acceleration data that was able to predict particle size with an adjusted R^2 value of 0.63 (Table 8.4, Fig 8.5). No improvement in this model was achieved by including the indicator variable, gender. The three major components of this model were the median tremor frequency during opening and the tremor amplitudes of Peak2 during both opening and closing. With the addition of EMG and EGN variables the accuracy of the model increased to an adjusted R^2 value of 0.78. The EMG variables were masseter RMS and iEMGnett and temporalis LAGipco. The EGN variables were cycle time, bimodal pathway and angle of approach to the intercuspal zone. The adjusted R^2 value of the model was increased to 0.82 by adding the indicator variable, gender.

Table 8.4. The components of a multivariate model with velocity and acceleration variables developed a model to predict chewing performance with an adjusted R^2 value of 0.63. With the addition of EMG and EGN data the R^2 value increased to 0.78. The influence of each component of the model is indicated by either + or - signs. The number of signs reflects the F-factor for adding or removing the variable from the model. Factor units (one sign = 4 F-factors).

	Independent variables	Influence	Adjusted R^2
TREMOR	Median Tremor Frequency (Opening)	- - - -	
	Tremor, amplitude Peak 2 opening	+	
	Tremor, amplitude Peak 2 closing	- - - -	
EMG	Masseter RMS	- -	
	Masseter iEMGnett	+ +	
	Temporalis LAGipco	+ +	
EGN	Cycle time	_	
	Bimodal Pathway	-	
	Angle of approach to I.C.	+	

Table 8.5. Averages and standard deviations for the sample data and values for two subjects selected from the top and bottom of the range of chewing performance. The residual is the difference between the observed particle size and the size predicted by the multivariate model. CHL has a high value for the median frequency of jaw tremor during opening, and high amplitudes for Peak2 during both opening and closing. These three variables were found to be good predictors of chewing performance.

	Particle Size (mm)	Residual (mm)	Velocity Closing (¶)	Tremor Median Freq.OP (Hz)	Tremor ampl Pk2 Opening (#)	Tremor ampl Pk2 Closing (#)	Mass RMS (μV)	Mass iEMG nett (μV.s)	Temp LAGip-co (s)	Cycle time (s)	Angle (deg)	Bimode (%)
Avg	2.10	0.00	17.9	11.2	6.5	7.1	39.7	27.0	-32.5	0.82	54.1	28.6
CHL	1.18	+0.01	41.5	22.9	13.0	17.7	78.5	65.8	-111.4	1.13	53.8	67.6
KDL	2.98	+0.45	16.9	11.4	5.9	4.9	17.0	6.7	64.5	0.52	75.6	51.4

¶ units are $mm.s^{-1}$

units are $mm.s^{-2}$ $x10^{-5}$

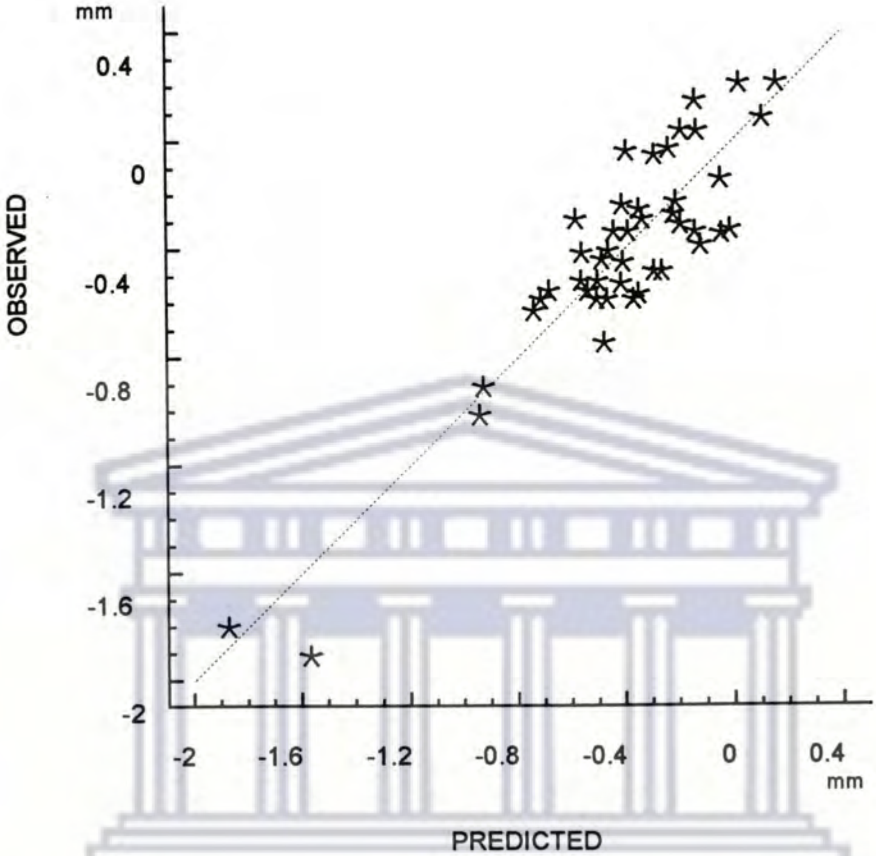

Figure 8.5 The observed particle size plotted against the particle size predicted using the multivariate model comprising variables derived from velocity, acceleration, EMG and jaw displacement during chewing. The adjusted R^2 value for this model was 0.78 without the indicator variable of gender.

DISCUSSION

Velocity

Jaw movements were divided into just two phases, opening and closing. Hiiemae (1976) proposed the use of four phases, beginning with fast closing (FC) followed by slow closing (SC) as the bolus was engaged; slow opening (SO) then preceded fast opening (FO) to complete the cycle. More recently Hiiemae Hayenga and Reese

(1994) confirmed the value of these phases in correlating tongue movement with jaw movement. The transition from SO to FO and FC to SC was determined as the intersection of two best fit lines drawn on a plot. The authors acknowledge that this process is subjective and sometimes it is not possible to detect a distinct phase change. The plots in Fig 8.1 a) and b) illustrate that at least one and sometimes more changes in velocity and reversals in acceleration during both the opening and closing movements. The irregular nature of these changes made subdivisions of the opening and closing phases difficult. This problem may have occurred because the velocity of the mid incisor point was analyzed in all three dimensions. A single velocity change in the sagittal plane, which might have been detected as a phase change, was masked in these data by the combined effects of velocity changes taking place in the horizontal and frontal plane.

The mean values of the velocity during opening were higher than closing, which merely, which confirms previously published work on humans and mammals (Ahlgren, 1966; Hiiemae, 1976; Jempt, Karlsson and Hedegard, 1979; and Schwartz et al, 1989.) A number of the subjects in this study however showed a reversal of this pattern, with faster closing than opening (Fig 8.1b). A correlation was found between closing velocity and RMS for the temporalis muscle but not with the masseter RMS (Table 8.4). This finding may be related to the difference in the mechanical advantage of the two muscles. Throckmorton and Dean (1993) calculate that the mechanical advantage of the anterior temporalis was less than that of the masseter muscle. Thus the temporalis has the greater velocity ratio of the two muscles and its activity therefore affects closing velocity more directly than the masseter muscles. A correlation was also found between closing velocity and the prevalence of a bimodal pathway of movement, a pattern of jaw movement found to be associated with improved chewing performance by Wilding and Lewin (1994) (Table 8.3). Closing velocity was inversely related to particle size (Table 8.3).

Acceleration

The relationship between a static vertical bite force at the first molar and agonist muscle activity has been shown (Ahlgren and Owall, 1970; Kawazoe Y., Kotani H. and Hamada T., 1979). Forces generated during the remainder of the cycle are difficult to estimate from EMG activity. This may be because the data derived from a few surface electrodes do not represent the complex synergies of all the agonist and antagonist muscle groups involved in dynamic jaw movement. Force may however be represented by acceleration provided other factors such as tissue viscosity and jaw mass are constant. Accelerometers have been used to estimate the forces occurring at the joints of a compound pendulum (Ladin and Wu, 1991) and at the lumbar spine during lifting and lowering weights (Gagnon and Smyth, 1992). It has not been possible in this study to estimate forces being applied to the joint or the teeth, as the morphometric data necessary for making such estimations was not available. Furthermore, the acceleration data was not comprehensive. The version of the Sirognathograph used is accurate in representation of translations in all three planes and rotations in the sagittal and horizontal planes but does not reflect rotations in the frontal plane (Lewin *et al* 1991).

The mean acceleration was calculated after rectifying all acceleration data to positive values. It thus reflects the resultants of forces applied to the mandible from both bolus resistance, muscle tension and joint reaction. Acceleration during closing had a negative correlation with particle size and positive correlation, with closing velocity, and temporalis muscle RMS, but not with masseter muscle RMS (Table 8.3). The absence of a correlation with masseter muscle suggests that the magnitude of the jaw's acceleration is more dependent on changes in velocity and direction, perhaps a function primarily of the temporalis muscle, than the development of high bite forces, which appears to be a feature of masseter activity (Throckmorton and Dean 1993).

Tremor

While it was difficult to divide the chewing cycle into rhythms of slow and faster movement, a spectral analysis of acceleration revealed a periodicity of movement which was time related rather than related to the chewing cycle. The power spectrum for acceleration was used by Salzer (1975) to measure tremor in the lower arm, hand and finger. He reported several reproducible peaks, indicating more than one main tremor frequency. Dominant peaks were found within a range of 2 to 15Hz. This range is wider than the bandwidth of 8-12 Hz which has been considered characteristic of normal physiological tremor (Burne, Lippold and Pryor, 1984) However Sakamoto *et al* (1992) found two distinct frequency peaks at 10Hz and 25 Hz in their evaluation of finger tremor in typists, and Viitasalo, Gajewski and Wit (1994) reported that 90% of the power spectrum for acceleration was to be found within a bandwidth between 7 and 20 Hz. The variety of ballistic influences and feedback pathways circumstances under which these tremors were recorded includes a variety of ballistic and feedback influences, which are mostly different and may explain the wide range of what has been termed physiological tremor.

Burne *et al* (1984) investigated the probable origins of hand tremor. They concluded that it was not of central origin, or of a ballistic nature, but due to resonance in the firing of motor neurones. This resonance is due to oscillations set up in the feedback loop of muscle stretch receptors. A strong correlation was found between the frequency of the peak amplitude tremor and the frequency of the peak amplitude of the EMG power spectrum for both masseter and temporalis muscles (Fig 8.4). These data are consistent with the role muscle activity appears to play in generating tremor. Sakamoto *et al* (1992) suggested that separate feedback loops would generate two different frequencies of oscillation, and might explain the frequency peaks they observed. The component of the lower frequency was thought to originate from the central nervous system as a long loop, and that of the higher frequency originated from the muscle-spine loop system as a short loop.

A significant difference was found between the frequencies of the highest two tremor amplitudes, which suggests that there were two distinct tremor frequencies in the subjects of this study. The Peak1 tremor frequency was lower during closing than opening, but there was no significant change in the amplitudes. The frequency of the second amplitude peak however was similar for both opening and closing tremor. There may be similar origins for these two second amplitude peaks, while the frequencies of Peak1 have different origins related to the different feedback pathways during opening and closing. Gresty and Buckwell (1990) point out that two apparently separate frequency peaks may not represent independent oscillators but be due to amplitude and frequency fluctuation of one essential oscillating pathway.

Changes in the tremor frequency during various tasks have been reported by a number of authors (Burne et al, 1984; Bain *et al* 1993; Viitasalo et al, 1994). In all these studies tremor frequency decreased during tasks which required skilled movement and coordinated muscle activity. The absolute values for limb tremor are not however comparable with jaw movement tremor in view of the differences in mass of forearms fingers and jaws. Changes have also been observed in jaw tremor frequency as feedback was altered (Broekhuijsen and van Willigen, 1994). The tremor frequency of jaw movement was found to increase after blocking periodontal feedback (Jacobs and van Steenberge (1993). These authors considered this increase in frequency due to the shorter feedback loop of jaw muscle spindles, unmodified by periodontal feedback. This conclusion was based on the assertion that input from muscle spindles is calibrated by periodontal afferents (Taylor and Elias (1984).

In view of the suggested reasons for a decrease in tremor frequency during fine movement, it might have been expected that low closing frequencies would have been associated with chewing performance, but no such association was found. There was however a strong correlation between particle size and the amplitude of the second peak tremor during closing with a R value of 0.63 (Table 8.3). The amplitude of Peak2 was also strongly associated with both opening (0.71) and closing (0.80) acceleration and closing velocity(0.76), each of which variables, on its own, had significant correlations with particle size. The amplitude of Peak2 appears, on its own, to contain more information relevant to chewing than the other three variables. In contrast to the Peak2 amplitude, the peak1 amplitude and its frequency showed little direct association with chewing performance in this study. The difference between the associated amplitudes of these two peaks does however suggest that the two frequencies may be due to separate oscillations and separate feedback pathways, one of which has greater influence on chewing activity than the other.

While no association was found between the closing tremor frequency and particle size, correlations between the opening tremor frequencies and particle size were found. The Peak1 tremor frequency during opening correlated with the peak amplitude of the digastric power spectrum. The opening frequencies are thus related to digastric muscle activity. Digastric iEMG was found to correlate weakly with chewing performance in a previous study.

Gender differences

Gender differences in acceleration and some aspects of tremor were found (Table 8.2). In a previous study it was reported that the vertical and lateral dimensions of the chewing cycle were larger in males than females (Wilding and Lewin, 1994). Gender differences in the EMG have also been reported (Wilding and Shaikh 1996, Visser and De Ruke 1974, Throckmorton and Dean, 1993). Some authors conclude that in order to achieve the same bite force as males, females have to compensate for their reduced muscle mass, by greater muscle activity. The difference in tremor amplitude found in this study may be a reflection of its association with opening and closing acceleration, which in turn are related to muscle activity.

In a previous study males were found to have a superior chewing performance to females (Wilding and Lewin (1994), but no satisfactory explanation for this difference was given. In a previous model used to predict particle size, the use of an indicator variable gender, improved the predictive accuracy of the model. In the first model used in this study, the indicator variable did not improve the prediction of the model. This may have been because one of the two variables, Peak2 amplitude already reflects gender differences. There was little effect on the final model which included EMG and EGN data by including an indicator variable, gender.

Gender has been a useful way of separating this data into two groups of different chewing performers. The final model developed in this study is only slightly affected by the gender indicator, so there are still some aspects of gender differences which the model does not account for.

Multivariate model

The model used to predict chewing performance in this study is less complex and more powerful than those that have been developed in previous studies (Wilding and Lewin, 1991b, Wilding and Lewin 1994, Wilding and Shaikh, 1995). Three variables, the opening median frequency, and the Peak2 amplitudes during both opening and closing, collectively account for 63% of the variance in the particle size data. While they are weakly related to each other, the two amplitude variables are strongly related to the variables of velocity and acceleration. None of them correlate with masseter RMS and they have weak correlations with jaw movement variables. The model which includes EMG and EGN variables is certainly more accurate but the dominant weight of the tremor variables in this model is still apparent (Table 8.4).

The variable *cycle time* remained a contributor to this model with a negative coefficient indicating that longer cycle time is associated with smaller particle size. It is possible that the time being spent in slow high performance cycles is during the intercuspal phase of chewing. Cycle time was recorded during chewing the test food (nuts) while all other jaw movement variables were recorded and analyzed during EGN recording while chewing a hard wine gum. Of all jaw movement variables, cycle time was therefore the most closely related to the particular dynamics required by the test food. It was suggested in chapter 6, that cycle time might be a useful indicator of chewing performance in circumstances where there was no sophisticated jaw tracking equipment available.

It was not possible to identify during closing, the exact point at which contact with the bolus is made, and therefore the chewing process could not be separated into the separate stages of food selection and breakage. This study confirms others which suggests that movement tremor is somehow associated with a skilled task but further study is required to understand the role of tremor as a predictor of chewing performance. There are no data from this study to explain the association of Peak2 tremor during closing with chewing performance, or to explain the absence of association of Peak1 tremor with chewing. The roles of both Peak1 and Peak2 tremors requires an understanding of the different origins of these two tremor frequencies which also requires further study. The association of movement tremor during opening suggests that food selection may be a skilled process requiring feedback and hence generating tremor, but it has not been possible to explain the absence of two distinct tremor frequencies during opening movement, in contrast to the two frequencies found during closing.

Further studies are required to determine the influence of altered feedback on tremor frequencies. Differences in tremor frequency may be found in edentulous patients and those with muscle pain and dysfunction. Longer term goals are to contribute to the development of research diagnostic criteria in patients with temporomandibular disorder in order to enable discrimination between diagnostic sub-populations as advocated by Widmar (1992).

CONCLUSIONS

1. Two distinct jaw tremor frequencies during closing movements were detected.
2. The tremor frequency of the Peak1 amplitude during closing correlates strongly with the frequency of the peak oscillation in the EMG signal from both masseter and temporalis muscles.
3. Differences in velocity, acceleration and movement tremor were detectable between males and females.
4. Tremor frequencies and amplitudes are strong predictors of chewing performance.
5. The association between feedback, jaw tremor and skilled function deserves further study.

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Chapter 9

Summary

General

The aim of this work was to study the function of the jaws during chewing. While there is a substantial body of information already available on the subject there were some identifiable gaps, particularly in the interpretation of data derived from two measuring devices commonly used to study jaw function, the electrognathograph (EGN) and the electromyograph (EMG). There was little support for either of these devices as diagnostic tools. One of the reasons for this may have been that the lack of normal data and the limitations of existing data, which had in general, been derived from observations of parts of a whole, made in isolation. The normal associations and interactions between jaw movement, occlusal contact area, muscle activity, acceleration and chewing performance had therefore been difficult to make. In this work it has been possible to study all these factors in the same subjects. In one respect however there was an important inconsistency, namely between the test food used to measure chewing performance and the test food used to record jaw movement and muscle activity. It is a challenge to future work of this sort to find a test food, equally suitable for both purposes. The work has nevertheless allowed some associations between chewing performance and jaw activity to be made. The use of EGN and EMG data has not been validated for diagnostic purposes in this work but methods of analysis have been developed which have been shown to be good descriptors of function and good predictors of performance. Further work lies ahead in using these methods to study patients with dysfunction caused by malocclusion or muscle pain.

Jaw movement

The purpose of the study described in chapter two, was to develop a method of representing jaw movement which would take into account the most frequented pathways of movement. Analysis of the distribution frequency allowed occasional eccentric displacements to be ignored. A central core of the most usual pathways was then built up. Eight variables were derived from this core and in order to distinguish between chewing sides, all 8 had to be taken into account in a multi-variate analysis. Some of these variables have been dropped from subsequent statistical models, including all those derived from the sagittal frequency matrix. This is not because they do not all provide useful information about movement, but because some appear to have less influence on chewing performance. There are at least three which have retained their descriptive power in the presence of variables of a different kind, such as EMG activity and acceleration. Firstly, AREAR was derived from calculating the core area of the functional envelope of the chewing pathways. AREAR in fact was the ratio of the core areas on the chewing side to the non chewing side. It thus described the degree to which the pathways of chewing were bilateral. It emerged as a principle component in accounting for the variance in jaw movement (Table 2.5) and as a predictor of chewing performance (Table 6.3). High values for AREAR, indicating a unilateral movement pattern, were associated with decreased chewing performance. Secondly, ANGLE represented the degree to which lateral grinding movements prevailed during chewing. This variable would clearly be related to the consistency of the food bolus and therefore may have been seen more frequently in my sample because I used a tough variety of wine gum as a test food. In spite of the difference in consistency of the wine gum and the food which was used to determine chewing performance, the variable ANGLE emerged as a good predictor of chewing performance. The third movement variable was BIMODE, derived to represent the prevalence of a bimodal frequency distribution. It expresses the presence of two separate pathways in the chewing cycles. In the model of principle components it occupied a distinct and separate position from both AREAR and ANGLE (Fig.2.8), although it was found to correlate with both ANGLE (coeff -0.34) and AREAR (coeff 0.50).

