

4.2.3 The Time for Maximum Closing (Timeclos).

This parameter was measured as the time taken from the maximum opening position to the intercuspal position to be reached and the mandibular movement to stop.

A mean of 373 msec (sd = 76 msec) was calculated for the 20 individual subjects and the range varied from a minimum of 234 msec to a maximum of 680 msec (Appendix 9).

The mean for the closing time for gum was 395 msec which is slightly longer than the mean for nut- 351 msec (Appendix 10a and 10b).

The overall means for each individual subject, calculated on the basis of RUN, SESSION, FOOD and ACTION , show a wide distribution. The most consistent results were seen on the inter and intra sessional basis (Figure 4.3).

The t-test comparisons showed that sessional differences for the chewing movements using gum were not as significant than those for RUN (Tables 4.3a and 4.3b). The converse appeared to be true for the chewing of nut. The free choice chewing of gum and nut gave 4 out of 40 significant differences in the sessional comparison with free choice chewing of food showing the least significant differences of any chewing action. On the intra-sessional comparison, right and left, the chewing of nut only showed 1 out of 40 possible significant differences.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	2	10	6	18
NUT (n=40)	6	1	1	8
TOTAL (n=80)	8	11	7	

Table 4.3a. The number of times there was a significant difference in the time for maximum closing value between the means calculated on the basis of the RUN for nut and gum according to the side upon which the food was chewed.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	4	4	8	16
NUT (n=40)	4	6	5	15
TOTAL (n=80)	8	10	13	

Table 4.3b. The number of times there was a significant difference in the time for maximum closing value between the means calculated on the basis of the SESSION for nut and gum according to the side upon which the food was chewed.

The ANOVA (Appendices 14-17) show that RUN gave excellent reproducibility for most subjects with only 6 people showing significant differences. The comparisons made on the basis of SESSION, ACTION and FOOD all show that there were significant differences in these measurements.

The scatter-plot (Figure 4.3) also showed the group distribution of means for all foods and chewing actions. There was a range of values for all recordings with fewer differences noted between RUN and SESSION than FOOD or ACTION. The highlighted red plots illustrate the trends of the mean values for a single subject.

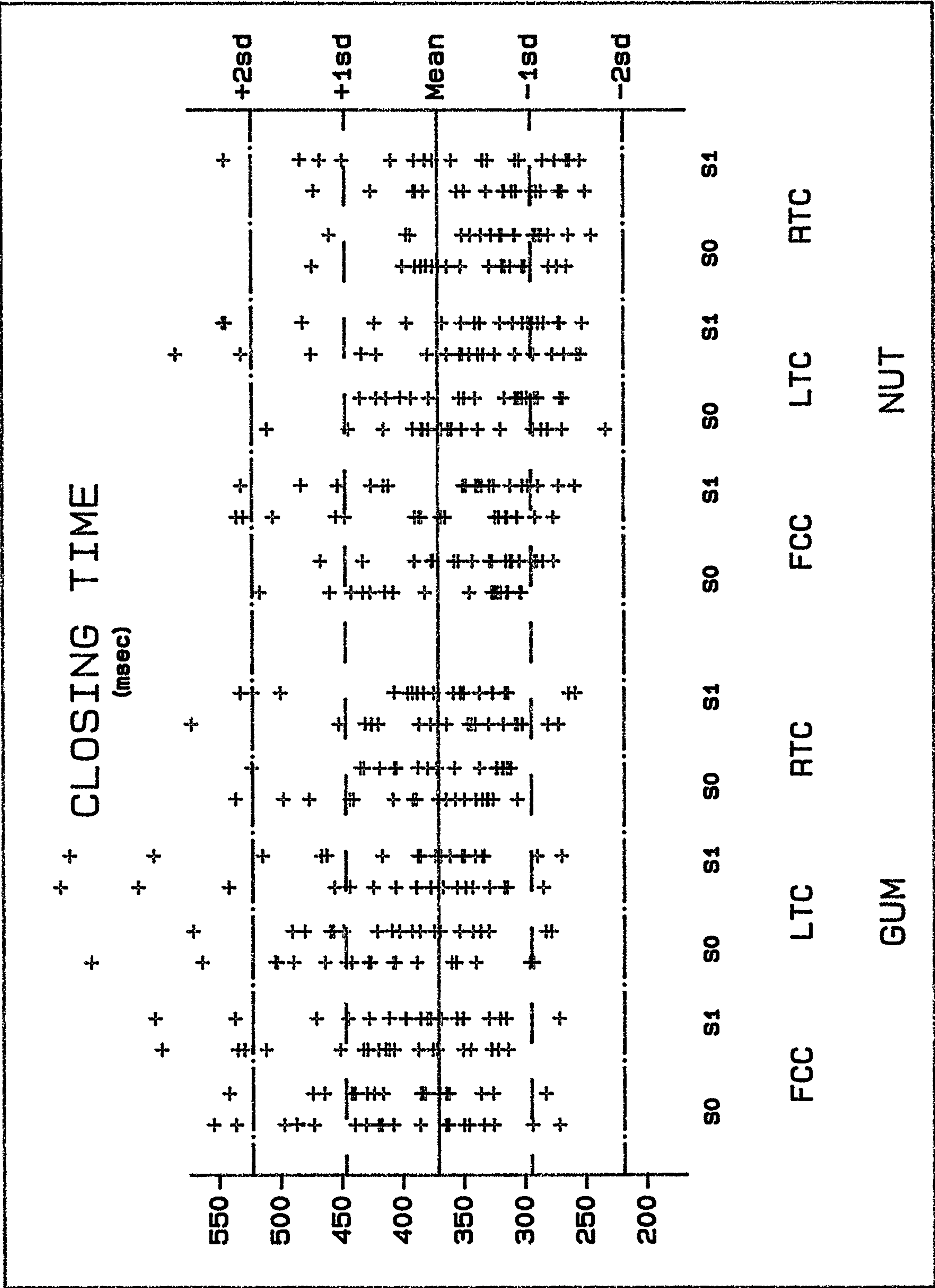


Figure 4.3 Scatter-plot to show individual mean values for time close for the 20 subjects for nut and gum. Values are given for free choice chewing (FCC), right-sided chewing (RTC) and left-sided chewing (LTC) for each food on session 0 (S0) and session 1 (S1).

4.2.4 The Time of the Intercuspal Pause (Timedwel).

The intercuspal pause was the duration between the chewing strokes when there was no mandibular movement and the teeth were in maximum tooth contact at the end of the chewing movement.

For the 20 subjects of this study the average duration of the intercuspal pause was 206 msec and the range was between 30 msec and 571 msec with a standard deviation of 60 msec (Appendix 9).

There was little difference in the values recorded for the intercuspal pause for the two foods. The means for gum and nut were 204 msec and 209 msec respectively (Appendix 10a and 10b).

The wide variation in the recorded times was particularly dependent upon the action used for the chewing movement with the subjects demonstrating wide differences between one another (Appendix 11).

T-tests showed that unilateral chewing actions displayed a greater number of significant differences in the sessional results than free chewing choice (Table 4.4b). Only 6% of free choice chewing actions for both FOODS displayed any significant differences on the basis of SESSION and 10% and 16% respectively showed significant differences for left and right chewing movements. There was little difference in the number of significant differences between the FOODS on the basis of SESSION although on the basis RUN, gum showed twice as many differences as nut (Table 4.4a).

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	2	7	4	13
NUT (n=40)	4	2	1	7
TOTAL (n=80)	6	9	5	

Table 4.4a. The number of times there was a significant difference in the time of intercuspal pause between the means calculated on the basis of the RUN for nut and gum according to the side upon which the food was chewed.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	4	6	4	14
NUT (n=40)	1	7	4	12
TOTAL (n=80)	5	13	8	

Table 4.4b. The number of times there was a significant difference in the time of intercuspal pause between the means calculated on the basis of the SESSION for nut and gum according to the side upon which the food was chewed.