The general shape of a chewing cycle with a low ANGLE, low AREAR and high BIMODE conforms in a general way to the 'normal' chewing cycle described by Ahlgren (1966), Lewin (1985) and Proeschel and Hofmann (1988). It is important to limit the description of this pattern to the term 'usual' rather than 'normal', as it does not reflect the variation displayed by healthy subjects. If jaw movement analysis is to play a useful role in diagnosis it will be important to set very liberal and broad definitions of normal in order to avoid over treatment. The need arose at this point in the study to identify some variable which would reflect the functional level of an individual's masticatory apparatus. With such a measure of output it would be possible to calibrate movement values and derive some optimal ranges based on function.

Chewing side preference

The first prospect of identifying of optimal jaw movement was to discover the characteristics of jaw movements which were preferred. It seemed reasonable to presume that if a particular chewing side was used because certain patterns of movement were possible on that side, some value could be attributed to those patterns of movement, and perhaps less value to those which were avoided. As this part of the study progressed it was evident that preference would have to be expressed as a degree of commitment to chewing on a preferred side, and that some subjects would show little preference. A multi variate model based on four variables was found to predict only 42% of the variance found in the sample (Fig. 3.2). While this result was not discouraging it seemed that preference was not determined by jaw movement but might be influenced by it. Consideration was then given to the possibility that tooth contact area might have a greater impact on the choice of chewing sides and might also be a determinant of jaw movement patterns.

Tooth contact area

It was necessary to develop a measuring method which would be accurate enough to discriminate between tooth contact areas on the left and right sides of the same subject. Such accuracy was called for, in view of the differences found in each subject, in jaw movements between left and right sided chewing. The analysis of images projected through inter-occlusal wax records provided suitable accuracy. Occlusal contact area was not associated with chewing side preference. This may have been because all subjects had a full complement of teeth and would not have been influenced by occlusal contact area unless one chewing side offered a distinct advantage over the other.

Chewing performance

Chewing performance is reduced in denture wearers and in patients who have lost posterior teeth (Slagter *et al*, 1993). It therefore could be said to reflect the functional capacity of the jaws and teeth. In subjects whose chewing performance is high it would follow that the determinants of chewing performance are optimal or ideal. For this reason chewing performance was used to calibrate the values already determined for jaw movement and occlusal contact area for the sample of normal subjects in this study. It seemed appropriate to use image analysis to measure the areas of comminuted food particles in order to avoid some of the difficulties in using the traditional sieving techniques for calculating particle size. There was no association found between occlusal contact area and chewing performance when data from different chewing sides was pooled. However a significant association was found within subjects, between chewing sides. It was concluded that within subjects, factors which may determine chewing performance were common. Chewing performance was thus seen to be affected by differences in occlusal contact area on the left and right chewing sides. This finding serves to confirm occlusion as an influential factor in chewing performance. This study failed to identify occlusion as influencing chewing performance between subjects.

Factors affecting chewing performance

The investigation then was extended to examine the influence of jaw movement on chewing performance and if possible to calibrate values for jaw movement variables based on their ability to predict chewing performance. Four jaw movement variables were found to be related to chewing performance. They were ANGLE, AREAR-r, BIMODE and OPENING. This last variable expressed the maximum vertical dimension of the chewing cycle. OPENING was found to be less in females than males. Chewing performance was also reduced in females and it was suggested that there may be some cultural determinant influencing maximum opening and therefore chewing performance. A model able to predict chewing performance was derived using these variables and the mean cycle time. Chewing cycles of longer duration were associated with improved chewing performance (Table 6.3). It was assumed that jaw movements which were associated with enhanced chewing performance were the most efficient and therefore the most optimal. This study provoked a further investigation into factors common to each subject and possibly not directly related to jaw movement.

The RMS and integrated EMG of the masseter muscles were associated with chewing performance. The RMS and integrated EMG of temporalis muscles had less affect whereas the timing of the chewing side and non-chewing side burst was a factor in chewing performance. The separate actions of these two major muscle adductors confirms the dual processes of selection and breakage which must occur for effective chewing. The multivariate model derived in this study was still dominated by movement factors with some contributions coming from muscle activity variables particularly of the temporalis muscle (Table 7.5 and 7.6). Differences in some muscle variable were found between males and females. In the final model the R^2 value of 0.69 was increased to 0.76 just by adding the indicator variable gender. This pointed to a powerful influence of gender in chewing performance but not one which had as yet been identified as a determinant of chewing performance. It was suggested that chewing performance is influenced more by skill, co-ordination and grace, than by force. In view of the difficulty in measuring grace, it was decide to analyze movement acceleration and tremor during chewing.

Movement tremor has been found to be associated with the performance of skilled tasks such as writing (van Galen et al 1993). Muscle tremor appears to be generated by oscillations in the discharge of motor neurons resulting from peripheral feedback, rather than synchrony which has central origins (Burne, Lippold and Pryor, 1984). In this part of the work, the outcomes of muscle activity, in terms of both movement patterns and the dynamics of movement, including tremor and acceleration were investigated. Gender differences in acceleration and tremor were found and these differences appeared to account for the gender differences in chewing performance. The final regression model predicted chewing performance with an R^2 value of 0.78 (Table 8.4) which was not materially improved by the addition of the indicator variable gender. This model was less complex and more powerful than those which were developed early in the progress of this work. It was dominated by variables associated with jaw movement tremor. The association of chewing performance with jaw movement tremor during opening, suggests that food selection may be a skilled process requiring feedback and hence generating tremor.

Further studies are required to determine the influence of altered feedback on tremor frequencies. Differences in tremor frequency may be found in edentulous patients and those with muscle pain and dysfunction.

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Chapter 10

Discussion

Grinding seeds and pounding corn

The process of breaking down food particles during chewing has much in common with the food-preparing processes of early man. As the climate of Africa became progressively less tropical, food was less plentiful, and hunter gatherers had to make do with what was available. Wild grains were hard and dry; roots and tubers woody and fibrous. In the semi-desert areas of Namibia and the Kalahari, flat grinding stones are still used by some isolated communities to break down small wild grain and roots so as to make them edible (Evans and Lewin 1986). The process of grinding requires the worker (usually a women) to kneel over the grinding rock and to work a smaller flattened stone, backwards and forwards over the seed. This process must have been wearying work according to anthropologist Theya Molleson (1995). She studied remains of the inhabitants of Abu Hureya a site in Syria occupied by neolithic people about 10,000 years ago. Careful examination of the skeletal remains revealed osteoarthritic degeneration of the big toe bone and buttressing of the humerus. These changes, she believes reflect firstly, the forces on the flexed big toe, as the woman thrust her body forwards with arms extended over the grinding stone. Secondly, the added mass of the humerus is evidence of the force used to keep the hand held stone pressing down on the grinding stone.

The effort and method used to crush hard wild seed and roots is contrasted by the comparative ease with which domestic cereals, particularly maize can be crushed. The traditional method of crushing maize in Africa is a pestle and mortar, made from a hollowed out trunk and a stout pole. The process of raising the pole and pounding down onto grain held in the bowl (also a female chore) is done with some lightness and accompanying song.

These examples of food preparation without machinery serve to highlight the two processes occurring during food breakdown, which have been referred to in this work, namely selection and breakage. Clearly some foods like hard nuts and seeds may require considerable force to shatter the outer husk; here breakage is a priority. Other foods like softer pulses and large grained maize require less force and better control to contain the mass of partially pounded food. Both processes depend on the deft separation of the ground food from the remaining large particles. This process requires rapping the mortar on the ground a few times, which tends to bring the larger particles of grain to the surface, where they can receive the best of the next few poundings. The final selection however, has to be done by turning the contents of the mortar out onto a mat. The women of Abu Hureyra may also have used woven mats to toss the partially ground seeds, an operation which can, in skilled hands, produce separate piles of flour, un-ground wheat and small stones and grit, the unwelcome by-product of the process. This type of selection appears to demand good sensory discrimination and fine muscle co-ordination. The same requirements which it has been suggested are required during the selection process of chewing.

While it would be indefensible to suggest that women were made to grind corn, it is nevertheless a demanding task, an indicator of the condition of the many physiological systems that contribute to the performance. In short, a women who can grind corn must be reasonably healthy. It is more defensible to claim that the function of the jaws and teeth is to chew food. Hence I have assumed that chewing performance is some indicator of a healthy functioning chewing apparatus.

It is possible that some women are more efficient corn grinders than others. At least this would be the case if the same output was achieved with less effort. I have identified the good chewers in my sample. They have particular patterns of movement and muscle activity which appear to be predictors of high output. I have not been able to measure the work done in the process, and it is for this reason that I have not used the term chewing efficiency. Yet it is tempting to speculate that if a subject chewed with grace and good "style", less effort would be required.

Chewing performance is not an isolated process but in fact has close analogues, like that of grinding corn. The same can be said for machines which crush ore before the mineral can be extracted. In fact it is in mining engineering, that a reliable method for sizing particles was first developed. The most crucial discovery was that the distribution of particle sizes after ore crushing is not a normal one. There are disproportionately few particles of a larger size and those which are larger, contribute a disproportionate percentage of the total weight. It is for this reason that the *average* particle size of a sample of crushed ore is a meaningless quantity.

Chewing as a power function

The expression used to calculate the median particle size, required a plot to be made of the "sieve size" against the mass of particles, using logarithms for both scales. The relationship between particle size can otherwise be expressed in a simplified form as;

$$Y = X^n \qquad [1]$$

or

$$Log(Y) = n \times Log(X)$$

where Y is the mass of particles, in a category of size X, and n is a distribution function (Partridge 1966). The function means that when $n > 1$, large particles make up a disproportionate part of the total weight of chewed particles. The rate of reduction of food particles is also a power function of the number of chewing strokes, though in this case it is an inverse function (Olthoff et al 1984) given as;

$$X_{50} = kN^{-d}, \qquad [2]$$

or

$$Log(X_{50)} = K - d \times Log(N)$$

where X_{50} is the median particle size, N is the number of chews and d is the rate of particle size reduction. This function means that as the number of chewing strokes increases, the particle size gets smaller but at a diminishing rate when d

is less than one. For example in this study the value for d was 0.52 which is close to 1/2 or the square root of N.

In nature, power laws are common (Schroeder 1995). Their general formula is;

$$f(X) = X^{\alpha} \qquad [3]$$

For example Newton's laws of gravitation are expressed as a power function with $\alpha = -2$, indicating that gravitational force decreases as the square of the distance. Many biological phenomena are related by power laws, for example the frequency distribution of large animals, or even the distribution of long words in a language

(Schroeder 1995).

In these studies correlations were found between particle size and the various features of jaw function measured. However the correlations and multivariate models were always more accurate if the logarithm of the particle size was used. Hence;

$$\mathrm{Log}(X_{50}) = K \times \text{Jaw activity} \qquad [4]$$

From [2], the rate of particle size reduction *d*, is also a linear function of X_{50}. Thus jaw activities are linearly related to the rate of particle size reduction. This process of reasoning brings the relationship between jaw activity and output into a more direct relationship. It appears to support the use of chewing performance, or the rate of particle size reduction as measure of output of the masticatory system. Chewing efficiency could now perhaps be defined as a ratio, between the rate of particle size reduction and level of jaw activity required in the process.

This work in a South African context

In South Africa 8.5% of the GDP is spent on health, which is more than in most developing countries. Yet the health status of the population is relatively poor. Most of the expenditure occurs within the private sector of health care, for example 93% of dentists work in private practice. However only 23% of the population have access to private practice; the remainder are dependent on health care provided by the state (DoH, 1966).

It is therefore not surprising that most children in South Africa have little or no access to orthodontic treatment (Owen, 1996). This is due to the high cost of treatment, and a shortage of orthodontists willing to work for state hospitals. With limited resources it becomes necessary to be able to identify those who are most disabled, and who would therefore receive priority care. In orthodontic assessment, the degree of malocclusion is estimated by divergence from anatomical norms or by assessing treatment needs (Omar *et al,* 1989). It may be appropriate to add to these methods of assessment, a measure of the degree of functional disability of the child in order to give the process of assessment as broad a base as possible.

There are also limited resources for funding prosthodontic rehabilitation in South Africa. It may therefore be equally useful to assess how functionally disabled a prosthodontic patient is. There are some rough guides suggested by Kayser (1985) who maintains that a shortened arch (without molars), provides adequate function. In a WHO report (1982), mention is made of 20 strategic teeth being adequate, although there are no data to support either of these guidelines.

The cost of providing orthodontic and prosthodontic treatment also needs to be reduced. At the present time the cost of specialised treatment is escalating faster than the rate of inflation. Hospital based services are therefore going to face restrictions on the number of specialised services and pressure to reduce the cost per unit service (DoH, 1966). Reducing the cost of a service may involve making some compromises in the level of outcomes expected. If compromises are to be made in restoring masticatory function in the orthodontic and prosthodontics patient, treatment goals will need to be revised. In order to avoid down-grading into second rate treatment, these new goals will have to be both socially and biologically acceptable, and most important, be measurable.

The methods of functional analysis described in this work could be used firstly, to increase the biological basis for assessment, and thus allow fairer and more rational case selection. Secondly it could be used to monitor outcomes, in accordance with revised treatment goals, for both orthodontic and prosthodontic services in South Africa.

Other applications of this work

The need for normal data in order to assess the diagnostic capabilities of EMG and EGN equipment has been emphasised (Lund and Widmar, 1989). This work provides some normal data which may assist in determining the extent of the dysfunction in TMD patients. Further studies are planned to investigate TMD patients, with a view to establishing the sensitivity and specificity of the methods as diagnostic tools.

The logical extension of this work is to determine maximum particle sizes for different foods which can still be adequately digested. With such data it would be possible to set criteria for minimal levels of oral function which are compatible with digestion.

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Appendix

Programme codes written in TRU-BASIC for determining the following;