The ANOVA indicated that the reproducibility of results on the basis of RUN were good for most of the tested subjects (Appendix 14). There was a wider variation in results on the basis of SESSION (Appendix 15) while FOOD and ACTION had equal influence on the number and significant differences of the chewing movement (Appendices 16 & 17).

The scatter-plot (Figure 4.4) illustrates a wide range of values for both foods and all chewing actions on an inter and intra-sessional basis. For the subject group, there appeared not to be any specific trends in the means with a wide range of standard deviations.

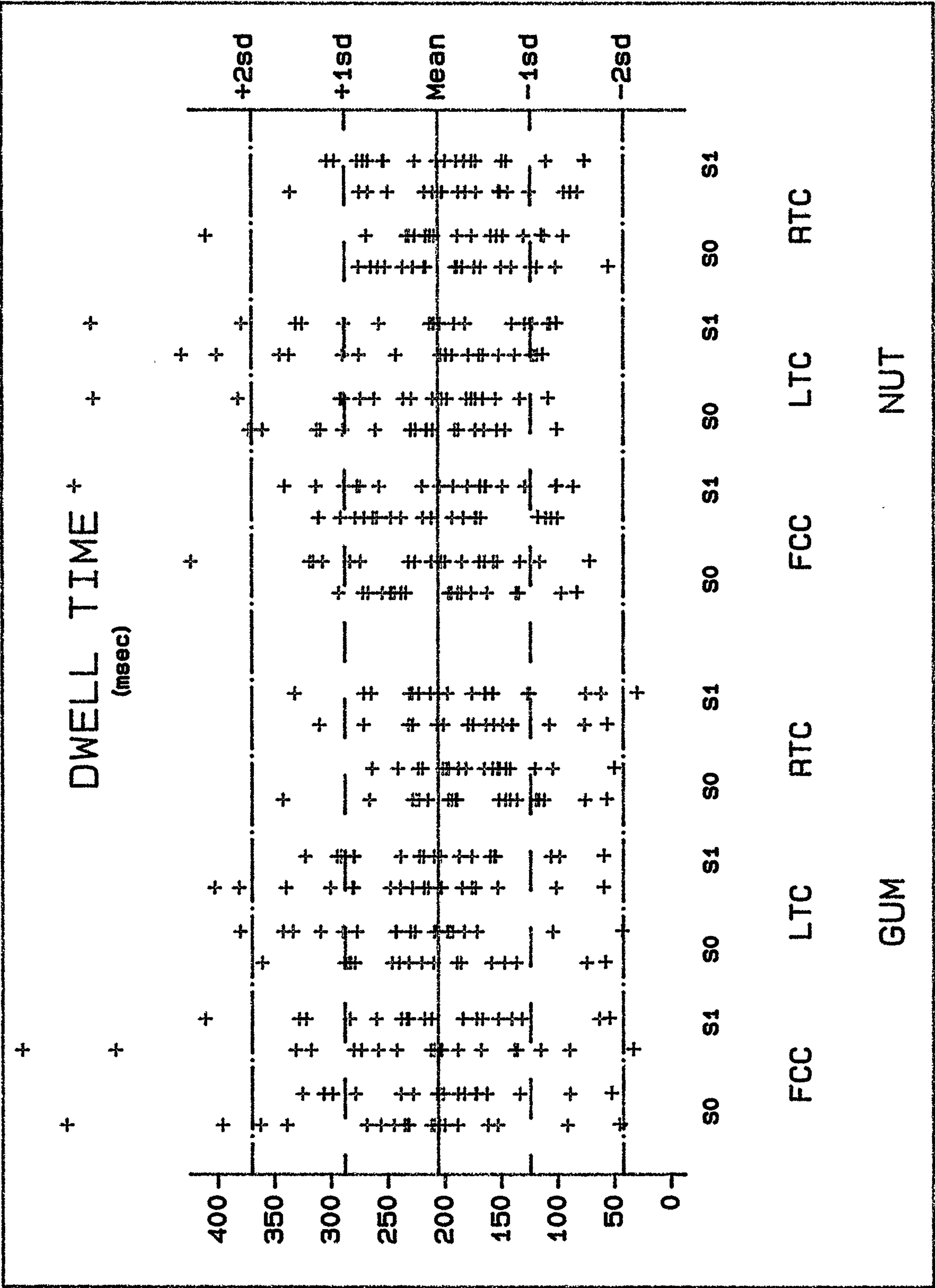


Figure 4.4 Scatter-plot to show individual mean values for time dwell for the 20 subjects for nut and gum. Values are given for free choice chewing (FCC), right-sided chewing (RTC) and left-sided chewing (LTC) for each food on session 0 (S0) and session 1 (S1).

4.2.5 The Time Of the Chewing Movement (Timemove).

The time of the chewing movement was the sum of the time for the maximum opening movement and the time for the maximum closing movement. It did not include the value taken for the intercuspal pause.

The average value for this parameter was 714 msec with a standard deviation of 146 msec. The range was between 418 msec and 1196 msec (Appendix 9).

The large variation in means was caused by differences in the FOOD with mean values of 780 msec and 648 msec for gum and nut respectively (Appendix 10a & b). The action of the chewing movement and the individuals themselves contributed to the wide variation in the values shown. The differences according to the RUN or the SESSION were less significant in the variation of means.