PRANAL

```
1030 ! 1. ARTLEW has provided for a disc file (*W#.PRN) which contains the frequency
1040 !    distributions from BRANAL. Most are too large for TRUBASIC (over 6100
1050 !    bytes), but can be halved at the separation between frontal and sagital
1060 !    frequencies. This is done BY INSERTING A LINE FEED between the
1070 !    frontal and sagital data using pctools.
1080
1090 ! 2. Data is read in TWO strings from the "NAME/wn/SIDE/W/NUMBER".prn file
1100 !     into an array.
1110
1120 ! 3. The carriage returns are located and stripped.
1130
1140 ! 4. The POS function is used to locate the position of blanks
1150 !    between the numberS. The numberS values between blanks are
1160 !    then written as separate sub-strings into the first array.
1170
1180 ! 5. The array has two dimensions, S for rows and I for columns.
1190 !    Every 20 columns a new row begins. This stores left over
1200 !   right. i.e. left data is uneven rows. The frontal and sagital
1210 !   frequencies are in  separate arrays.
1220
1230 ! 6. The 1st three modes for each row (level) are calculated.
1240
1250 ! 7. The total frequency for the level is divided into quartiles
1260 !    and their  distances from the left edge of the matrix is found
1270 !    by looping along the row adding frequencies until past a
1280 !    quartile. The exact position of the quartile is calculated.
1290
1300 ! 8. The results for each level can be printed or read into a
1310 !    file. The program ignores values from a level ifther was
1320 !    not at least one occurance every other cycle. Hence cycles/2.
1000  !            C:PRAN94
1010 CLEAR
1020
1030
```

```
1040 SOUND 1000,0.1
1050 !INPUT PROMPT "TYPE THE FIRST 3 LETTERS OF THE FILENAME ": F$
1060 print
1070 !INPUT PROMPT  "HOW MANY CYCLES FOR EACH TRIAL ? " :Cy
1080 print
1090 !INPUT PROMPT  "HOW MANY TRIALS EACH SIDE ? " :T
1100 print
1110 !INPUT PROMPT  "WHAT IS THE NUMBER OF THE FIRST TRIAL ? " :TN
1120     print
1130 !INPUT PROMPT  "WHICH SIDE DO YOU WANT ANALYSED (1 both, 2 left) " :SD
1140 let cy = 10
1150 let t = 5
1160 let tn = 5
1170 let sd = 1        ! 1 left 2 rigth
1180 LET CYC = 50
1190
1200 DO    ! NOT NECESSARY TO REPEAT  THE ABOVE WITH DATA FILENAMES
1210 PRINT  "  ***********************************************"
1220 READ F$
1230
1240 DIM FI$(6),FO$(6)
1250
1260    FOR A = SD TO 2
1270      IF A = 1 THEN
1280       LET SD$ = "lefw"
1290      ELSE
1300       LET SD$ = "rigw"
1310      END IF
1320
1330                 !! FOR B = TN TO T
1340     LET FI$(1)= "b:" & F$ & SD$ & "5.PRN"
1350     LET FO$(1)= "A:" & F$  & SD$ &  STR$(B) & ".OUT"
1360
1370     LET CYCLES = Cy * (T - TN +1)
1380
1390                        ! number of cycles per trial
1400 print fi$(1),
1410 CLEAR
1420 PRINT # 0: " STARTED  PROCESSING "; FI$(1)
1430 OPEN #1:NAME FI$(1)
1440 OPEN #3:PRINTER                        !name FO$(1),create new
1450 DIM FREL$(5000)
1460 DIM FRES$(5000)
1470 DIM SFRE(40,40)         ! To store the SAGITAL plane of data
1480 DIM LFRE(40,40)         ! To store the FRONTAL plane of data, left over right
1490
1500 DO WHILE MORE #1
1510  LINE INPUT #1:L$,S$       ! Loads two strings of text separated by line feed
1520   LET FREL$(1) = L$
1530   LET FRES$(1) = S$
1540  LOOP
1550    LET DIG = 15          !DIG is the pos of the first digt on .prn files
1560   CALL INPUT(FREL$(),DIG,LFRE(,))
1570    LET DIG = 1          ! sgittal string not preceded by the 14 name chrs
1580   CALL INPUT(FRES$(),DIG,SFRE(,))
1590
1600 CLEAR
1610  let c = 1
1620
1630 !!!!!!!!!!!!!!!!!!!!!! LATERAL MATRIX !!!!
1640   FOR IPCO = 1 TO 2
1650     IF SD$ = "rigw"  THEN   !
1660       IF IPCO = 1 THEN    ! FOR THE IPSILATERAL SIDE, RIGHT
1670        LET Of = 20
```

```
1680         LET Ce = 0
1690  CALL FREQUENCY(LFRE(,),Of,Ce,IPFRE,IPAREA,IPMOPER,IPANGLE)
1700        else    IF IPCO  = 2 THEN  ! FOR THE COLATERAL
1710         LET Of = 0
1720         LET Ce = 20
1730  CALL FREQUENCY(LFRE(,),Of,Ce,COFRE,COAREA,COMOPER,COANGLE)
1740        END IF   !IPCO
1750
1760      END IF    ! SDS
1770     IF SD$ = "lefw" THEN
1780      IF IPCO = 1 THEN    ! FOR THE IPSILATERAL SIDE, LEFT
1790        LET Of = 0
1800        LET Ce = 20
1810  CALL FREQUENCY(LFRE(,),Of,Ce,IPFRE,IPAREA,IPMOPER,IPANGLE)
1820       else IF IPCO  = 2 THEN  ! FOR THE COLATERAL
1830         LET Of = 20
1840         LET Ce = 0
1850  CALL FREQUENCY(LFRE(,),Of,Ce,COFRE,COAREA,COMOPER,COANGLE)
1860       END IF
1870     END IF !     SDS
1880
1890    NEXT IPCO
1900      LET FREQR = ROUND(IPFRE/(ipfre +COFRE) *100,2)
1910      LET AREAR = ROUND(IPAREA/(IPAREA + COAREA) *100,2)
1920    SET # 3: ZONEWIDTH 10
1930  PRINT #3: "NAME",    "FREQR",   "AREAR",   "IPMOP",  "COMOP",   "IPANG",    "COANG"
1940  PRINT #3: F$&SD$,FREQR,AREAR,IPMOPER,COMOPER,IPANGLE,COANGLE
1950  PRINT  F$&SD$,FREQR,AREAR,IPMOPER,COMOPER,IPANGLE,COANGLE
1960
1970
1980  !!!!!!!!!!!!!!! SAGITTAL MATRIX
1990      LET Of = 1
2000      let Ce = 0
2010  CALL FREQUENCY(SFRE(,),Off,Cen,SFREQ,SAREA,SMOPER,SANGLE)
2020
2030
2040
2050 CLOSE #1
2060 CLOSE #3
2070 NEXT A     ! FOR THE FOR A IS 1 TO 2
2080
2090 PRINT # 0: " FINISHED""!"" PROCESS ANOTHER FILE  OR CTRL-BREAK"
2100 SOUND 500,.3
2110
2120 LOOP
2130
2140 DATA  CH1,CH2
2150
2160 END     !PROGRAM
2170
2180    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!! INPUT   !!! OUTSIDE !!!!!!!!!!!!!
2190    SUB INPUT(DAT$(),FDIG,FRE(,))
2200      LET S = 0            !  This sets the Array to zero
2210      LET N = 0
2220
2230                  !position of the first digit of each sub string
2240                  ! starts at 15 because the file has 14 chrs heading
2250                  ! the .prn files are to big  to load so TWO strings
2260                  ! made with PCT4
2270  DO WHILE  S < 37  ! this is the number of LEFT AND RIGHT vertical levels
2280     LET S = S + 1
2290       LET sp =  POS(DAT$(1)[1:MAXNUM],"  ",FDIG)
2300       LET DAT$(1)[sp:sp] = "" !remvs dbl space left by stripped car.ret
2310       ! PRINT "sp at  "; sp
```

```
2320        LET CR =  POS(DAT$(1)[1:MAXNUM],chr$(013),FDIG)
2330        LET DAT$(1)[CR:CR] = ""  !CAR RETremv line feed left by WP halving .prn
2340        !PRINT DAT$(1)[1:lf];
2350     FOR I = 1 TO 40          !Reads 40 number$  for each level
2360         LET nextblank = POS(DAT$(1)[1:MAXNUM]," " ,FDIG)
2370         LET NUM$ = DAT$(1)[FDIG:(nextblank - 1)]
2380         LET FDIG = nextblank +1
2390                   !PRINT NUM$ ;
2400                    !PRINT ;
2410         LET  FRE(S,I) = VAL (NUM$)    !reads numbers to the lateral array
2420     NEXT I
2430
2440  LOOP
2450
2460
2470 CLOSE #1
2480 END SUB !INPUT
2490
2500 !!!!!!!!!!!!!!!!!!!!!!!!!SUB FREQUENCY
2510 SUB FREQUENCY(LFRE(,),Off,Cen,FREQT,AREAT,MOPER,ANGLE)
2520    LET FREQT,AREAT,MOPER,angle = 0
2530    DIM AREA(40)
2540    DIM DMED(40)
2550    DIM FREQ(40)
2560    DIM MODE(40)
2570 FOR S = 1 TO 37
2580 LET TOTFRE,MODPER,MODE1 = 0
2590 FOR I = 1 TO 20       ! off, determine the matrix side
2600     LET TOTFRE = TOTFRE + LFRE(S,I+off)
2610     IF LFRE(S,I+off) > MODE1 THEN
2620       LET MODE1 = LFRE(S,I+off)
2630     END IF
2640 NEXT I
2650
2660 IF TOTFRE > 25 THEN
2670   LET MODPER = ROUND(MODE1 / TOTFRE * 100,1)
2680   LET MED = TOTFRE  / 2
2690   LET FSTQRT = TOTFRE / 4
2700   LET TRDQRT = TOTFRE / 4 * 3
2710
2720
2730      LET I = 0
2740      LET SUBTOT = 0
2750      LET NSUBTOT = 0
2760 DO  WHILE NSUBTOT < FSTQRT
2770      LET I = I + 1
2780      LET SUBTOT = NSUBTOT
2790      LET NSUBTOT = SUBTOT + LFRE(S,I+off) ! provides a running total for each loop
2800      LET DISFST  = cen - (I - (NSUBTOT-FSTQRT) / (NSUBTOT-SUBTOT+.1))
2810           Let DISFSTR = ABS(round(DISFST,1))
2820           Let  disfst$ = str$(disfstR)
2830 LOOP
2840
2850     LET I = 0            ! Returns to the first item in the array
2860     LET SUBTOT = 0        ! re-sets the subtot to zero
2870     LET nSUBTOT = 0        ! re-sets the subtot to zero
2880 DO  WHILE NSUBTOT < MED
2890       LET I =  I + 1
2900       LET SUBTOT = NSUBTOT
2910       LET nSUBTOT = SUBTOT + LFRE(S,I+off)
2920       LET DISMED  =  cen - ( I  - (nSUBTOT-MED) / (nSUBTOT - SUBTOT+.1))
2930          Let DISMEDR = ABS(round(DISMED,1))
2940          Let  dismed$ = str$(dismedR)
2950 LOOP
```

```
2960
2970       LET I = 0
2980       LET SUBTOT = 0
2990       LET NSUBTOT = 0
3000  DO  WHILE NSUBTOT < TRDQRT
3010       LET I = I + 1
3020       LET SUBTOT = NSUBTOT
3030       LET NSUBTOT = SUBTOT + LFRE(S,I+off)
3040       LET DISTRD  = cen - (I - (NSUBTOT-TRDQRT) / (NSUBTOT- SUBTOT+.1) )
3050
3060            Let distrdr= ABS(round(distrd,1))
3070            Let  distrd$ = str$(distrdr)
3080  LOOP
3090 LET AR = ABS(DISTRDR - DISFSTR)
3100
3110            Let AR = round(AR,1)
3120 END IF                     !THE CONDITION WAS THAT TOTFRE >12
3130
3140     LET AREA(S) = AR
3150     LET DMED(S) = DISMEDR
3160     LET FREQ(S) = TOTFRE
3170     LET MODE(S) = MODPER
3180
3190 NEXT S
3200
3210     FOR S = 12 TO 24      ! THE MID THIRD
3220      LET FREQT = FREQT + FREQ(S)
3230      LET AREAT = AREAT + AREA(S)
3240     NEXT S
3250        LET N = 1
3260     FOR S = 12 TO 24      ! THE MID THIRD
3270          IF MODE(S) > 0 THEN
3280           LET N = N + 1
3290       LET MOPER = MOPER + MODE(S)
3300          END IF
3310     NEXT S
3320
3330            LET T,S1,S2,S3,S4,S5,M,C,R,D = 0        ! will do least squares for best fit
3340
3350         FOR p = 1 TO 6
3360           LET T = T  +1
3370           LET S1 = S1 + LOG(p) * LOG(DMED(p))
3380           LET S2 = S2 + LOG(p)
3390           LET S3 = S3 + LOG(DMED(p))
3400           LET S4 = S4 + Log(p)^2
3410           LET S5 = S5 + Log(DMED(p))^2
3420         NEXT p
3430
3440          LET M = ( S1 - S2 * S3 / T) / (S4 - S2^2 / T)  !slope
3450   LET MOPER = ROUND( MOPER / N, 2)
3470   OPTION ANGLE DEGREES
3480   LET ANGLE  = ROUND(90 -  ATN(M) ,1)
3490
3500  END SUB !FREQUENCY
3510 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3520
3530 SUB ZERO   !!!!!!!!!!!!!!!!!!!!!!!!!!!!  ZERO !!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3540    LET MODE1=0
3550    LET DISMODE1 = 0
3560    LET MODE2=0
3570    LET DISMODE2 = 0
3580    LET MODE3=0
3590    LET DISMODE3 = 0
3600    LET TOTFRE = 0
```

```
3610    LET DISMED = 0
3620    LET SUBTOT = 0
3630    LET NSUBTOT = 0
3640    let DISFST = 0
3650    LET DISMED = 0
3660    LET DISTRD = 0
3670    let modPER = 0
3680  LET FMODIST =0
3690  LET SMODIST =0
3700    LET AR = 0
3720 END SUB
```

BITPLOT

Estimating occlusal contact area

```
1120 clear
1130     PRINT TAB(15,30)
1140 !INPUT PROMPT "NAME OF SUBJECT ?":N$
1150 INPUT PROMPT "how many records each subject ?":BNTOT
1155 INPUT PROMPT "where to begin?":TN
1200 input prompt "LOOKUP value for .4 mm? (30,80)":W
1210 input prompt "LOOKUP value for .1 mm? (180,)":U
1211 DO WHILE MORE DATA
1212 READ N$
1220 LET T1 = 230
1230 LET T2 = 180
1240 LET T3 = 140
1250 LET T44 = 80
1260 DIM AI$(6)
1270 DIM AO$(2)
1280 DIM TOTAL(2)
1290 CLEAR
1300  SET MODE "ega"
1310 LET N = 1
1320 LET K = 0
1330 LET AA = 1          ! COUNTERS FOR ROWS
1340 LET BB = 1          !               AND COLUMNS
1350
1360  set window -2,300,-1,186
1370 set back 0
1380 set color 15     !WHITE
1390 box area -.50,.50,-.5 ,.5
1400 box keep -.50,.50,-.5 ,.5  in box1$
1410 set color 1
1420 box AREA -.5,.5,-.5,.5
1430 box keep -.5,.5,-.5,.5 in box2$
1440 set color 14
1450 BOX AREA -.5,.5,-.5,.5
1460 box keep -.5,.5,-.5,.5 in box3$
1470 set color 4
1480 box area -.5,.5,-.5,.5
1490 box keep -.5,.5,-.5,.5 in box4$
1500
1510  FOR BN = TN TO BNTOT
1515  LET BN$ = STR$(BN)
1520 FOR FI = 1 TO 2       !step -1
1530   IF FI = 1 THEN
1540     LET SD$ = "L"
1550     LET AI$(FI) ="A:"& N$ & BN$ & SD$ & ".IMg"          ! uses file 1
```

```
1560    LET AO$(FI) = "c:" & "bitdata"& ".OUT"
1570    LET X = 20              ! will be used to scale J
1580   ELSE IF FI = 2 THEN       !uses file 2
1590    LET SD$ = "R"
1600    LET AI$(FI) ="A:" & N$ & BN$ & SD$  & ".IMg"
1610    LET AO$(FI) = "c:" & "bitdata "& ".OUT"
1620    LET X = 100            ! used to scale J for second file
1630   END IF
1640
1650 OPEN #1: NAME AI$(FI), ORGANIZATION BYTE, CREATE OLD, RECSIZE 1
1660 OPEN #3: NAME AO$(FI), ORGANIZATION RECORD, RECSIZE 100, CREATE NEWOLD
1670 SET #1: POINTER BEGIN                    ! Sets pointer at start
1680 DIM lookup(256)        ! Correction tables for each value
1690
1700 LET A,B,C,D = 0
1710 LET TOT = 0
1720
1730                    ! calculate the correction needed for every value
1740
1750       FOR  V =  1 TO 256
1760  LET LOOKUP(V)  = (230-80 ) / (U -W ) * V  + ( ( 80 * U) - (230 * W )  ) / ( U -W )
1770       NEXT V
1780                       ! GO TO 2380
1790      LET N = 1
1800  FOR I = 1 TO 300 STEP AA
1810   FOR J = X TO (X+60)     ! x will position the two files
1820      SET #1:  RECORD N
1830      READ #1:AI$(FI)
1840      LET  VAL  =  LOOKUP( ORD( AI$(FI) ) +1)
1850
1860   IF VAL > T1 THEN              ! <.1mm
1870       LET A = A + 1              !COUNTER FOR HISTOGRAM
1880       BOX SHOW BOX1$ AT I,J       ! REMOVE ! FOR COLOR
1890
1900   ELSE IF VAL > T2 AND VAL < (T1 +1) THEN     !<.2mm
1910       LET B = B + 1              !COUNTER FOR HISTOGRAM
1920       BOX SHOW BOX2$ AT I,J
1930
1940
1950   ELSE IF VAL > T3 AND VAL < (T2 + 1) THEN    !<.3mm
1960       LET C = C + 1              !COUNTER FOR HISTOGRAM
1970       BOX SHOW BOX3$ AT I,J
1980
1990   ELSE IF VAL > T44 AND VAL < (T3+1) THEN     !<.45mm
2000       LET D = D + 1              !COUNTER FOR HISTOGRAM
2010       BOX SHOW BOX4$ AT I,J
2020
2030
2040   ELSE IF VAL  < (T44 +1) THEN       !       > .45
2050   SET COLOR 4
2060       PLOT I,J
2070    END IF
2080      LET N = N + 1
2090   NEXT J
2100   NEXT I
2110
2120  LET TOT = A + B + C + D
2130  LET TOTAL(FI) = TOT
2140 LET AR = ROUND( A / TOT * 100)
2150  LET BR = ROUND( B / TOT * 100)
2160  LET CR = ROUND( C / TOT * 100)
2170  LET DR = ROUND( D / TOT * 100)
2180  PLOT TEXT, AT 10,(X+65):USING$("##########   ###    ####    ####    #####   ########", N$ & SD$ &BN$,
A,B,C,D,TOT)
```

```
2190      SET COLOR 15
2200  PLOT TEXT, AT 50,-2:"< .1 MM"
2210      SET COLOR 1
2220  PLOT TEXT, AT 100,-2:"< .2 MM"
2230      SET COLOR 14
2240  PLOT TEXT, AT 150,-2:"< .3 MM"
2250      SET COLOR 4
2260  PLOT TEXT, AT 200,-2:"< .45 MM"
2270    SET #3: POINTER END
2280    WRITE #3:N$ & SD$ & BN$,TOT, A,B,C,D,U,W
2290 !  CLOSE #1
2300 !  CLOSE #3
2310    ! NEXT FI     !Will select the next file
2320 LET RATIO = TOTAL(2) /( TOTAL(1) + TOTAL(2) )
2330 SET COLOR 15
2340  PLOT TEXT, AT 100,(X+75):USING$("LEFT PROPORTION = .##",RATIO)
2370 SET COLOR 1
2380  !pRINT "RETURN TO PLOT"
2390  !get key zz
2400
2410   ! OPEN #1: NAME AI$(FI), ORGANIZATION BYTE, CREATE OLD, RECSIZE 1
2420  ! SET #1: POINTER BEGIN                    ! Sets pointer at start
2430  ! OPEN #2:PRINTER
2440  ! LET DI = ROUND( D / TOT * 100)
2450
2460
2470 ! PLOTTING BEGINS
2480
2490      !FOR FI = 1 TO 2
2500       !IF FI = 1 THEN
2510      ! LET X = 1
2520     ! ELSE IF FI = 2 THEN
2530      ! LET X =  100
2540       !END IF
2550
2560 !   LET N = 1200
2570 ! FOR I = 20 TO 260
2580 !   FOR J = X TO (X+59)
2590  !     SET #1:  RECORD N
2600   !    READ #1:AI$(FI)
2610    !   LET VAL = LOOKUP(ORD(AI$(FI))+1) !the light val scaled
2620   ! IF VAL > T1 THEN
2630    !     PRINT#2:"J1"               ! PEN NO 1
2640     !    PRINT#2:"M";(I *8);","; (J * 12)  !NOTE FORMAT FORVARIABLES PG 4-11 DXY
2650      !   PRINT#2:"D";(I *8);","; (J * 12)  !NOTE FORMAT FORVARIABLES PG 4-11 DXY
2660        ! PRINT#2:  "T2,8,8,4,2"
2670  !  END IF
2680   !    LET N = N + 1
2690  ! NEXT J
2700 !  NEXT I
2710
2720 !LET N = 1200
2730 !FOR I = 20 TO 260
2740  !  FOR J= X TO (X + 60)
2750  !     SET #1:  RECORD N
2760   !    READ #1:AI$(FI)
2770    !   LET VAL = LOOKUP(ORD(AI$(FI))+1) !the light val scaled
2780   ! IF VAL > T2 AND VAL < (T1+1) THEN
2790    !     PRINT#2:  "J1"              ! PEN NO 1
2800    !     PRINT#2: "M";(I *8);","; (J * 12)  !NOTE FORMAT FORVARIABLES PG 4-11 DXY
2810    !     PRINT#2: "d";(I *8);","; (J * 12)  !NOTE FORMAT FORVARIABLES PG 4-11 DXY
2820        ! PRINT#2:  "T2,8,8,4,2"
2830   ! END IF
2840    !   LET N = N + 1
```

```
2850 !  NEXT J
2860 ! NEXT I
2870
2880
2890! LET N = 1200
2900 !FOR I = 20 TO 260
2910  !  FOR J = X TO (X+60)
2920   !    SET #1:  RECORD N
2930    !   READ #1:AI$(FI)
2940     !  LET VAL = LOOKUP(ORD(AI$(FI))+1) !the light val scaled
2950   ! IF VAL > T3 AND VAL < (T2 +1) THEN
2960   !      PRINT#2:  "J1"                    ! PEN NO 1
2970    !     PRINT#2: "M";(I *8);","; (J * 12)  !NOTE FORMAT FORVARIABLES PG 4-11 DXY
2980  !    !  PRINT#2: "d";(I *8);","; (J * 12)  !NOTE FORMAT FORVARIABLES PG 4-11 DXY
2990     !   PRINT#2:  "T2,8,8,4,2"
3000   ! END IF
3010    !   LET N = N + 1
3020  ! NEXT J
3030 ! NEXT I
3040
3050
3060                          ! BORDER
3070 !LET N = 1200
3080 !FOR I = 20 TO 260
3090  !  FOR J = X TO (X+ 60)
3100  !     SET #1:  RECORD N
3110   !    READ #1:AI$(FI)
3120    !   LET VAL = LOOKUP(ORD(AI$(FI))+1) !the light val scaled
3130   ! IF VAL > T44 AND VAL < (T3 + 1) THEN
3140    !      PRINT#2:  "J2"
3150     !     PRINT#2: "M";(I *8);","; (J * 12)
3160      ! !  PRINT#2: "d";(I *8);","; (J * 12)
3170       !  PRINT#2:  "T2,8,8,4,2"      ! NO HATCHING
3180   ! END IF
3190    !   LET N = N + 1
3200  ! NEXT J
3210 ! NEXT I
3220               ! KEY TO PATTERNS
3230
3240 !        PRINT#2:  "J1"
3250  !       PRINT#2: "M";300;",";1
3260   !      PRINT#2:  "T2,30,30,4,2"      ! NO HATCHING
3270    !     PRINT#2: "M";350;",";1
3280     !    PRINT#2: "P < .1mm"
3290      !     for  p = 1 to 30 step 10
3300      !     for  q = 1 to 30 step 10
3310
3320       ! PRINT#2:  "J1"
3330      !  PRINT#2: "M";p+ 700;",";q
3340       ! PRINT#2: "d";p +700;",";q
3350        !   next q
3360         !   next p
3370
3380       ! PRINT#2: "M";750;",";1
3390        ! PRINT#2: "P < .2mm"
3400
3410       ! PRINT#2:  "J1"
3420        ! PRINT#2: "M";1100;",";1
3430       ! PRINT#2:  "T3,30,30,4,1"      ! HATCHING
3440       ! PRINT#2: "M";1150;",";1
3450       ! PRINT#2: "P < .3mm"
3460
3470       ! PRINT#2:  "J2"
3480       ! PRINT#2: "M";1500;",";1
```

```
3490       ! PRINT#2:  "T3,30,30,4,1"     ! NO HATCHING
3500       ! PRINT#2: "M";1550;",";1
3510       ! PRINT#2: "P < .44mm"
3520  CLOSE #1
3530  CLOSE #3
3540 NEXT FI
3541 clear
3545 NEXT BN
3550  !        PRINT #2:  "H"
3555 sound 1000, .25
3557 sound 800, 1
3560 loop
3561 DATA tr
3570 END
```

PARTAN

Analysis of chewing particle size

```
1000 !latest files needs scaling only for the dmin data
1010 ! sqr area for particle diam and area8 mdiam have best discrim fo jt and ch
1020 !CHEW 4 SERIES WITH 8 SIEVES READ AND FOUR PLOTTED
1030 !this program will read from data listed at the end or from
1040 !separate files loaded through input
1050
1060
1070 CLEAR
1080 INPUT PROMPT "SCALE FACTOR, .113 OR 1 (NORM) ?":SCALE
1090 INPUT PROMPT "HOW MANY COLUMNS OF DATA? (2 or 4)":CN
1100 INPUT PROMPT "NAME OF THE RECORD FILE YOU WANT TO USE ?":R$
1110
1120 CLEAR
1130 DO WHILE MORE DATA
1140    READ N$
1150
1160    DIM NA$(3)
1170    DIM NAO$(3)
1180
1190    LET NA$(1) = "a:" & N$ & ".TXT"
1200    LET NAO$(1) = "a:" & R$ & ".OUT"
1210
1220    OPEN #1: NAME NA$(1)
1230    OPEN #3: NAME NAO$(1),ORGANIZATION RECORD,RECSIZE 100,CREATE NEWOLD
1240    SET #1: POINTER BEGIN          ! Sets pointer at start
1250    OPEN #2:PRINTER
1260
1270    DIM AREA(2500)                  ! size each particle,sorted descending order
1280    DIM VOL(2500)                  ! size each particle,sorted descending order
1290    DIM X(2500)                  ! size each particle,sorted descending order
1300    DIM YW(10)                   ! total of particle "weight" (size^3) for each sieve size
1310    DIM YwP(10)                  ! percent "weight" each siev size
1320    DIM Yc(10)                  ! cummulative percent passing each siev size
1330    DIM LLR(10)                  ! Log.Log. 100 / Yc - 100 ( all logs are natural)
1340    DIM LX(10)                  ! Log siev sizes
1350    DIM S(10)                  ! siev sizes
1360    DIM COUNT(10)                  ! number on each sieve
1370
1380    LET N = 0                  !number of particles
1390    LET YW(1),YW(2),YW(3),YW(4),YW(5),YW(6),YW(7),YW(8),YW(9),YW(10)  = 0
1400    IF CN = 2 THEN             ! COLUMN NUMBER
1410    LET FC = 1
1420    ELSE IF CN = 4 THEN
1430    LET FC = 22             ! first comma in data record
```

```
1440   END IF
1450
1460
1470 LET N = 0
1480   DO WHILE MORE #1
1490     LET N = N + 1
1500     LINE INPUT #1: DATA$
1510     LET AWIDTH$ = DATA$[1:5]  !reads THE FIRST 5 figures
1520     LET CPOS = POS(DATA$,",",FC)  ! pos first comma (FC) AFTER which to read data
1530     LET DWIDTH$ = DATA$[(CPOS+1):(CPOS+5)]  !reads 5 numbers after the comma
1540
1550     LET AREA(N) = VAL(AWIDTH$)            ! * SCALE *SCALE
1560     LET X(N) = VAL(DWIDTH$)*SCALE
1570
1580   LOOP
1590   PRINT "SIEVING   " ;N$
1600
1610  LET S(1) = 2
1620 LET S(2) = 1.8
1630 LET S(3) = 1.6
1640 LET S(4) = 1.4
1650 LET S(5) = 1.2
1660 LET S(6) = 1
1670 LET S(7) = .8
1680 LET S(8) = .6
1690 LET S(9) = .4
1700 LET S(10) = .2
1710
1720 !FOr Volume, I Tried, vol recta (diam * area); and volume of sphere
1730 ! ( 4/3 * pi * r ^3); using diam/2 for r and sq rt of area/2
1740 ! settled for latter / 2 i.e half a sphere., so 4/6 used
1750 FOR A = 1 TO N
1760  IF X(A) > 2 THEN
1770     LET YW(1) = YW(1) + ( 4/3 * PI *( SQR(AREA (A) ) /2 ) ^3  ) !USING
1780
1790  ELSE IF X(A) > 1.8 THEN
1800  lET YW(2) = YW(2) + ( 4/3 * PI *( SQR(AREA(A))/2) ^3  ) !USING
1810
1820   ELSE IF X(A) > 1.6 THEN
1830    LET YW(3) = YW(3) + ( 4/3 * PI *( SQR(AREA(A))/2) ^3  ) !USING
1840
1850   ELSE IF X(A) > 1.4 THEN
1860    LET YW(4) = YW(4) + ( 4/3 * PI *( SQR(AREA(A))/2) ^3  ) !USING
1870
1880   ELSE IF X(A) > 1.2 THEN
1890    LET YW(5) = YW(5) + ( 4/3 * PI *( SQR(AREA(A))/2) ^3  ) !USING
1900
1910   ELSE IF X(A) > 1.0 THEN
1920    LET YW(6) = YW(6) + ( 4/3 * PI *( SQR(AREA(A))/2) ^3  ) !USING
1930
1940   ELSE IF X(A) > .8 THEN
1950    LET YW(7) = YW(7) + ( 4/3 * PI *( SQR(AREA(A))/2) ^3  ) !USING
1960
1970   ELSE IF X(A) > .6 THEN
1980    LET YW(8) = YW(8) + ( 4/3 * PI *( SQR(AREA(A))/2) ^3  ) !USING
1990
2000   ELSE IF X(A) > .4 THEN
2010    LET YW(9) = YW(9) + ( 4/3 * PI *( SQR(AREA(A))/2) ^3  ) !USING
2020
2030   ELSE IF X(A) > .2 THEN
2040    LET YW(10)= YW(10)+ ( 4/3 * PI *( SQR(AREA(A))/2) ^3  ) !USING
2050
2060   END IF
2070 NEXT A
```

```
2080
2090            !YwTOT is the total mass
2100
2110    LET  YWTOT = 0          ! used to calc total weight but if most of the nut
2120    FOR  A = 1 TO 9      ! had been chewed up there was a very small ywtot
2130    LET YWTOT = Yw(A) + YWTOT   !so the size was unrealistically large
2140    NEXT A
2150
2160    FOR A = 1 TO 9                 !YwP is the % mass each sieve size
2170       LET YwP(A) = ( Yw(A) / YwTOT) * 100
2180    NEXT A
2190
2200     LET Yc(1) = 100-  YwP(1)        ! starts doing cummulative percents
2210    LET Yc(2) = 100- (YwP(1)  + YwP(2) )
2220    LET Yc(3) = 100- (ywp(1)  + YwP(2) + YwP(3) )
2230    LET Yc(4) = 100- (ywp(1) + YwP(2) + YwP(3)  +YwP(4) )
2240    LET Yc(5) = 100- (ywp(1)  + YwP(2) + YwP(3)  +YwP(4) +YwP(5) )
2250    LET Yc(6) = 100- (ywp(1) + YwP(2) + YwP(3)  +YwP(4) +YwP(5) +YwP(6) )
2260    LET Yc(7) = 100- (ywp(1)  + YwP(2) + YwP(3)  +YwP(4) +YwP(5) +YwP(6) +YwP(7) )
2270    LET Yc(8) = 100- (ywp(1)  +YwP(2) + YwP(3)  +YwP(4) +YwP(5) +YwP(6) +YwP(7)+ YwP(8) )
2280   LET Yc(9) = 100- (ywp(1)  +YwP(2) + YwP(3)  +YwP(4) +YwP(5) +YwP(6) +YwP(7)+ YwP(8) + YwP(9) )
2290    !LET Yc(10) = 100- (ywp(1) +YwP(2) + YwP(3)   +YwP(4) +YwP(5) +YwP(6) +YwP(7)+ YwP(8) + YwP(9)
+YwP(10))
2300
2310
2320    FOR A = 1 TO 8
2330       LET LLR(A) = LOG( LOG( 100 / ( 100 - Yc(A) ) )    )
2340    NEXT A
2350
2360    FOR A = 1 TO 8
2370       LET LX(A) = LOG(S(A))
2380    NEXT A
2390
2400    LET T,S1,S2,S3,S4,S5 = 0        ! will do least squares for best fit
2410
2420    FOR A = 1 TO 8
2430       LET T = T  +1
2440       LET S1 = S1 + LX(A) * LLR(A)
2450       LET S2 = S2 + LX(A)
2460       LET S3 = S3 + LLR(A)
2470       LET S4 = S4 + LX(A)^2
2480       LET S5 = S5 + LLR(A)^2
2490    NEXT A
2500    LET B = ( S1 - S2*S3 / T) / (S4 - S2^2/T)  !slope
2510    LET I = (S3 - B * S2)/T                     !intercept
2520    LET R = (T * S1 - S2 * S3) / SQR(T * S4-S2 ^ 2) /SQR(T*S5-S3^2)
2530
2540
2550    ! When Yc is 50% then 100/ 100 - Yc = 2.  LOGe.LOGe (2) = -.3665
2560    !substituting in  LLR = I + B* LX
2570    !         OR       LX  = (LLR - I) / B
2580
2590    LET X50,X25 = 0
2600
2610    LET X50 = EXP( ( -.3665 - I) / B)
2620    LET X25 = EXP( ( -1.246 - I) / B)
2630    LET CX50 = X50 * (1000/YwTOT)
2640
2650 !  SOUND 500,.1
2660 set zonewidth 8
2670 set #3:zonewidth 8
2680    PRINT #0:N$
2690    PRINT #0: "SIZE ",
2700    PRINT #0: "Log SIZE",
```

```
2710   PRINT #0:"WEIGHT",
2720   PRINT #0:"%WGT",
2730   PRINT #0:"CUM %WGT",
2740   PRINT #0:"Log.LogR"
2750   PRINT #0:
2760
2770   FOR A = 1 TO 9
2780               PRINT  #  0,  USING  "##.#       ##.###         ####.##           ##.#       ##.#
##.###":S(A),LX(A),Yw(A),YwP(A),Yc(a),LLR(A)
2790  print #0
2800   NEXT A
2810
2820   PRINT # 0, USING"#######, VOL: ####, R:##.##, B:##.###, X50:#.###, A: ##":N$,YWTOT,R,B,X50,A-1
2830
2840   SET #3: POINTER END
2850   WRITE #3:N$,YWTOT,ROUND(R,3),ROUND(B,3),ROUND(X50,3),ROUND(CX50,3)
2860   CLOSE #1
2870   CLOSE #2
2880   CLOSE #3
2890
2900
2910 LOOP
2920 ! These files have four columns- need to change POS to comma AFTER 22
2930 !DATA BBL, bbr, CNL,CNR,BHL,BHR,CJL2,CJR1,HGR,HGL
2940 !DATA JEL,JEL100,JER,MKL,MKR,NRL,NRR,ETL,ETR
2950 !DATA OLL,OLR,RCL,RCR,RML,RMR,GFL,GFR              !rwl1 is rubbish
2960 !DATA SNL,SNR,TVL,TVR
2970 !DATA KDR,KDL
2980
2990       ! DATA ROBL6,ROBL8,ROBL12               !FROM ROBCHEW A:REDO\
3000       !DATA ROBL2,ROBL11, ROBL9,ROBL10,ROBL1,ROBR4,ROBR7,ROBR5 !FROM ROBCHEW
3010  ! ALL THE FOLLOWIHG IS TW0 COLUMN DATA
3020 ! THE FOLLOWING DATA NEEDS TO BE RE-SCALED
3030 !DATA CHL2,CHR2
3040               !DATA RJWL12,RJWL2,RLWL6          !FROM SIEVED
3050 ! the following data was chewd 20 times
3060 ! This data also has to be re scaled by  0.113
3070 !DATA  tSSL,tSSR,TRMR,TRML, TAKR,TAKL
3080 !DATA TTRL,TTRR
3090 !This data does not have to be scaled, recorded 31/7/92
3100
3110 !DATA TJTR1,TJTL1,TGFR1,TGFL1
3120 !DATA TKDR1,TKDL1,TJEL1,TJER1
3130 !DATA TRWR3,TRWL3
3140 ! REcorded on 4/8/92 with 3 dishes
3150 !DATA TRCR1,TRCL1,TJWL1,TJWR1
3160 !DATA TANR1,TANL1,TOLL1
3170 !DATA TOLR1
3180 ! Recorded on FRi 11/9/92 with 3 dishes
3190 !DATA TCHR1,TCHL1,TETL1,TETR1,TMKL1,TMKR1,TCJL1,TCJR1,TTVL1,TTVR1,TBBL1,TBBR1
3200 !DATA TSNL1,TSNR1,TCNL1,TCNR1
3210 !data gary10l,gary10r,gary20l,gary20r,manz10l,manz10r,manz20l,manz20r
3215 !data mp10l,mp10r,mp20l,mp20r
3220 ! these files have two column data - need to use POS ist comma to 14 data
3230 !DATA AKL,AKR,JTL,JTR,TRL,TRR,ANL,ANR,SSL,SSR,JER
3240 !data robl8.robr4
3250 !recorded on fri 10th oct using new vidas, scale the dmin data only
3260 !data SAL1,SAR1,TSAL1,TSAR1,TGLR1,TGLL1,TBHL1,TBHR1
3265 data rob10l,rob10r,rob20l,rob20r
3270 PAUSE 3.0
3280 SOUND 500,.3
3290 SOUND 370,.2
3300 SOUND 350,.1
3310 SOUND 370,.1
```

```
3320 SOUND 390,.3
3330 SOUND 370,.2
3340
3350
3360 PRINT "IF YOU WANT TO READ THE RECORDS TO A .TXT FILE PRESS RETURN"
3370 PRINT " IF THERE IS MORE DATA TO PROCESS PRESS CTRL/BREAK"
3380 GET KEY ZZ
3390
3400 CLEAR
3410 DIM ROS(3)                    ! Records Out
3420
3430 LET ROS(1) = "C:\TRU\" & RS & ".TXT"
3440
3450 OPEN #1: NAME NAOS(1),ORGANIZATION RECORD,RECSIZE 100,CREATE NEWOLD
3460 OPEN #3: NAME ROS(1),ORGANIZATION TEXT,CREATE NEW
3470 OPEN #2:PRINTER
3480
3490 DO
3500   INPUT PROMPT "OUTPUT TO  PRINTER (P) OR FILE (F)??":ANS$
3510   LET ANS$ = UCASE$( ANS$)
3520   IF ANS$ = "F" THEN
3530     LET CH = 3
3540   ELSE IF ANS$ = "P" THEN
3550     LET CH = 2
3560   ELSE
3570     PRINT "ANSWER THE QUESTION CORRECTLY!"
3580   END IF
3590 LOOP UNTIL ANS$ = "S" OR ANS$ = "P" OR ANS$ = "F"
3600
3610
3620 SET ZONEWIDTH 8
3630 SET # CH: ZONEWIDTH 8
3640
3650 PRINT "NAME",
3660 PRINT "NUTVOL",
3670 PRINT "INTERCEPT",
3680 PRINT "SLOPE",
3690 PRINT "RVAlue",
3700 PRINT "SIZE"
3710 PRINT "CORRECTED",
3720
3730
3740 PRINT # CH: "NAME",
3750 PRINT # CH: "NUTVOL",
3760 PRINT # CH:"INTERCEPT",
3770 PRINT # CH:"SLOPE",
3780 PRINT # CH:"RVALUE",
3790 PRINT # CH:"SIZE"
3800 PRINT # CH:"CORRECTED",
3810
3820
3830 DO WHILE MORE #1
3840   READ #1:NAME$
3850   PRINT #CH: NAME$,
3860   PRINT NAME$,
3870
3880   FOR RECORD = 1 TO 5
3890     READ #1:D
3900     PRINT #CH: D,
3910     PRINT  D,
3920   NEXT RECORD
3930   PRINT #CH:
3940   PRINT
3950 LOOP
```

```
3960
3970 CLOSE #1
3980 CLOSE #2
3990 CLOSE #3
4000
4010 PRINT "DONE"
4020 PAUSE .9
4030 !SOUND 470,.2
4040 PAUSE .3
4050 !SOUND 500,.3
4060
4070
4080
4090 END
```