The t-tests on the basis of RUN indicated that free choice chewing of gum gave only 3 of the 40 comparisons showed significant differences (Table 4.5a). This contrasts with 7 of the a maximum 40 comparisons for the chewing movements on the basis of SESSION (Table 4.5b). Free choice chewing actions showed the least number of significant differences for both the SESSION and RUN comparisons. Overall, the chewing movements with nut only had 9 of the 120 individual results showing significant differences on the basis of RUN and twice this number (17 of 120) gave significant differences on the basis of session. The comparison on the inter and intra-session basis showed similar results for gum with 24 and 27 comparisons respectively (out of a maximum 120) showing significant differences.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	3	15	9	27
NUT (n=40)	5	3	1	9
TOTAL (n=80)	8	18	10	

Table 4.5a. The number of times there was a significant difference in the total movement time for the means calculated on the basis of the RUN for nut and gum according to the side upon which the food was chewed.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	7	7	10	24
NUT (n=40)	4	7	6	17
TOTAL (n=80)	11	14	16	

Table 4.5b. The number of times there was a significant difference in the total movement time value for the means calculated on the basis of the SESSION for nut and gum according to the side upon which the food was chewed.

The ANOVA comparisons indicated that the most significant cause for the variation in the results was due to the food bolus eaten rather than the SESSION, RUN or chewing ACTION (Appendix 14). The incidence of differences according to food was 19 out of a maximum 20 occurrences.

The scatter-plot shown in Figure 4.5, illustrates a wider range in the standard deviations for the individual means for gum than for nut. There are fewer differences between the mean values on the basis of RUN or SESSION although there are larger differences between means on the basis of ACTION.