MYOGAN
Calculation of emg variables

```
1210
1220     DIM XRE     ( 1 )
1230     DIM XIM     ( 1 )
1240     DIM FFTRE   ( 1 )
1250     DIM FFTIM   ( 1 )
1260     DIM TEMPRE  ( 1 )
1270     DIM TEMPIM  ( 1 )
1280     DIM IBR     ( 1 )
1290     DIM KOS     ( 1 )
1300     DIM ZIN     ( 1 )
1310     DIM AGNrw(1)
1320     DIM AGNco(1)
1330     DIM VERT(1)
1340     DIM LAT(1)
1350     DIM DIG(1)
1360     DIM DIGco(1)
1370     DIM AGNsm(1)
1380     DIM AGNact(1)
1390
1400
1410 DIM NAI$(1)
1420 DIM NAO$(2)
1430 DIM NAMES$(100)
1440 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1450  set mode "ega"
1460
1470 DO
1480  CALL DEFAULTS
1490  CALL BANNER
1500  IF def$ =  "R" then
1510  CALL  SETUP
1520   IF OUT$ = "PRINTER" THEN
1530      open#2:printer
1540      set #2: zonewidth 7
1550 PRINT #2 :
"File","cyc","opav","wdav",mu$&"rst",MU$&"rms",mu$&"int",MU$&"mx",Mu$&"pint",MU$&"pmx",mu$&"actv","drms",
mu$&"-dg",mu$&"p_dg",
mu$&"-mc","dg_"&mu$,"dg_p"&mu$,mu$&"ipco",mu$&"mdfr",mu$&"turn","SWAC","SWANG","CLAC","CLSTD","CLA
NG","FRAC"
1560      close #2
1570  end if
1580  ELSE IF DEF$  = "C" THEN
1590   IF OUT$ = "PRINTER" THEN
```

```
1600      open#2:printer
1610      set #2: zonewidth 7
1620 !PRINT #2: "File","cyc","opav","wdav",mu$&"rst",MU$&"rms",mu$&"int",MU$&"mx",Mu$&"pint",MU$&"pmx",mu$&"actv","drms",mu$&"-dg",mu$&"p_dg",mu$&"-mc","dg_"&mu$,"dg_p"&mu$,mu$&"ipco",mu$&"mdfr",mu$&"turn","SWAC","SWANG","CLAC","CLSTD","CLANG","FRAC"
1630  PRINT #2: "File","opav","dev","SWAC","SWANG","SWSTD","CLAC","CLANG"
1640      close #2
1650  end if
1660  END IF
1670                        ! for 22 sec =227 hz so x 4.4
1680  IF EXT$ = ".std" THEN
1690     let smo = 20    ! for the length of the smooth window
1700     let zo = 70     ! for the zone around reversal points
1710     let hzf = 3     !  5000 in 15 sec = 300 hz so X 3 for milli secs
1720  ELSE IF EXT$ = ".TRB" THEN
1730     let smo = 40
1740     let zo = 300
1750      let hzf = 1.2    ! 5000 in 6 sec = 830 hz so x 1.2
1760 END IF
1770  CALL NAMESIN
1780                       ! LOOPS AFTER THE LAST NAME(nm)
1790 FOR F = 1 TO NM-1  ! ( THE LAST ONE IS Z!)
1800 LET N$ = NAMES$(F)
1810
1820 open #8:screen 0, 1, .49, 1            !text
1830 open #9:screen 0, 1, 0, .48            !graph
1840 FOR Sd = 2 TO 3      ! NORMALLY 2 TO 3 DOES LEFT AND RIGHT ONLY
1850  if sd = 1 then
1860   LET SIDE$ = "W"
1870  else if sd = 2 then
1880   LET SIDE$ = "L"
1890  else if sd = 3 then
1900  LET SIDE$ = "R"
1910  END IF
1920 set mode "ega"
1930  FOR AGONIST = 1 TO 1     ! CHANGE TO 2
1940       IF AGONIST = 1 THEN
1950        LET MU$ = "M"
1960 MAT REDIM AGNrw(0:4000)
1970 MAT REDIM AGNco(0:4000)
1980 MAT REDIM VERT(0:4000)
1990 MAT REDIM LAT(0:4000)
2000 MAT REDIM DIG(0:4000)
2010 MAT REDIM DIGco(0:4000)
2020    CALL INMAS
2030     CALL CYCLES
2040     CALL BIMODE
2050 !    CALL DIGSMOOTH
2060 !   CALL WAVEANAL   ! 7900
2070 ! ELSE IF AGONIST = 2 THEN
2080 !       LET MU$ = "T"
2090 !       MAT REDIM AGNrw(0:4000)
2100 !         MAT REDIM AGNco(0:4000)
2110 !   CALL INTEM
2120 !   CALL WAVEANAL    !@7100
2130     END IF
2140     CALL OUTPUT(NAO$())       ! AT 9810
2150  NEXT AGONIST
2160 NEXT Sd     !SIDE
2170 close #8
2180 close #9
2190
```

```
2200 NEXT F      !FILE
2210 LOOP
2220
2230
2240                                          !!!!!!!!!!!!!!!!!!!!!!!!!!!!
2250 !!!!!!!!!!!!!!!!!!!!!!!!!! DEFAULTS
2260  SUB DEFAULTS
2270
2280  LET DRIVE$ = "C:\EMG\std\"
2290  LET EXT$ = ".std"
2300  LET OUT$  = "FILE"
2310  let cht$ = "N"
2320  ! smo 20,40 and zo (60,250) are defined at 1800
2330  ! Act > 100
2340  end sub
2350 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!   BANNER
2360  SUB BANNER
2370
2380  OPEN #7:SCREEN 0,.91,.45,.95 !  Text
2390  WINDOW #7
2400  set window 0,10,0,10
2410  set zonewidth 7
2420  SET BACK  1
2430  set color 7
2440 plot  2.5,7.5;  2.5,2;  7.5,2;  7.5,7.5;  2.5,7.5
2450  SET COLOR 6
2460  print tab (1,34);
2470  PRINT"EMG ANALYSIS"
2480  print tab (2,25);
2490  print"Wilding/Morrison; May 1994"
2500  print tab (4,35);
2510  PRINT "Defaults";
2520  print tab (5,20);
2530 print "1. Drive for data = "; DRIVE$
2540  print tab (6,20);
2550 PRINT "2. Data will  be sent to  ";OUT$
2560  print tab (7,20);
2570 PRINT "3. Will chartfile  be made ?  " ;cht$
2580  print tab (8,20);
2590 PRINT "4. The EMG sample rate was  ";EXT$
2600  print tab (11,25);
2610 Input prompt "Press C to continue, R to reset ":def$
2620 let def$ = ucase$(def$)
2630 END SUB ! BANNER                         !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2640
2650 !!!!!!!!!!!!!!!!!!!!!!!!!!  SETUP
2660  SUB SETUP
2670  SET BACK  1
2680  SET COLOR 6
2690  DO
2700 DO
2710  CLEAR
2720 LET X1 = 2   ! left
2730 LET X2 = 9.5 ! left
2740 LET Y1 = 3   ! bottom
2750 LET Y2 = 8 ! top
2760 PLOT X1,Y1 ; X2,Y1 ; X2,Y2 ; X1,Y2 ; X1,Y1
2770  print tab (1,34);
2780 PRINT " New defaults ",
2790  print tab (3,20);
2800 print "1. Drive for input file................ "
2810  print tab (4,20);
2820 print "2. Extension for input file............ "
2830  print tab (5,20);
```

```
2840 print "3. Data to printer (P) or file(F) ?.... "
2850  print tab (6,20);
2860 print "4. Chartfile ? (Y/N)................... "
2870  print tab (7,20);
2880 !print "5. EMG data  ""STD"" or ""TRB"" ?.... "
2890 ! print tab (9,20);
2900
2910  print tab (3,60);
2920 input prompt "":drive$
2930  print tab (4,60);
2940 input prompt "":ext$
2950  print tab (5,60);
2960 input prompt "":ans$
2970  print tab (6,60);
2980 input prompt "":cht$
2990 ! print tab (7,60);
3000 ! input prompt "":EXT$
3010   LET ANS$ = UCASE$( ANS$)
3020  IF ANS$ = "F" THEN
3030      LET OUT$ = "FILE"
3040   ELSE IF ANS$ = "P" THEN
3050      LET OUT$   = "PRINTER"
3060   ELSE
3070    PRINT,,,,,,,,, "TRY AGAIN!"
3080    PAUSE 2
3090   END IF
3100 LOOP UNTIL ANS$ = "P" OR ANS$ = "F"
3110
3120 LET cht$ = UCASE$(cht$)
3130 LET MU$ = UCASE$(MU$)
3140 SET COLOR 14
3150  print tab (10,20);
3160 Input prompt "Press C to continue, R to reset ":er$
3170 let er$ = ucase$(er$)
3180 LOOP UNTIL ER$ = "C"
3190
3200  END SUB !SETUP                    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3210
3220 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3230 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!   NAMESIN
3240  SUB NAMESIN
3250
3260 CLEAR
3270  SET COLOR 6
3280 PRINT TAB(3,20),
3290 INPUT PROMPT "Data input via the keyboared (Y/N) ? ":DATA$
3300 LET DATA$ = UCASE$(DATA$)
3310 IF DATA$ = "Y" THEN
3320 CLEAR
3330 DO
3340     LET NM = 0
3350       PRINT" Type file names (example ""AB1""), without .ext or side and press RETURN"
3360      PRINT TAB(7,10),
3370       PRINT "To end press  Z, then press C to continue or R to correct"
3380      DO
3390       LET NM = NM + 1
3400       !PRINT TAB ( INT( (12 + NM)/10 ) ,(NM*5));
3410       PRINT TAB (2,1)
3420     OPEN #10: SCREEN .92,1,.96,1
3430       INPUT PROMPT"" :nam$
3440     CLOSE #10
3450       print tab (5,10),
3460       let nam$ = ucase$(nam$)
3470       LET NAMES$(NM) = NAM$
```

```
3480        set zonewidth 7
3490        MAT PRINT NAME$
3500      LOOP UNTIL NAM$ =  "Z"   ! space
3510  INPUT PROMPT "Continue ? ":AN$
3520   LET AN$ = UCASE$(AN$)
3530 LOOP UNTIL AN$ = "C"
3540
3550 ELSE  IF DATA$ = "N" THEN
3560
3570 LET nm = 0
3580 DO WHILE MORE DATA
3590  LET NM = NM + 1
3600  READ NAM$
3610  LET NAME$(NM) = NAM$
3620 LOOP
3630 print tab(5,10)
3640 MAT PRINT NAME$
3650 print tab(9,20),
3660 PRINT " If this is okay, press any key to continue..."
3670 print tab(10,20),
3680 PRINT " otherwise CTRL BREAK to input names"
3690 !!!!!!!!!!!!!!!!!!!!!!!!!          DATA            !!!!!!!!!!!!
3700 ! data BB,CH         !TR,TV,BH,CN are mssing either lat or vert
3710 ! DATA cj,et,gdt,gf,je
3730 ! Data jt,jw,kd,mk, ms1,msh,
3732   DATA nr,rc,rw,rm,SN,SS,tr
3740 ! data AO11, AO12, AO13, AO21
3750 ! DATA  FA11, FA12, FA13, FA21, FA23, GM11
3760 ! data  HC11, HC12, HC13, HC21, HC22, HC23, JH11, JH12, JH13, JM11
3770 ! data  LM11, RT11, RT12, RT13
3780 ! data PP11, PP12, PP13, RU11
3790 ! data  RU13, MS11, MS12, MS13, FA31
3810
3820 DATA Z
3830 END IF    !DATA$ = ?
3840 close #7
3850  END SUB !NAMESIN
3860 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3870
3880 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!    INMAS !!!!!!!!!!!!!!!!!!!!
3890 SUB INMAS
3900
3910    LET NAI$(1) = DRIVE$ & N$ & side$ & EXT$
3920   CLEAR
3930
3940   OPEN #1: NAME NAI$(1)
3950     WINDOW #8
3960    set window 0,1,0,1
3970    SET BACK 0
3980    SET #8 :ZONEWIDTH 7
3990    SET COLOR 7
4000 PRINT TAB (1,55),
4010 PRINT N$ & SIDE$ & mu$
4020    LET A,T = 0
4030     FOR DA = 1 TO  5
4040      LINE INPUT #1:DATA$
4050      IF DA = 2 THEN
4060      LET TRIAL$ = DATA$
4070      END IF
4080     NEXT DA
4090
4100     LET MIN = 0         ! Finds the vertical zero offset
4110     LET MINMAS = 100
4120    DO
```

```
4130 PRINT TAB (1,65),
4140   print ;INT( (4000 - A)/100)
4150       LINE INPUT #1: DATA$                    ! UP TO THESE COMAS
4160       LET CPOS1 = POS(DATA$,",",1)            ! vertical
4170       LET CPOS2 = POS(DATA$,",",CPOS1+1)      !ap
4180      LET CPOS3 = POS(DATA$,",",CPOS2+1)      !lateral
4190       LET CPOS4 = POS(DATA$,",",CPOS3+1)      !velo
4200       LET CPOS5 = POS(DATA$,",",CPOS4+1)      ! R temporalis
4210       LET CPOS6 = POS(DATA$,",",CPOS5+1)      ! R MASSETER
4220       LET CPOS7 = POS(DATA$,",",CPOS6+1)      ! L masseter
4230       LET CPOS8 = POS(DATA$,",",CPOS7+1)      ! L TEMP
4240       LET CPOS9 = POS(DATA$,",",CPOS8+1)      !
4250      LET CPOS10= POS(DATA$,",",CPOS9+1)      !CH 6
4260      LET CPOS11= POS(DATA$,",",CPOS10+1)     !CH 7
4270
4280      let ch1$ = data$[1:(CPOS1-1)]
4290      let CH2$ = data$[(CPOS1+1):(CPOS2-1)]
4300      let lat$ = data$[(CPOS2+1):(CPOS3-1)]
4310      let VEL$ = data$[(CPOS3+1):(CPOS4-1)]
4320
4330       let massR$ = data$[(CPOS5+1):(CPOS6-1)]
4340       let massL$ = data$[(CPOS6+1):(CPOS7-1)]
4350
4360      let maspoR$ = data$[(CPOS8+1):(CPOS9-1)]     !R POST MASS
4370      let digR$ = data$[(CPOS9+1):(CPOS10-1)]
4380      let digL$ = data$[(CPOS10+1):(CPOS11-1)]
4390      let maspoL$ = data$[(CPOS11+1):(CPOS11+5)]     !NO COMMA AFTER LAST VALUE
4400
4410
4420   LET A = A +1
4430   LET VERT(A) = VAL(CH1$)
4440   LET LAT(A) = VAL(lat$)
4450      IF vert(A) < MIN THEN        ! TO FIND THE OFFSET FROM ZERO
4460      LET min = vert(A)
4470      End If
4480 IF SIDE$ = "W" THEN
4490   LET AGNrw(A) = VAL(massL$)
4500   LET DIG(A) = VAL(massR$)
4510   LET DIGco(A) = VAL(massL$)
4520   LET AGNco(A) = VAL(massR$)
4530 ELSE IF SIDE$ = "L" THEN
4540   LET AGNrw(A) = VAL(massL$)
4550   LET DIG(A) = VAL(digL$)
4560   LET DIGco(A) = VAL(digR$)
4570   LET AGNco(A) = VAL(massR$)
4580 ELSE IF SIDE$ = "R" THEN
4590   LET AGNrw(A) = VAL(massR$)
4600   LET DIG(A) = VAL(digR$)
4610   LET DIGco(A) = VAL(digL$)
4620   LET AGNco(A) = VAL(massL$)
4630 END IF
4640 LOOP until a =  4000
4650   CLOSE #1
4660 print
4670 END SUB  !INMAS
4680 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
4690
4700 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!   INTEM !!!!!!!!!!!!!!!!!!
4710 SUB INTEM
4720
4730   LET NAI$(1) = DRIVE$ & N$ & side$ & EXT$
4740   CLEAR
4750
4760   OPEN #1: NAME NAI$(1)
```

```
4770     WINDOW #8
4780    set window 0,30,0,1
4790    SET BACK 0
4800    SET #8 :ZONEWIDTH 7
4810    SET COLOR 7
4820 PRINT TAB (1,55),
4830 PRINT N$ & SIDE$ & mu$
4840    LET A,T = 0
4850     FOR DA = 1 TO  5
4860      LINE INPUT #1:DATA$
4870      IF DA = 2 THEN
4880      LET TRIAL$ = DATA$
4890      END IF
4900     NEXT DA
4910
4920     LET MIN = 0        ! Finds the vertical zero offset
4930     LET MINMAS = 100
4940    DO
4950  PRINT TAB (1,65),
4960    print ;INT( (4000 - A)/100)
4970       LINE INPUT #1: DATA$                  ! UP TO THESE COMAS
4980       LET CPOS1 = POS(DATA$,",",1)            ! vertical
4990       LET CPOS2 = POS(DATA$,",",CPOS1+1)       !ap
5000      LET CPOS3 = POS(DATA$,",",CPOS2+1)       !lateral
5010       LET CPOS4 = POS(DATA$,",",CPOS3+1)      !velo
5020       LET CPOS5 = POS(DATA$,",",CPOS4+1)      ! R temporalis
5030       LET CPOS6 = POS(DATA$,",",CPOS5+1)      ! R MASSETER
5040       LET CPOS7 = POS(DATA$,",",CPOS6+1)      ! L masseter
5050       LET CPOS8 = POS(DATA$,",",CPOS7+1)      ! L TEMP
5060       LET CPOS9 = POS(DATA$,",",CPOS8+1)      !
5070      LET CPOS10= POS(DATA$,",",CPOS9+1)      !CH 6
5080      LET CPOS11= POS(DATA$,",",CPOS10+1)      !CH 7
5090
5100       let tempR$ = data$[(CPOS4+1):(CPOS5-1)]
5110       let tempL$ = data$[(CPOS7+1):(CPOS8-1)]
5120
5130
5140    LET A = A +1
5150  IF SIDE$ = "W" THEN
5160    LET AGNrw(A) = VAL(tempL$)
5170    LET AGNco(A) = VAL(tempR$)
5180  ELSE IF SIDE$ = "L" THEN
5190    LET AGNrw(A) = VAL(tempL$)
5200    LET AGNco(A) = VAL(tempR$)
5210  ELSE IF SIDE$ = "R" THEN
5220    LET AGNrw(A) = VAL(tempR$)
5230    LET AGNco(A) = VAL(tempL$)
5240  END IF
5250 LOOP until a =  4000
5260    CLOSE #1
5270 print
5280 END SUB  !INTEM
5290 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
5300     !!!!!!!!!!!!!!!!!!!!!!!!!! CYCLES !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
5310 SUB CYCLES             !called at 2110
5320 DIM OPEN(40)       ! an address of maximum opening
5330 DIM CLOSE(40)      ! an address of maximum INTERCUSPATION
5340 mat open = 0
5350 mat close = 0
5360
5370 FOR N = 1 TO 4000
5380 LET vert(N) = - (vert(N) - MIN)            !MIN IS TH EOFFSET FROM ZERO
5390 NEXT N
5400      LET SUBMN,OPAV,WIDAV,MX,LATOFSUB = 0
```

```
5410     LET CLOSE(1) = 1
5420     LET CYC = 1
5430  FOR N = zo +1 TO (4000 - zo )    !!!!!!!!!!seeking close points
5440      LET MN = -10
5450        IF VERT(N) >  (VERT(N+zo)+1) AND VERT(N) > VERT(N-zo)  THEN
5460          FOR Q = N TO N+zo
5470            IF VERT(Q) > MN THEN
5480              LET CR = Q
5490              LET LATOFF = LAT(Q)      !The error in lateral offset
5500             LET MN = VERT(Q)
5510            END IF
5520          NEXT Q
5530               LET CYC  = CYC + 1
5540               LET CLOSE(CYC) = CR    !CLOSE is an array of addresses
5550               LET N = N + 2*ZO
5560               LET LATOFSUB = LATOFSUB + LATOFF
5570         END IF
5580   NEXT N
5590 LET SUBMX,subd = 0                   !!!!!!!!!!!!  seeking open points
5600 IF CYC > 0 THEN
5610 FOR PH = 1 TO CYC -1
5620  LET MX = 0
5630   FOR N = CLOSE(PH) TO CLOSE(PH+1)
5640    IF VERT(N) < MX THEN
5650     LET MX = VERT(N)
5660     LET OPEN(PH) = N              !OPEN  ia na array of addreses
5670     let d = lat(n) ! the lateral deviation at opening
5680    END IF
5690   NEXT N
5700  let subd = subd + d
5710   LET SUBMX = SUBMX + MX
5720 NEXT PH
5730 LET OPAV = abs(ROUND(SUBMX/(CYC-1),1))
5740 LET DEV = ROUND(SUBD/(CYC-1),1)
5750  !!!!!!!!!!!!!!!!  Seeking lateral displacements
5760 !! Correcting any error in lateral zero
5770     LET LATOFF = LATOFSUB / CYC
5780      FOR N = 1 TO 4000
5790        LET lat(N) =  lat(N) - latoff  ! , the offset from centre
5800      NEXT N
5810 LET N,SUBLAT,MAXLAT,MINLAT = 0
5820 FOR  L = 1 TO CYC-1
5830   LET MAXLAT = 0
5840  FOR N = CLOSE(L) TO CLOSE(L+1)
5850   if side$ = "L" then
5860     IF LAT (N) > MAXLAT THEN ! negative displacemetns to the left
5870      LET MAXLAT = LAT(N)
5880     END IF
5890   else if side$ = "R" then
5900  IF LAT (N) < MAXLAT THEN  ! POSITIVE DISPL TO THE RIGHT
5910    LET MAXLAT = LAT(N)
5920    END IF
5930   end if    ! if side$ =
5940  NEXT N
5950  LET SUBLAT = SUBLAT + ABS(MAXLAT)
5960 NEXT L
5970 LET WIDAV = ROUND(SUBLAT/(CYC-1),1)
5980   END IF ! CYC > 0
5990  set back 0
6000 WINDOW # 9
6010   clear
6020 set window -50,4000,-10,+500
6030   set color 1
6040   box area -50,4000,-10,500
```

```
6050  set color 13
6060 for n = 1 to 4000
6070 plot n,(500 + 10 *vert(n))
6080 next n
6090      FOR PH = 1 TO CYC-1
6100       set color 15
6110       plot close(ph),500 + 10 * vert(close(ph));close(ph),520 + 10 * vert(close(ph))
6120       set color 15
6130       plot open(ph),500 + 10 * vert(open(ph));open(ph),520 + 10 * vert(open(ph))
6140      NEXT ph
6150      SET COLOR 7
6160 print "widav  ";widav
6170 SET COLOR 7
6180 PLOT 0,400;4000,400
6190  set color 11
6200 for n = 1 to 4000
6210 plot n,(400 + 10 *LAT(n))
6220 next n
6230      PRINT tab (1,20),
6240      set color 2
6250      print "OPEN",
6260      set color 4
6270      print "CLOSE"
6280          SET COLOR 7
6290    ! PLOT 0,300;4000,300
6300
6310      FOR PH = 1 TO CYC
6320          SET COLOR 7
6330          PLOT CLOSE(PH),300;CLOSE(PH),100
6340        SET COLOR  10   !green
6350         LET C = CLOSE(PH)
6360      FOR N = CLOSE(PH) TO OPEN(PH)
6370         PLOT C + 10*LAT(N), 10*VERT(N)+300
6380      NEXT N
6390        SET COLOR  12    !red
6400      FOR N = OPEN(PH) TO CLOSE(PH+1)
6410      PLOT C + 10*LAT(N), 10*VERT(N)+300
6420      NEXT N
6430      NEXT PH
6440 END SUB ! CYCLES
6450 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
6460        SUB DIGSMOOTH
6470  window #8
6480    print tab (2,1),
6490   PRINT "SMOOTHING Digastrics"
6500
6510  !   May need to correct zero offset, so..
6520      LET SUBDig,SUBDco,CD,CDco = 0
6530        FOR I = 0 TO 500
6540         LET SUBDig = SUBDig + DIG(I)
6550         LET SUBDco = SUBDco + DIGco(I)
6560      NEXT I
6570      LET CD = SUBDig/500              ! C is the zero offset
6580      LET CDco = SUBDco/500              ! C is the zero offset
6590
6600   LET AV,SUBSQ = 0
6610      FOR I = 0 TO (4000 -smo/2)
6620    print tab (2,25),
6630    print ;4000 - i
6640        LET SUBSQ = 0
6650         FOR N = 0 TO smo/2
6660            LET SUBSQ = SUBSQ +  (DIG(I+N)-CD)^2
6670         NEXT N
6680            LET AV = ROUND(  SQR( SUBSQ / (smo/2))   ,2)
```

```
6690          LET DIG(I) = AV
6700     NEXT I
6710
6720    set color 6
6730   LET AV,SUBSQ = 0
6740     FOR I = 0 TO (4000 -smo/2)
6750    print tab (2,25),
6760    print ;4000 - i
6770       LET SUBSQ = 0
6780        FOR N = 0 TO smo/2
6790           LET SUBSQ = SUBSQ +  (DIGco(I+N)-CDco)^2
6800        NEXT N
6810           LET AV = ROUND(  SQR( SUBSQ / (smo/2))   ,2)
6820           LET DIGco(I) = AV
6830     NEXT I
6840
6850          LET DRMS,RMS  = 0
6860          FOR CH = 1 TO CYC-1
6870          LET RMS,N    = 0
6880          FOR PH = CLOSE(CH) TO OPEN(CH)
6890              LET RMS = RMS +( DIG(PH) ^2)
6900              let N = N +1
6910          NEXT PH
6920          LET DRMS = DRMS + SQR(RMS/N)
6930           NEXT CH
6940          LET DRMS = int(DRMS/(cyc-1) )
6950
6960
6970
6980
6990 END SUB  !DIGSMOOTH
7000    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
7010   SUB WAVEANAL   !!!!!!!!!!!!!!!!! WAVEANAL !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
7020 ! open #9:screen 0, 1, 0, .49          !graph
7030         MAT REDIM AGNsm(0:4000)
7040         MAT REDIM AGNact(0:4000)
7050  CALL PHASES(AGNsm(),NAOS())
7060   IF Act > 100 THEN                        !Act is the number of active values
7070       ! mat reDIM VERT(1)
7080       ! mat reDIM LAT(1)
7090        mat reDIM AGNco(1)
7100        mat redim AGNact(1)
7110        mat redim AGNsm(1)
7120   CALL WAVEFORM(AGNrw(),Act,D,AVINT,TURNS)
7130   dim fft(500)
7140    LIBRARY "B:FFTLIBE"
7150   !! CALL RUNFFT1(ti, N, NU, AGNrw(),XRE(), XIM(), FFTRE(), FFTIM(),TEMPRE(),TEMPIM())
7160    CALL RUNFFTA(HZF,ti, N, Act, AGNrw,FFT(),MEDFRE,PKFR1,PKFR2,PKFR3,PEAK1,PEAK2,PEAK3)
7170  ! GET KEY ZZ
7180   END IF
7190    END SUB !WAVEANAL
7200
7210   !!!!!!!!!!!!!!!!!!!!!  PHASE !!!!!!!!!!!!!!!!!!!!!!!!!!!
7220 SUB PHASES(AGNsm(),NAO$())
7230  LET SUBM,SUBMco,CM,CD = 0
7240  !   May need to correct zero offset, so..
7250    FOR I = 0 TO 500
7260     LET SUBM = SUBM + AGNrw(I)
7270     LET SUBMco = SUBMco + AGNco(I)
7280     NEXT I
7290   LET CM = SUBM/500              ! C is the zero offset
7300   LET CMco = SUBMco/500              ! C is the zero offset
7310 WINDOW # 8
7320 set color 7
```

```
7330 print tab (2,1),
7340   PRINT "SMOOTHING Agonists   "
7350    !now the data is rectified and smoothed using a 20 point window
7360   LET AV,SUBSQ = 0
7370     FOR I = 0 TO (4000 -smo)
7380    print tab (2,25),
7390    print ;4000 - i
7400       LET SUBSQ = 0
7410        FOR N = 0 TO smo
7420           LET SUBSQ = SUBSQ + abs(AGNrw(I+N)-CM)
7430        NEXT N
7440           LET AV = ROUND( SUBSQ / smo ,1)
7450           LET AGNsm(I) = AV
7460     NEXT I
7470 set color 6
7480   LET AV,SUBSQ = 0
7490     FOR I = 0 TO (4000 -smo)
7500    print tab (2,25),
7510    print ;4000 - i
7520       LET SUBSQ = 0
7530        FOR N = 0 TO smo
7540           LET SUBSQ = SUBSQ +abs(AGNco(I+N)-CMco)
7550        NEXT N
7560           LET AV = ROUND(SUBSQ / smo ,1)
7570           LET AGNco(I) = AV
7580     NEXT I
7590
7600  LET MINMAS = 100
7610      FOR I = 0 TO 4* zo    !looks for the mean initial resting level
7620       IF AGNsm(I)  < MINMAS THEN
7630        LET MINMAS = round(AGNsm(I),1)
7640        END IF
7650      NEXT I
7660 set color 7
7670 print tab (2,1),
7680   PRINT "Active EMG      ",
7690  LET Act,R = 0                          !phase starts at 1
7700    FOR N = 1 TO 4000
7710    print tab (2,25),
7720    print ;4000 - n
7730    IF  AGNsm(N) > MINMAS  + 20  THEN      !ABOVE REST
7740     LET Act = Act + 1         ! Act counts the active
7750     LET AGNact(Act) = N     ! an array of active data addreses
7760     LET AGNrw(Act) = AGNrw(N)  ! replace the raw with active data
7770    END  IF
7780   NEXT N
7790 PRINT TAB (2,40),
7800 PRINT "Act/Cy  ";Act/CYC,
7810 !!!!!!!!!!!!!!!!! Agonists - Antagonists; Ipsi - contra !!!!!!!!!!
7820
7830   IF Act > 100 THEN
7840     LET M_DG,Mco_DG,SUB,SUBco,DIFMMco,SUBINT,MSUB,MRMS,DIFMD,DIFMDCO  = 0
7850
7860        FOR N = 1 TO ACT
7870         LET M_DG = AGNsm(AGNact(n)) - DIG(AGNact(n))
7880         LET Mco_DG = AGNco(AGNact(n)) - DIGco(AGNact(N))
7890           LET SUB = SUB + M_DG
7900           LET SUBco = SUBco + Mco_DG
7910           LET DIFMMco =  AGNsm(AGNact(n)) - AGNco(AGNact(n))
7920           LET SUBINT  = SUBINT + DIFMMco
7930           LET MSUB = MSUB +( AGNsm(AGNact(N)) ^2)
7940        NEXT N
7950
7960    LET MRMS = INT(SQR(MSUB/act))
```

```
7970        if sub < 0 then
7980          let DIFMD = - int (sqr(abs(sub*hzf))/cyc)
7990        else if sub > 0 then
8000           LET DIFMD = INT(SQR(SUB*hzf)/cyc)
8010        end if
8020        if subco < 0 then
8030          let DIFMDco = - int (sqr(abs(subco*hzf))/cyc)
8040        else if subco > 0 then
8050           LET DIFMDco = INT(SQR(SUBco*hzf)/cyc)
8060        end if
8070         if SUBINT > 0   THEN
8080          LET DIFMMco = INT(SQR(subint*hzf)/CYC)
8090         else if SUBINT < 0  THEN
8100          LET DIFMMco = - INT(SQR(abs(subint*hzf))/CYC)
8110         end if
8120          LET DGAG,dgagco,Mres = 0
8130         !!!!!!!!!!!! digastric - agonist
8140     FOR CH = 1 TO CYC-1
8150          LET SUB,subco,SUBres,CNT     = 1
8160          FOR PH =  CLOSE(CH) + 10   TO OPEN(CH) -10
8170            LET SUB = SUB + DIG(PH) - AGNsm(PH)
8180            LET SUBco = SUBco + DIGco(ph) - AGNco(PH)
8190            LET SUBres = SUBres +( AGNsm(PH) ^2)
8200            LET CNT = CNT +1
8210          NEXT PH
8220          LET DGAG = DGAG + SUB
8230          LET DGAGco = DGAGco + SUBco
8240          LET Mres = Mres + SQR(SUBres/CNT)   !  Total / num
8250           NEXT CH
8260          LET MRES = INT(Mres/( cyc-1))
8270
8280               if dgag > 0 then
8290          LET DGAG = int( SQR(DGAG*hzf)/(cyc-1)     )
8300           else if dgag < 0 then
8310          LET DGAG = - int( SQR(abs(DGAG)*hzf)/(cyc-1)     )
8320                   end if
8330               if DGAGco > 0 then
8340          LET DGAGco = int( SQR(DGAGco*hzf)/(cyc-1)     )
8350           else if DGAGco < 0 then
8360          LET DGAGco = - int( SQR(abs(DGAGco*hzf))/(cyc-1)     )
8370          end if
8380 !!!!!!!!!!!!!!!!!!!!!!  Peak and Integrals of agonists !!!!!!!!
8390      LET MipSUB,McoSUB,MipPK,McoPK,ipco,Dt,IPint,COint = 0
8400    FOR CH = 1 to CYC-1
8410        LET MipMX,McoMX = 0
8420            LET agint,agcoint, hagint, hagcoint = 0
8430       FOR PH = OPEN(CH) TO CLOSE(CH+1)
8440            let agint = agint + (AGNsm(ph)*hzf)      !adds up the integral smoothed AGNsm
8450         IF AGNsm(PH) >  MipMX THEN
8460              LET MipMX = AGNsm(PH)
8470          END IF
8480
8490          let agcoint = agcoint +( AGNco(ph) *hzf)
8500         IF AGNco(PH) >  McoMX THEN
8510              LET McoMX = AGNco(PH)
8520          END IF
8530      NEXT PH
8540
8550       LET MipSUB = MipSUB + MipMX
8560       LET McoSUB = McoSUB + McoMX
8570           !!!!!! find the time point of half the integral
8580
8590       LET PH = OPEN(CH)
8600             do until  hAGint  > AGint / 2
```

```
8610            let ph = ph +1
8620            let hAGint = hAGint + ( AGNsm(PH)*hzf)
8630         loop
8640              LET IPt = PH
8650
8660       LET PH = OPEN(CH)
8670             do until  hAGcoint  > agCOint / 2
8680            let ph = ph +1
8690            let hAGcoint = hAGcoint + ( AGNco(PH)*hzf)
8700         loop
8710              LET COt = PH
8720              LET Dt  = Dt + IPt-COt
8730              LET IPint = Ipint + agint
8740              LET COint = COint + agcoint
8750   NEXT CH
8760       LET MipPK = int(MipSUB/(CYC-1))
8770       LET McoPK = int(McoSUB/(CYC-1))
8780       LET COint = int(sqr(COint/(CYC-1)))  !Coint = mean  int co-lat rms
8790       LET IPint = int(sqr(IPint/(CYC-1)))
8800           LET IPCO = round((Dt/cyc-1),2)
8810
8820  END IF     ! if act > 100
8830       If mus$ = "M" then
8840       set color 7
8850       else if mu$ = "T" then
8860       set color  2
8870       end if
8880 print tab(3,1),
8890 print MU$&"rst";Mres,
8900 print mu$&"rms";MRMS,
8910 print mu$&"int";Coint + Ipint,
8920 print mu$&"ip-co";DIFMMco,
8930 PRINT "DRMS" ;DRMS,
8940 print mu$&"-D";DIFMD,
8950 print "D-"&mu$;Dgag
8960 WINDOW # 9
8970 set window -10,4000,-10,+500
8980     set color 15
8990 for mv = 1 to 4000-1
9000    plot mv, AGNsm(mv);
9010 next mv
9020 plot mv,AGNsm(MV)
9030
9040    set color 10
9050 for mv = 1 to 4000-1
9060    plot mv, DIG(mv);
9070 next mv
9080    plot mv, DIG(mv)
9090
9100                      !Diff between AGNsm and AGNco
9110 for m = 1 to Act
9120   set color 12
9130   plot AGNact(m),AGNco(AGNact(m));AGNact(m), AGNsm(AGNact(m))
9140 next m
9150     IF cht$ = "Y" then                        ! AND MU$ = "M" then
9160   CALL CHARTFILE
9170     END IF
9180 plot lines: 1,Mres;4000,Mres
9190   END SUB !PHASES !!!!!!!!
9200                       !!!!!!!!!!!!!!!!!!! WAVEFORM !!!!!!!!!!!!!!!!!!!!!!
9210 SUB WAVEFORM(AGNrw(),Act,D,AVINT,TURNS)
9220       !! FRACTAL
9230   LET X, L, DD, D1, N, SUBD  = 0
9240   LET XI = -1
```

```
9250 LET XO = 0
9260 LET YO =  AGNrw(1)
9270 FOR i = 0 TO Act
9280   LET N =  N + 1
9290   LET XI = XI + 4
9300   LET X = XI + 4
9310  LET YI = (AGNrw(i))
9320   LET Y =  (AGNrw(i+1))
9330   LET D1 = SQR( (X - XO)^2 + (Y - YO)^2  )
9340 IF D1 > DD THEN
9350   LET DD = D1
9360  END IF
9370   LET L = L + SQR( (X - XI)^2 + (Y - YI)^2 )
9380  IF N > 1 THEN
9390   LET D = round(LOG(N) / ( LOG( N ) + LOG( DD / L ) ),3)
9400   END IF
9410 NEXT i
9420 LET D = ROUND(D,3)
9430
9440      !!!!!!!!!!!!! TURNS
9450 DIM PEAKS(1500)
9460  LET     PK,TU,TURNS,intV,AVINT = 0
9470   FOR N = 1 TO Act
9480     IF  AGNrw(n) > AGNrw(n-1) AND AGNrw(n) > AGNrw(n+1)  THEN
9490       LET PK = PK +1
9500       LET PEAKS(PK) = AGNrw(N)
9510     END IF
9520  NEXT n
9530  FOR N = 1 TO PK
9540    IF ABS(PEAKS(N+1) - PEAKS(N) ) > 25 THEN
9550     LET TU = TU +1
9560     LET INTV = INTV + ABS( PEAKS(N+1) - PEAKS(N))
9570    END IF
9580  NEXT N
9590 LET AVINT = int(INTV/TU)           !AVERAGE TURN INTERVAL
9600 LET TURNS =  ROUND( TU /10 ,1)      ! 10 SECONDS OF DATA
9610
9620 ! The active phases of the data are collected together adjacent to each other
9630 WINDOW #8
9640 PRINT TAB (4,1),
9650 print "avint ";avint,
9660 print "frac " ;d,
9670
9680 MAT PEAKS = 0
9690 let runt = time - start
9700 END SUB !WAVEFORM              !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
9710     !!!!!!!!!!!!!!!!!!!!!!!!!!!!! SUB OUTPUT  !!!!!!!!!!!!!!!!!!!!!!!!!!!!
9720 SUB OUTPUT(NAOS())
9730  !let actv  = round(act*hzf/cyc)
9740  LET NAOS(1) = "b:\" & N$ & SIDE$ & mu$ &".OUT"
9750 IF outS = "PRINTER" THEN
9760   open #2: printer
9770   set #2: zonewidth 7
9780 !print#2:
N$&SIDE$&MU$,cyc,opav,widAV,Mres,MRMS,IPint,MipPK,COint,McoPK,ACTv,DRMS,DIFMD,DIFMMco,dgag,ipco,M
EDFRE,avint,SWAC,SWANG,CLAC,SWSTDA,CLANG,D
9790 print #2: N$&SIDE$&MU$,opav,dev,SWAC,SWANG,SWSTDA,CLAC,CLANG
9800 ELSE if outS = "FILE" then
9810   OPEN #2: NAME NAO$(1),organization text, create new
9820   set #2: zonewidth 7
9830   SET # 2: MARGIN 250
9840   set #2: zonewidth 10
9850 !PRINT#2:
"File","cyc"."opav","wdav",mu$&"rst",MU$&"rms",mu$&"int",MU$&"mx",Mu$&"pint",MU$&"pmx",mu$&"actv","drms",
```

```
mu$&"-dg",mu$&"p_dg", mu$&"-mc","dg_"&mu$,"dg_p"&mu$,mu$&"ipco",mu$&"mdfr",mu$&"turn"
9860 !print #2:
N$&SIDE$&MU$,cyc,opav,widAV,Mres,MRMS,IPint,MipPK,COint,McoPK,ACTv,DRMS,DIFMD,DIFMDco,DIFMMco,d
gag,DGAGCO,ipco,MEDFRE,avint
9865  PRINT #2: "File","cyc","opav","wdav","ang","bimo","mop"
9870  print #2: N$&SIDE$&MU$,cyc,opav,widAV,ANGLE,BIMO,moper
9880  end if
9890
9900 close #2
9910 END SUB !OUTPUT
9920  !!!!!!!!!!!!!!!!!!!!!!!!!!!!  CHARTFILE
9930  SUB CHARTFILE
9940  LET NAO$(2) = "c:\emg\cht\" & N$ & SIDE$ & mu$ & ".CHT"
9950  open # 2:NAME NAO$(2),ORGANIZATION TEXT,CREATE NEW
9960  PRINT #2:"AGNsm","AGNco","DIG","Vert"
9970  FOR N = 1500 TO 2500
9980  PRINT #2:AGNsm(N),AGNco(N),DIG(N), vert(n),LAT(N)
9990  NEXT N
10000  CLOSE #2
10010
10020  END SUB
10030 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
10040  SUB BIMODE
10050                    !! MAKING A FREQUENCY MATRIX
10060    DIM LMODE(40)
10070    DIM FMODIS(40,2)
10080    DIM LFRE(0:40,40)
10081    MAT LFRE = 0
10082    MAT LMODE = 0
10083    MAT FMODIS = 0
10090    WINDOW #8
10100    set window -20,60,-30,5
10110    let m = 50              ! %  of the mode
10120        FOR N = 1  TO 4000
10130        LET LFRE(INT(ABS(VERT(N))),INT(LAT(N)+20)) = LFRE(INT(ABS(VERT(N))),INT(LAT(N)+20)) + 1
10140        NEXT N
10150
10160     LET Z = 3
10170
10180    LET MOPER, BIMO,A = 0
10190  FOR S = 1 TO 30
10200              LET DIV, BI = 0
10210              LET totfre = 0
10220              LET LOWPT = 0
10230              LET LOWFRE = 0
10240              LET LTOTFRE = 0
10250              LET RTOTFRE = 0
10260              LET MODE1 = 0
10270        ! First we calcualte the first mode and the total fre for eacg level
10280     FOR I = 1 TO 40
10290        IF LFRE(S,I) > MODE1 THEN
10300          LET MODE1 = LFRE(S,I)
10310          LET FMODIS(S,1) = I    ! THE position of the mode
10320         END IF
10330         LET totfre = totfre + lfre(s,i)
10340     NEXT I
10350          IF MODE1 > 0 THEN
10360             LET A = A +1
10370             LET MOPER = MOPER + MODE1/TOTFRE
10380             LET LMODE(S) = MODE1    ! The mode
10390          END IF
10400         IF S < 15 THEN
10410         LET Z = Z + .33       ! Z peaks at 7 at level 15
10420          ELSE IF S > 15 THEN
```

```
10430         LET Z = Z -.33
10440       END IF
10450
10460  FOR I = 1 to 40     ! looking for second mode
10470      IF LFRE(S,I) > (.5 * MODE1) AND  (FMODIS(S,1) + Z) < I  THEN
10480         LET FMODIS(S,2) = I
10490      ELSE  IF LFRE(S,I) > (.5 * MODE1) AND  (FMODIS(S,1) - Z) > I  THEN
10500         LET FMODIS(S,2) = I
10510       LET BIMO = BIMO + 1      !counts bimode freq
10520      END IF
10530 NEXT I
10540  NEXT S
10550  LET MOPER = round(MOPER/A * 100,1)
10560   LET BIMO  = round(BIMO/A * 100,1)
10570  PRINT "Moper ";moper
10580  PRINT "Bimo   ";bimo
10590
10600                !!!!!!!!! ANGLE !!!!!!!!!!!!!!
10610       !finding freq centre on chewing side
10620    LET SUBMOD,X,Y = 0
10630
10640    IF SIDES ="L" THEN
10650      LET SI = 20
10660
10670    ELSE IF SIDES = "R" THEN
10680      LET SI = 10
10690    END IF
10700
10710  FOR S = 1 TO 10
10720     LET MODIS,MODE1 = 0
10730    FOR I = SI TO SI+10
10740       IF LFRE(S,I) > MODE1 THEN
10750         LET MODE1 = LFRE(S,I)
10760         LET MODIS = I     ! THE position of the mode
10770       END IF
10780    NEXT I
10790     LET SUBMOD = SUBMOD + MODIS
10800   NEXT S
10801
10802     LET X = SUBMOD/10
10820
10830       LET SUBMOD = 0
10840  FOR I = SI TO SI+10
10850        LET MODIS,MODE1 = 0
10860    FOR S = 1 TO 10
10870     IF LFRE(S,I) > MODE1 THEN
10880        LET MODE1 = LFRE(S,I)
10890        LET MODIS = S     ! THE position of the mode
10900     END IF
10910    NEXT S
10920      LET SUBMOD = SUBMOD + MODIS
10930  NEXT I
10940      LET Y = SUBMOD/10
10960      OPTION ANGLE DEGREES !!!!!!!!!!!!!!!!
10970      LET Xc = 20
10980   IF X > Xc THEN     ! ie on the plus >20 side of centre
10990      LET ANGLE = INT(ATN(Y/(X-Xc)))
11000    ELSE  IF X < xC THEN
11010      LET ANGLE = int(ATN(Y/(Xc-X)))
11012    ELSE IF X = Xc THEN
11013      LET ANGLE = 90
11020   END IF
11030       PRINT "Angle  ";angle
11040 !!!!!!!!!!!!!!!!!!!!! plotting!!!!!!!!!!
```

```
11050          SET COLOR 10                    !green
11060          box LINES -.3, .3, -.3, .3
11070          box keep -.3, .3,-.3, .3 in box1$
11080          SET COLOR 4
11090          BOX AREA -.3,.3,-.3,.3
11100          BOX KEEP -.3, .3,-.3, .3 in box2$
11110          SET COLOR 15
11120 FOR S = 1 TO 37
11130   FOR I = 1 TO 40
11140       IF LFRE(S,I) > 0 THEN
11150         SET COLOR 15
11160         PLOT I , -S
11170        END IF
11180   NEXT I
11190 NEXT S
11210 FOR S = 1 TO 37
11220   FOR I = 1 TO 40
11230      IF LFRE(S,I) > (LMODE(S) * M/100) THEN
11240            set color 10
11250        plot I ,-S
11260       END IF
11270   NEXT I
11280      IF FMODIS(S,1) > 0 THEN
11290       BOX SHOW BOX2$ AT FMODIS(S,1) ,-S
11300      END IF
11310  NEXT S
11320   SET COLOR 7
11330   PLOT 20,-30;20,0
11332   PLOT 15,0;25,0
11335   SET COLOR 15
11340   plot X,-Y;20,0
11360  END SUB
11370 END ! PROGRAM
```