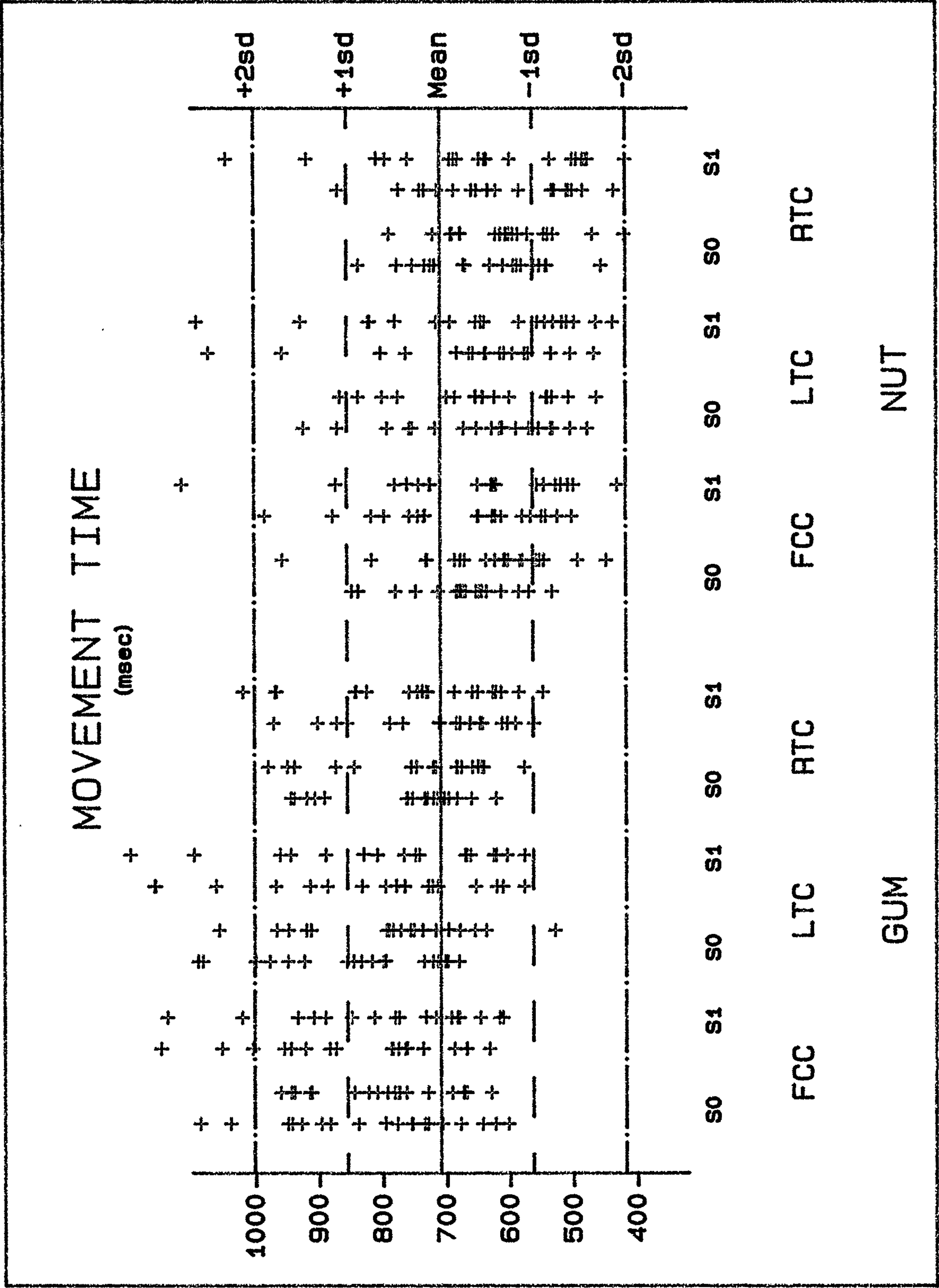


Figure 4.5 Scatter-plot to show individual mean values for time move for the 20 subjects for nut and gum. Values are given for free choice chewing (FCC), right-sided chewing (RTC) and left-sided chewing (LTC) for each food on session 0 (S0) and session 1 (S1).

4.2.6 Maximum Opening Velocity (Maxopvel).

A three dimensional jaw position was calculated every one two-hundredths of a second. The distance between each of these successive points was calculated and divided by the fixed time interval. This gives an instantaneous velocity. The maximum velocity was recorded for the opening movement in millimeters per second.

The mean for all the individuals for the opening velocity was 83 mm/sec (sd = 24). The range of the means was between 35 mm/sec and 150 mm/sec (Appendix 9).

For the 20 individual subjects that were included in this study the variability of the results was influenced most by differences in FOOD. The means for the gum and nut were 75 mm/sec and 91 mm/sec respectively. The variations on the basis of SESSION or RUN were also present (Appendix 11).