ACCELAN

Analysis of acceleration

```
1010 ! close is defined as pt Q and opcl and clop 1mm open
1040  !REST IS CLOSE + 100 TO OPEN - 50
1220
1230
1240    DIM XRE     ( 1 )
1250    DIM XIM     ( 1 )
1260    DIM FFTRE   ( 1 )
1270    DIM FFTIM   ( 1 )
1280    DIM TEMPRE  ( 1 )
1290    DIM TEMPIM  ( 1 )
1300    DIM IBR     ( 1 )
1310    DIM KOS     ( 1 )
1320    DIM ZIN     ( 1 )
1330    DIM VERT(1)
1340    DIM pro(1)
1350    DIM LAT(1)
1360    DIM OPEN(40)      ! an address of maximum opening
1370    DIM OPCL(40)      ! an address of PTS IMM SHORT OF I.C.
1380    DIM CLOP(40)      ! an address "     "      "     "
1390    DIM CLOSE(40)      ! an address of INTERCUSPATION
1400    DIM VELO(1)
1410    DIM ACCL(1)
1420    DIM ACFFT(1)
1430
1440 DIM NAI$(1)
1450 DIM NAO$(2)
```

```
1460 DIM NAME$(100)
1470 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1480  set mode "ega"
1490
1500 DO
1510  CALL DEFAULTS
1520  CALL BANNER
1530  IF def$ =  "R" then
1540  CALL  SETUP
1550   IF OUT$ = "PRINTER" THEN
1560      open#2:printer
1570      set #2: zonewidth 7
1590      close #2
1600  end if
1610  ELSE IF DEF$  = "C" THEN
1620   IF OUT$ = "PRINTER" THEN
1630      open#2:printer
1640      set #2: zonewidth 7
1650   PRINT #2: "File"."vf","af","mac","stdac","ma","stda","medf","pkfr"
1670      close #2
1680  end if
1690  END IF
1700                    ! for 22 sec =227 hz so x 4.4
1710  IF EXT$ = ".STD" THEN
1720     let smo = 10    ! for the length of the smooth window
1730     let zo = 50  !70  ! 100 for the zone around reversal points
1740     let hzf = 3.15    !  5000 /15 sec  = 333 hz so * 2048 = 3.07
1750  ELSE IF EXT$ = ".TRB" THEN
1760     let smo = 20
1770     let zo = 300
1780      let hzf = 1.28    ! 5000 in 6.2 sec = 806 hz so x 2048 = 1.26
1790 END IF
1800  CALL NAMESIN
1810    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!! LOOPS AFTER THE LAST NAME(nm)
1820 FOR File = 1 TO NM-1  ! ( THE LAST ONE IS Z!)
1830 LET N$ = NAMES(File)
1840  ! GET KEY ZZ
1850 FOR S = 2 TO 3      ! NORMALLY 2 TO 3 DOES LEFT AND RIGHT ONLY
1860  if s = 1 then
1870   LET SIDE$ = "W"
1880  else if s = 2 then
1890   LET SIDE$ = "L"
1900  else if s = 3 then
1910  LET SIDE$ = "R"
1920  END IF
1930  open #8:screen 0, 1, .49, 1            !text
1940  open #9:screen 0, 1, 0, .48            !graph
1950 set mode "ega"
1960       LET MU$ = "M"
1970 MAT REDIM VERT(0:4096)
1980 MAT REDIM pro(0:4096)
1990 MAT REDIM LAT(0:4096)
2000  CALL INMAS
2010  CALL CYCLES
2020
2030  close #9
2040  close #8
2050        LET CRSF = 1 ! close train goes open(n) to close(n +1)
2060 CALL
ACCEL(VELO(),ACCL().ACFFT(),OPEN(),close(),CRSF,LAT(),VERT(),PRO(),DT,HZF,f,CYC,CLmac,CLSTDac,CLma,C
LSTDa,CLpeak1,CLpeak2.CLpeak3,CLfr1,CLfr2,CLfr3,CLmedfr,CLmv,CLmvsd)
2070        LET CRSF = 0  ! Open train
2080 CALL
ACCEL(VELO(),ACCL().ACFFT(),CLOSE(),OPEN(),CRSF,LAT(),VERT(),PRO(),DT,HZF,f,CYC,OPmac,OPSTDac,OPma,
```

```
OPSTDa,OPpeak1,OPpeak2,OPpeak3,OPfr1,OPfr2,OPfr3,OPmedfr,OPmv,OPmvsd)
2090    CALL OUTPUT(NAO$())      ! AT 9810
2100 !  GET KEY ZZ
2110 NEXT S      !SIDE
2120  ! get key zz
2130 NEXT File       !FILE
2140 LOOP
2150
2160
2170                                      !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2180 !!!!!!!!!!!!!!!!!!!!!!!!!!!! DEFAULTS
2190  SUB DEFAULTS
2200
2210  LET DRIVE$ = "c:\emg\std\"
2220  LET EXT$ = ".STD"              ! REMENBER MUST BE CAPS!
2230  LET OUT$  = "FILE"
2240  let cht$ = "N"
2250  ! smo 20,40 and zo (60,250) are defined at 1800
2260  LET DT = 40
2270   LET SECT = 0    !     SECT = 0 FOR THE FIRST 4096 DAT POINTS
2280  end sub            ! SET FFT AT 7150
2290 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!  BANNER
2300  SUB BANNER
2310
2320  OPEN #7:SCREEN 0,.91,.45,.95 !  Text
2330  WINDOW #7
2340  set window 0,10,0,10
2350  set zonewidth 7
2360  SET BACK  1
2370  set color 7
2380 plot  2.5,7.5;  2.5,2;  7.5,2;  7.5,7.5;  2.5,7.5
2390  SET COLOR 6
2400  print tab (1,34);
2410  PRINT"EMG  ANALYSIS"
2420  print tab (2,25);
2430  print"Wilding/Morrison; May 1994"
2440  print tab (4,35);
2450  PRINT "Defaults";
2460  print tab (5,20);
2470 print "1. Drive for data = "; DRIVE$
2480  print tab (6,20);
2490 PRINT "2. Data will  be sent to  ";OUT$
2500  print tab (7,20);
2510 PRINT "3. Will chartfile  be made ?  " ;cht$
2520  print tab (8,20);
2530 PRINT "4. The EMG sample rate was  ";EXT$
2540  print tab (11,25);
2550 Input prompt "Press C to continue, R to reset ":def$
2560 let def$ = ucase$(def$)
2570 END SUB ! BANNER                          !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2580
2590 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!  SETUP
2600  SUB SETUP
2610  SET BACK  1
2620  SET COLOR 6
2630  DO
2640 DO
2650  CLEAR
2660 LET X1 = 2   ! left
2670 LET X2 = 9.5 ! left
2680 LET Y1 = 3   ! bottom
2690 LET Y2 = 8 ! top
2700 PLOT X1,Y1 ; X2,Y1 ; X2,Y2 ; X1,Y2 ; X1,Y1
2710  print tab (1,34);
```

```
2720 PRINT " New defaults ",
2730  print tab (3,20);
2740 print "1. Drive for input file................ "
2750  print tab (4,20);
2760 print "2. Extension for input file............ "
2770  print tab (5,20);
2780 print "3. Data to printer (P) or file(F) ?.... "
2790  print tab (6,20);
2800 print "4. Chartfile ? (Y/N)................... "
2810  print tab (7,20);
2820 !print "5. EMG data  ""STD"" or ""TRB"" ?.... "
2830 ! print tab (9,20);
2840
2850  print tab (3,60);
2860 input prompt "":drive$
2870  print tab (4,60);
2880 input prompt "":ext$
2890  print tab (5,60);
2900 input prompt "":ans$
2910  print tab (6,60);
2920 input prompt "":cht$
2930 ! print tab (7,60);
2940 ! input prompt "":EXT$
2950   LET ANS$ = UCASE$( ANS$)
2960  IF ANS$ = "F" THEN
2970     LET OUT$ = "FILE"
2980   ELSE IF ANS$ = "P" THEN
2990     LET OUT$   = "PRINTER"
3000   ELSE
3010    PRINT,,,,,,,, "TRY AGAIN!"
3020    PAUSE 2
3030   END IF
3040 LOOP UNTIL ANS$ = "P" OR ANS$ = "F"
3050
3060 LET cht$ = UCASE$(cht$)
3070 LET MU$ = UCASE$(MU$)
3080 SET COLOR 14
3090  print tab (10,20);
3100 Input prompt "Press C to continue, R to reset ":er$
3110 let er$ = ucase$(er$)
3120 LOOP UNTIL ER$ = "C"
3130
3140  END SUB !SETUP                  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3150
3160 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3170 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!  NAMESIN
3180  SUB NAMESIN
3190
3200 CLEAR
3210  SET COLOR 6
3220 PRINT TAB(3,20),
3230 INPUT PROMPT "Data input via the keyboared (Y/N) ? ":DATA$
3240 LET DATA$ = UCASE$(DATA$)
3250 IF DATA$ = "Y" THEN
3260 CLEAR
3270 DO
3280     LET NM = 0
3290       PRINT" Type file names (example ""AB1""), without .ext or side and press RETURN"
3300      PRINT TAB(7,10),
3310       PRINT "To end press  Z, then press C to continue or R to correct"
3320      DO
3330       LET NM = NM + 1
3340       !PRINT TAB ( INT( (12 + NM)/10 ) ,(NM*5));
3350       PRINT TAB (2.1)
```

```
3360     OPEN #10: SCREEN .92,1,.96,1
3370       INPUT PROMPT"" :nam$
3380     CLOSE #10
3390       print tab (5,10),
3400       let nam$ = ucase$(nam$)
3410       LET NAME$(NM) = NAM$
3420        set zonewidth 7
3430       MAT PRINT NAME$
3440     LOOP UNTIL NAM$ =  "Z"   ! space
3450  INPUT PROMPT "Continue ? ":AN$
3460   LET AN$ = UCASE$(AN$)
3470 LOOP UNTIL AN$ = "C"
3480
3490 ELSE  IF DATA$ = "N" THEN
3500
3510 LET nm = 0
3520 DO WHILE MORE DATA
3530  LET NM = NM + 1
3540  READ NAM$
3550  LET NAME$(NM) = NAM$
3560 LOOP
3570 print tab(5,10)
3580 MAT PRINT NAME$
3590 print tab(9,20),
3600 PRINT " If this is okay, press any key to continue..."
3610 print tab(10,20),
3620 PRINT " otherwise CTRL BREAK to input names"
3630 !!!!!!!!!!!!!!!!!!!!!!!!!          DATA          !!!!!!!!!!!!
3640 ! data kd,cn,bh
3650 ! data BB,cj,et,gdt,gf,je,jt,jw,MK
3660 ! data ms1,msh,nr,rc,rm,rw,ss,tr
3670 ! data rw,ss          ! tv,sn
3680
3690 ! data AO11, AO12, AO13, AO21
3700 ! DATA  FA11, FA12, FA13, FA21, FA23, GM11
3710 ! data  HC11, HC12, HC13, HC21, HC22, HC23, JH11, JH12, JH13, JM11
3720 ! data  LM11, RT11, RT12, RT13
3730 ! data PP11, PP12, PP13, RU11
3740 ! data  RU13, MS11, MS12, MS13, FA31
3750 ! data vb7
3760   DATA CH,sn,mp1
3770 DATA Z
3780 END IF   !DATA$ = ?
3790 close #7
3800  END SUB !NAMESIN
3810 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3820
3830 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!   INMAS !!!!!!!!!!!!!!!!!!!
3840 SUB INMAS
3850
3860   LET NAI$(1) = DRIVE$ & N$ & side$ & EXT$
3870  CLEAR
3880
3890  OPEN #1: NAME NAI$(1)
3900    WINDOW #8
3910   set window 0,1,0,1
3920   SET BACK 0
3930   SET #8 :ZONEWIDTH 7
3940   SET COLOR 7
3950 PRINT TAB (1,55),
3960 PRINT N$ & SIDE$ & mu$
3970   LET an,T,N = 0
3980    FOR DA = 1 TO  5
3990     LINE INPUT #1:DATA$
```

```
4000     IF DA = 2 THEN
4010     LET TRIALS = DATA$
4020     END IF
4030    NEXT DA
4040
4050
4060    LET minop = 0        ! Finds the vertical zero offset
4070    LET MINMAS = 100
4080    LET A = 0
4090   DO
4100   LET N  =  N + 1
4110     IF N > SECT * 4096 THEN    ! SECT set in setup
4120     LET A = A + 1
4130        END IF
4140
4150
4160 PRINT TAB (1,65),
4170   print ;INT( (4096 - A)/100)
4180      LINE INPUT #1: DATA$                    ! UP TO THESE COMAS
4190      LET CPOS1 = POS(DATA$,",",1)               ! vertical
4200      LET CPOS2 = POS(DATA$,",",CPOS1+1)           !ap
4210     LET CPOS3 = POS(DATA$,",",CPOS2+1)          !lateral
4220      LET CPOS4 = POS(DATA$,",",CPOS3+1)          !velo
4230      LET CPOS5 = POS(DATA$,",",CPOS4+1)          ! R temporalis
4240      LET CPOS6 = POS(DATA$,",",CPOS5+1)          ! R MASSETER
4250      LET CPOS7 = POS(DATA$,",",CPOS6+1)          ! L masseter
4260      LET CPOS8 = POS(DATA$,",",CPOS7+1)          ! L TEMP
4270      LET CPOS9 = POS(DATA$,",",CPOS8+1)          !
4280     LET CPOS10= POS(DATA$,",",CPOS9+1)          !CH 6
4290     LET CPOS11= POS(DATA$,",",CPOS10+1)          !CH 7
4300
4310      let vert$ = data$[1:(CPOS1-1)]
4320      let pro$ = data$[(CPOS1+1):(CPOS2-1)]
4330      let lat$ = data$[(CPOS2+1):(CPOS3-1)]
4340      let VEL$ = data$[(CPOS3+1):(CPOS4-1)]
4350
4360       let massR$ = data$[(CPOS5+1):(CPOS6-1)]
4370       let massL$ = data$[(CPOS6+1):(CPOS7-1)]
4380
4390      let maspoR$ = data$[(CPOS8+1):(CPOS9-1)]    !R POST MASS
4400      let digR$ = data$[(CPOS9+1):(CPOS10-1)]
4410      let digL$ = data$[(CPOS10+1):(CPOS11-1)]
4420      let maspoL$ = data$[(CPOS11+1):(CPOS11+5)]    !NO COMMA AFTER LAST VALUE
4430   LET VERT(A) = VAL(VERT$)
4440   LET PRO(A) = VAL(PRO$)
4450   LET LAT(A) = VAL(lat$)
4460     IF vert(A) < minop THEN     ! TO FIND THE OFFSET FROM ZERO
4470     LET minop = vert(A)
4480     End If
4490 IF SIDE$ = "W" THEN
4500 !  LET AGNrw(A) = VAL(massL$)
4510 !  LET DIG(A) = VAL(massR$)
4520 !  LET DIGco(A) = VAL(massL$)
4530 !  LET AGNco(A) = VAL(massR$)
4540 ELSE IF SIDE$ = "L" THEN
4550 !  LET AGNrw(A) = VAL(massL$)
4560 !  LET DIG(A) = VAL(digL$)
4570 !  LET DIGco(A) = VAL(digR$)
4580 !  LET AGNco(A) = VAL(massR$)
4590 ELSE IF SIDE$ = "R" THEN