The t-tests comparisons showed that chewing of gum for all chewing actions gave 23 out of 120 values as being significantly different on the basis of RUN with only 12 of 120 comparisons, or 10%, showing significant differences on the basis of SESSION (Tables 4.6a and 4.6b). When comparing chewing actions, left-sided chewing showed only 6% incidence of significant differences on the basis of RUN with over 20% significant differences for free choice and right-sided chewing of gum. There were few disparities in significantly different values for any chewing ACTION on a sessional basis.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	9	10	4	23
NUT (n=40)	7	8	1	16
TOTAL (n=80)	16	18	5	

Table 4.6a. The number of times there was a significant difference in the maximum opening velocity values for the means calculated on the basis of the RUN for nut and gum according to the side upon which the food was chewed.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	3	5	4	12
NUT (n=40)	8	5	5	18
TOTAL (n=80)	11	10	9	

Table 4.6b. The number of times there was a significant difference in maximum opening velocity values for the means calculated on the basis of the SESSION for nut and gum according to the side upon which the food was chewed.

The ANOVA indicated that there was some variation of results according to the RUN or SESSION recorded with 8 out of 20 individuals showing significant differences for both measurements (Appendix 14 & 15) while ACTION showed 11 of the 20 subjects with significant differences (Appendix 17). The type of FOOD gave 16 of the 20 significant differences (Appendix 16).

The individual means for all of the chewing strokes (Figure 4.6) show fewer differences in standard deviations for each chewing movement for gum than for nut. There appear to be few differences on the basis of SESSION or RUN.

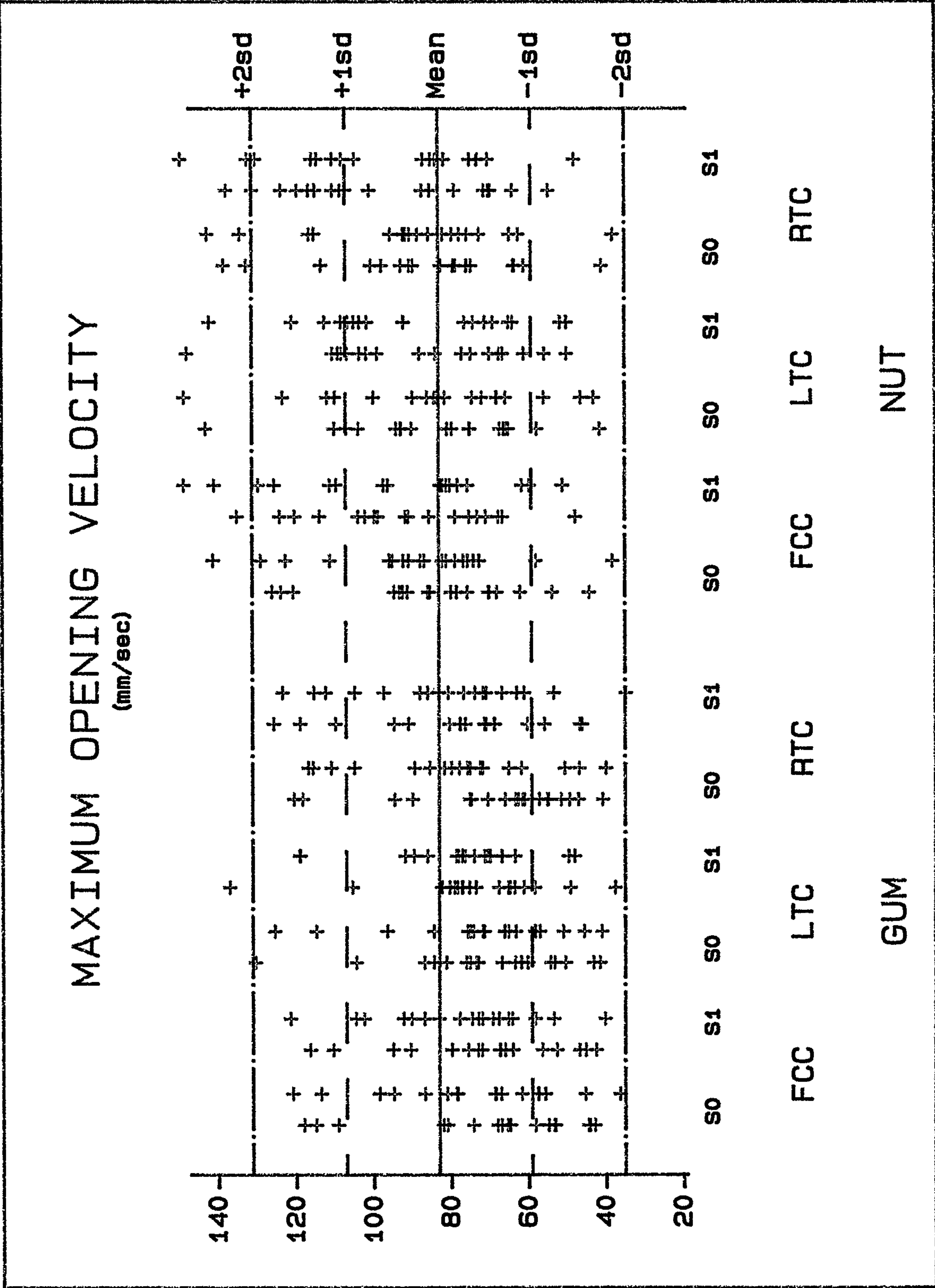


Figure 4.6 Scatter-plot to show individual mean values for maximum opening velocity for 20 subjects for nut and gum. Values are given for free choice chewing (FCC), right-sided chewing (RTC) and left-sided chewing (LTC) for session 0 (S0) and session 1 (S1).

4.2.7 The Maximum Closing Velocity (mm/sec).

A three dimensional jaw position was calculated every one two-hundredths of a second. The distance between each of these successive points was calculated and divided by the fixed time interval. This gives an instantaneous velocity. The maximum velocity was recorded for the closing movement in millimeters per second.

The average value for the closing velocity of the mandible, was 79 mm/sec with a $sd = 19$ mm/sec. There was a wide range of means between 41 mm/sec and 153 mm/sec (Appendix 9).

For the individuals of the study the variability of the results was influenced by the chewing ACTION and the change in FOOD. There was a small difference in the overall means for nut and gum which were calculated at 82 mm/sec and 76 mm/sec respectively (Appendix 10a and 10b). The mean values for each chewing stroke calculated on the basis of SESSION, RUN, FOOD and ACTION are represented numerically (Appendix 11).

The paired t-tests indicated that on either an intra or inter-sessional basis, there was little difference in the number of significant differences between the foods (Tables 4.7a and 4.7b). Nineteen of 120 values gave significantly different values above the 0.01 level while only 14 and 15 of the 120 results showed any significant differences on the basis of session. Eleven comparisons which showed significant differences on the basis of RUN and SESSION for left chewing movements for both FOODS. Right chewing movements gave the least significant differences on a sessional basis than any other ACTION.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	5	8	6	19
NUT (n=40)	7	7	5	19
TOTAL (n=80)	12	15	11	

Table 4.7a. The number of times there was a significant difference in the maximum closing velocity values for the means calculated on the basis of the RUN for nut and gum according to the side upon which the food was chewed.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	4	6	5	15
NUT (n=40)	6	2	6	14
TOTAL (n=80)	10	8	11	

Table 4.7b. The number of times there was a significant difference in maximum closing velocity values for the means calculated on the basis of the SESSION for nut and gum according to the side upon which the food was chewed.

The ANOVA gave the significant differences on the basis of RUN and SESSION, (Appendix 14 & 15), for a total of 6 and 8 subjects respectively, while on the basis of food, half of the subjects showed significant differences (Appendix 16). The incidence of significant differences occurring according to the chewing ACTION used, showed differences for 11 of the 20 subjects (Appendix 17).

The distribution of the means for each individual subject show a small standard deviation with most values falling within two standard deviations of the population mean (Figure 4.7). There few differences in the mean values on the inter or intra-sessional basis.