4600 !  LET AGNrw(A) = VAL(massR$)
4610 !  LET DIG(A) = VAL(digR$)
4620 !  LET DIGco(A) = VAL(digL$)
4630 !  LET AGNco(A) = VAL(massL$)
```

```
4640  END IF
4650 LOOP until A =  4096
4660    CLOSE #1
4670 print
4680 END SUB  !INMAS
4690 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
4700
4710     !!!!!!!!!!!!!!!!!!!!!!!! CYCLES !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
4720 SUB CYCLES            !called at 2110
4730 mat open = 0
4740 mat close = 0
4750
4760 FOR N = 1 TO 4096
4770 LET vert(N) = - (vert(N) - minop)            !MIN IS TH EOFFSET FROM ZERO
4780 NEXT N
4790     LET SUBMN,OPAV,WIDAV,MX = 0
4800     LET CLOSE(1) = 1
4810     LET CYC = 0
4820  FOR N = zo +1 TO (4096 - zo )    !!!!!!!!!!seeking close points
4830      LET MN = -10
4840        IF VERT(N) >  (VERT(N+zo)+1) AND VERT(N) > VERT(N-zo)  THEN
4850          FOR Q = N TO N+zo
4860            IF VERT(Q) > MN THEN
4865                 LET CL = Q
4870             LET MN = VERT(Q)
4890            END IF
4900          NEXT Q
4940               LET N = N + 2*ZO
4942               LET CYC  = CYC + 1
4945               LET CLOSE(CYC) = CL      !CLOSE is an array of addresses
4960        END IF
4970   NEXT N
5160
5170 LET SUBMX,subd = 0                  !!!!!!!!!!!!  seeking open points
5180 IF CYC > 0 THEN
5190 FOR PH = 1 TO CYC
5200  LET MX = 0
5210   FOR N = CLOSE(PH) TO CLOSE(PH+1)
5220    IF VERT(N) < MX THEN
5230     LET MX = VERT(N)
5240     LET OPEN(PH) = N             !OPEN  ia na array of addreses
5250     let d = lat(n) ! the lateral deviation at opening
5260    END IF
5270   NEXT N
5280  let subd = subd + d
5290   LET SUBMX = SUBMX + MX
5300 NEXT PH
5310 LET OPAV = abs(ROUND(SUBMX/(CYC),1))
5320 LET DEV = ROUND(SUBD/(CYC),1)
5330  !!!!!!!!!!!!!!!!  Seeking lateral displacements
5340
5350 LET N,SUBLAT,MAXLAT,MINLAT = 0
5360 FOR  L = 1 TO CYC-1
5370   LET MAXLAT = 0
5380  FOR N = CLOSE(L) TO CLOSE(L+1)
5390   if side$ = "L" then
5400     IF LAT (N) > MAXLAT THEN ! negative displacemetns to the left
5410      LET MAXLAT = LAT(N)
5420     END IF
5430   else if side$ = "R" then
5440  IF LAT (N) < MAXLAT THEN   ! POSITIVE DISPL TO THE RIGHT
5450    LET MAXLAT = LAT(N)
5460    END IF
5470   end if    ! if side$ =
```

```
5480  NEXT N
5490  LET SUBLAT = SUBLAT + ABS(MAXLAT)
5500 NEXT L
5510 LET WIDAV = ROUND(SUBLAT/(CYC),1)
5520   END IF ! CYC > 0
5530  set back 0
5540 WINDOW # 9
5550   clear
5560 set window -10,4096,-10,+500
5570   set color 1
5580   box area -10,4096,-10,500
5590  set color 13
5600 for n = 1 to 4096
5610 plot n,(500 + 20 *vert(n));      !default is 10
5620 next n
5630 PLOT
5640   SET COLOR  14
5650 for n = 1 to 4096 STEP DT
5660 plot n,(500 + 20 *vert(n))      !default is 10
5670 next n
5680  set color 15
5690       for cy = 1 to cyc
5700       plot close(cy),(500 +20*vert(close(cy)));close(cy),(500 +20 *vert(close(cy)))
5710       plot open(cy),(500 +20*vert(open(cy)));open(cy),(550 +20 *vert(open(cy)))
5720       next cy
5721
5730 PRINT "CYCLES "; CYC
5740 PLOT
5750 SET COLOR 0
5760 PLOT 0,400;4096,400
5770 PLOT
5780  set color 11
5790 for n = 1 to 4096
5800 plot n,(400 + 20 *LAT(n));    !  default is 5
5810 next n
5820 ! GET KEY ZZ
5830 END SUB ! CYCLES
5840 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
5850     !!!!!!!!!!!!!!!!!!!!!!!!!!! SUB OUTPUT  !!!!!!!!!!!!!!!!!!!!!!!!!
5860 SUB OUTPUT(NAO$())
5870  !let actv  = round(act*hzf/cyc)
5880  LET NAO$(1) = "C:\EMG\" & N$ & SIDE$ & mu$ &".OUT"
5890 IF out$ = "PRINTER" THEN
5900   open #2: printer
5910   set #2: zonewidth 7
5920 print #2: N$&SIDE$&MU$,opav,dev,vf,af,mac,stdac,ma,stda,medfre,PKFR1,pkper
5930 ELSE if out$ = "FILE" then
5940   OPEN #2: NAME NAO$(1),organization text, create new
5950   set #2: zonewidth 7
5960   SET # 2: MARGIN 500
5970   set #2: zonewidth 8
5980   PRINT #2: "File","a","asd","ang","angsd","pk1","pk2","pk3","fr1","fr2","fr3","medf","vel","velsd",
5990   PRINT #2: "aC","asdC","angC","angsdC","pk1C","pk2C","pk3C","fr1C","fr2C","fr3C","medfC","velC","velsdC"
6000 print #2:
N$&SIDE$&MU$,OPmac,OPstdac,OPma,OPstda,OPpeak1,OPpeak2,OPpeak3,OPfr1,OPfr2,OPfr3,OPmedfr,OPmv,OPmvsd,
6010  print #2: CLmac,CLstdac,CLma,CLstda,CLpeak1,CLpeak2,CLpeak3,CLfr1,CLfr2,CLfr3,CLmedfr,CLmv,CLmvsd
6020  end if
6030
6040 close #2
6050 END SUB !OUTPUT
6060  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!  CHARTFILE
6070  SUB CHARTFILE
6080  LET NAO$(2) = "b:" & N$ & SIDE$ & mu$ & ".CHT"
6090  open # 2:NAME NAO$(2),ORGANIZATION TEXT,CREATE NEW
```

```
6100  SET # 2: MARGIN 250
6110  PRINT #2:"Vert","VELO","ACCL","ACFFT"
6120  FOR N = 1 TO 4096
6130  PRINT #2: vert(n),VELO(N),ACCL(N),ACFFT(N)
6140  NEXT N
6150  CLOSE #2
6160
6170  END SUB
6180 END ! PROGRAM
6190 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
6200
6210 SUB
ACCEL(VELO(),ACCL(),ACFFT(),START(),FINISH(),CRSF,LAT(),VERT(),PRO(),DT,HZF,F,CYC,mac,STDac,ma,STDa,p
eak1,peak2,peak3,PKfr1,PKfr2,PKfr3,medfre,mv,STDv)
6220     OPTION ANGLE DEGREES
6230
6240     OPEN #8:SCREEN 0,1,.49,1
6250     WINDOW # 8
6260      clear
6270      set window 0,4096,-400,400
6280      MAT REDIM VELO(0:4096)
6290      MAT REDIM ACCL(0:4096)
6300      LET MEANac.MEANa,MEANv,ac,an,V,SUBac,SUBa,SUBv  = 0
6310          LET F,C, c120.c60,c5 = 0
6320   FOR PH = 2 TO CYC -2
6330
6340   FOR N =  START(PH) TO FINISH(PH+CRSF)                        !+ 50
6350        LET VX0,VY0,vz0,VXYZ,AX,AY,AZ,AXZ,AXYZ = 0
6360        LET VX1,VY1,vz1,ang,angrat = 0
6370      LET F = F +1
6380        let vX1= ABS(LAT(N+dt) - LAT(N))/(hzf*dt)
6390        let vY1= ABS(VERT(N+dt) - VERT(N))/(hzf*dt)
6400        let vZ1= ABS(PRO(N+dt) - PRO(N))/(hzf*dt)
6410        let vX0 =ABS (LAT(N-dt) - LAT(N))/(hzf*dt)
6420        let vY0 =ABS (VERT(N-dt) - VERT(N))/(hzf*dt)
6430        let vZ0 =ABS (PRO(N-dt) - PRO(N))/(hzf*dt)
6440       let vXYZ =  sqr( vX1 ^2   + vZ1 ^2 +   vz1 ^2)
6450
6460        let aX = (vx1 - vx0)/(hzf*dt)
6470        let aY = (vY1 - vY0)/(hzf*dt)
6480        let aZ = (vZ1 - vZ0)/(hzf*dt)
6490      IF AX > 0 AND AZ > 0 THEN
6500       let AXZ =  sqr( Ax ^2   + AZ ^2 + z   )          ! + .5
6510       let ang = 90 - atn(AZ/(ax))
6520        ELSE IF AX < 0 AND AZ > O THEN
6530              IF ABS(AX) > ABS(AZ) THEN
6540            let AXZ = - sqr( Ax ^2   + AZ ^2 + z)   ! + .5
6550              ELSE
6560            let AXZ = + sqr( Ax ^2   + AZ ^2 + z)   !  + .5
6570              END IF
6580          let ang = 270 + atn(AZ/(ax))
6590      ELSE IF AX > 0 AND AZ < O THEN
6600              IF ABS(AX) > ABS(AZ) THEN
6610            let AXZ = + sqr( Ax ^2   + AZ ^2 + z)   ! + .5
6620              ELSE
6630            let AXZ = - sqr( Ax ^2   + AZ ^2 + z)    ! + .5
6640              END IF
6650          let ang = 90 + atn(AZ/(ax))
6660     ELSE IF AX < 0    AND AZ < 0 THEN
6670          let AXZ = - sqr( Ax ^2   + AZ ^2 + z)          !  + .5
6680          let ang = 270 - atn(AZ/(ax))
6690       ELSE IF AX = 0 AND AZ <> 0 THEN
6700          let AXZ = AZ
6710          let ang =  90
```

```
6720      ELSE IF AZ = 0 AND AX <> 0 THEN
6730        let AXZ = AX
6740        let ang =  0
6750    END IF   ! AX>0   ! was at 7180
6760
6770   IF AXZ > 0 AND AY > 0 THEN
6780     let AXYZ =  sqr( AxZ ^2   + AY ^2  )          ! + .5
6790     let ang = 90 - atn(AY/(axZ))
6800        LET C = C +1                 !will count ,including zeros
6810   ELSE IF AXZ < 0 AND AY > O THEN
6820        LET C = C +1                 !will count ,including zeros
6830            IF ABS(AXZ) > ABS(AY) THEN
6840          let AXYZ = - sqr( AxZ ^2   + AY ^2 + z)   ! + .5
6850            ELSE
6860          let AXYZ = + sqr( AxZ ^2   + AY ^2 + z)   !  + .5
6870            END IF
6880         let ang = 270 + atn(AY/(axZ))
6890   ELSE IF AXZ > 0 AND AY < O THEN
6900        LET C = C +1                 !will count ,including zeros
6910            IF ABS(AXZ) > ABS(AY) THEN
6920          let AXYZ = + sqr( AxZ ^2   + AY ^2 + z)   ! + .5
6930            ELSE
6940          let AXYZ = - sqr( AxZ ^2   + AY ^2 + z)    ! + .5
6950            END IF
6960         let ang = 90 + atn(AY/(axZ))
6970    ELSE IF AXZ < 0   AND AY < 0 THEN
6980        LET C = C +1                 !will count ,including zeros
6990         let AXYZ = - sqr( AxZ ^2   + AY ^2 + z)        !  + .5
7000         let ang = 270 - atn(AY/(axZ))
7010    ELSE IF AXZ = 0 AND AY <> 0 THEN
7020        LET C = C +1                 !will count ,including zeros
7030         let AXYZ = AY
7040         let ang =  90
7050    ELSE IF AY = 0 AND AXZ <> 0 THEN
7060        LET C = C +1                 !will count ,including zeros
7070         let AXYZ = AXZ
7080         let ang =  0
7090    END IF   ! AX>0   ! was at 7180
7100
7110  LET angrat =  min(abs(ang - OLD),abs(360 - abs(ang-old ) ) )
7120  LET VELO(F) = vxyz
7130  LET ACCL(F) = axyz   ! for fft must include time all data pts
7140         LET An = An + angrat
7150         LET ac = ac + abs (axyz)
7160         LET V = V + abs (vxyz)
7170         let MEANac = ac / F            !running average
7180         let MEANa = An / F             !running average
7190         let MEANv = V / F            !running average
7200         LET SUBac = SUBac + (MEANac-axyz)^2 ! add the diff mean squared
7210         LET SUBa = SUBa + (MEANa-angrat)^2 ! add the diff mean squared
7220         LET SUBV = SUBV + (MEANv-vxyz) ^2
7230   print tab (1,1)
7240 IF N/100 = INT (N/100)  THEN
7250   print "                    "
7260  print tab (1,1)
7270   print angrat
7280 !get key zz
7290 end if
7300      set color 15
7310   plot n ,(vxyz *10^3);n,0
7320      SET COLOR 14
7330    plot n,(axyz *10^5 -200);n,-200
7340
7350         If angrat > 120 then
```

```
7360          let c120 = c120 +1
7370          else if angrat > 60 and angrat < 121 then
7380          let c60 = c60 + 1
7390          else if angrat > 5 and angrat < 61 then
7400          let c5 = c5 + 1
7410          end if
7420  let old = Ang                    ! plot n,(aXY*1000-200);n,-200
7430  NEXT N
7450 NEXT PH
7460   LET STDac = round( SQR(SUBac / F)*10^5 ,2)
7470   LET mac = round( (ac / F) *10^5,4)
7480   LET STDa = round (SQR(SUBa / F),3)
7490   LET ma =  round ((an / F) ,4)
7500   LET STDv = round (SQR(SUBv / F)*10^5,2)
7510   LET mv = round ((V / F)*10^5 ,2)
7520
7530        print "accel (s)",
7540        print mac,
7550        set color 15
7560        print "counts",
7570        print ma,STDa
7580        print "velo",
7590        print mv
7600 OPEN #9:SCREEN 0,1,0,.48
7610      set color 1
7620  PLOT 0,0;4096,0          !zero line
7630         WINDOW #9
7640    set color 15
7650 !!!!!!!!!!!!!!!!!!!!!!!!!!!
7660 ! GET KEY ZZ
7670 !  MAT REDIM VERT(1)
7680 ! MAT REDIM LAT(1)
7690 ! MAT REDIM PRO(1)
7700 MAT REDIM VELO(1)
7710 MAT REDIM ACFFT(512)
7720  LIBRARY "fftliba"
7730 CALL RUNFFTA(hzf,ti, N, F, ACCL(),ACFFT(),MEDFRE,PKFR1,PKFR2,pkfr3,peak1,peak2,peak3)
7740   !  MAT REDIM ACCL(1)
7750    MAT REDIM ACFFT(1)
7760 CLOSE #8
7770 END SUB !ACCELsub
7780        !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

. . . .