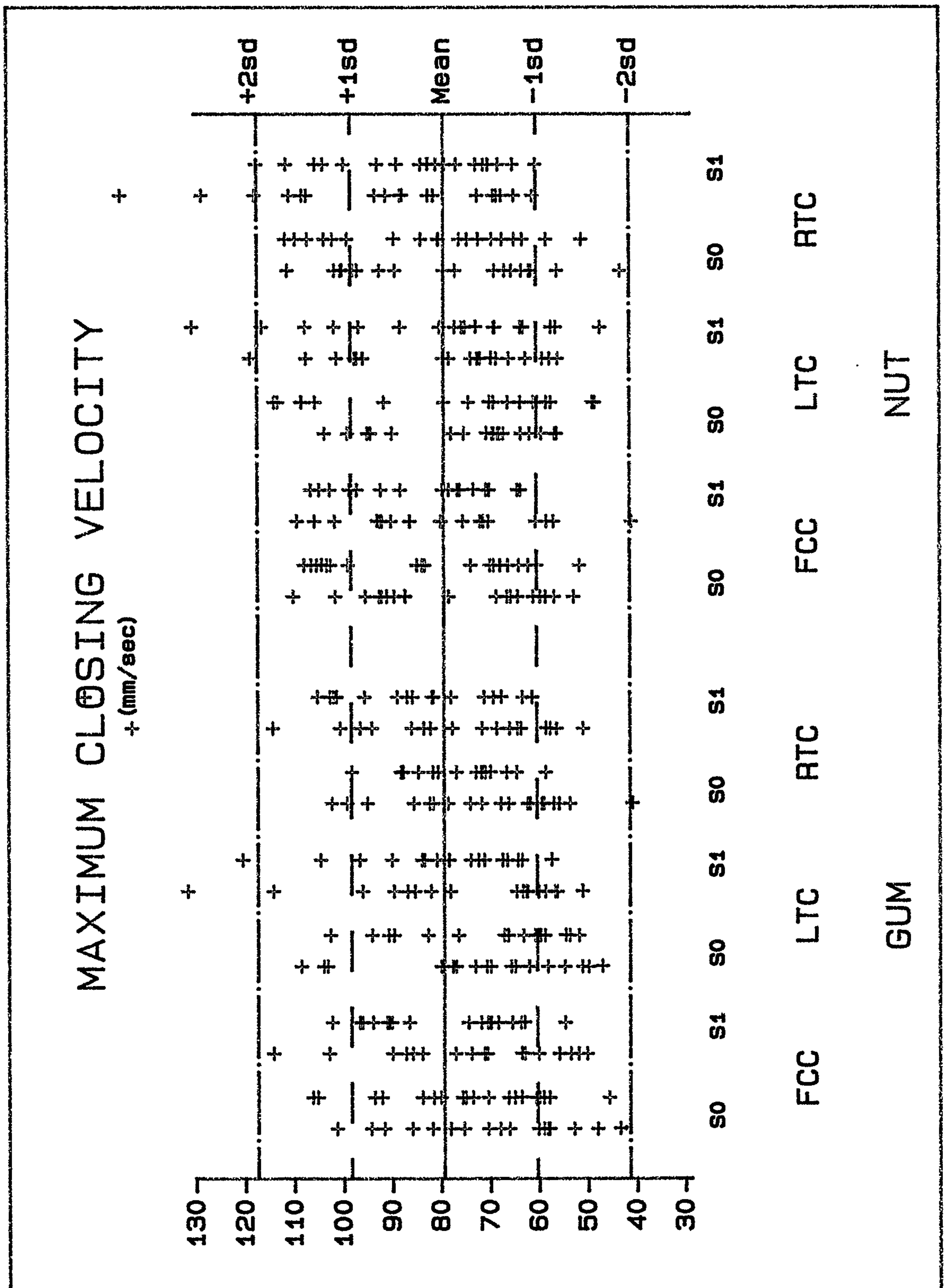


Figure 4.7 Scatter-plot to show individual mean values for maximum closing velocity for 20 subjects for nut and gum. Values are given for free choice chewing (FCC), right-sided chewing (RTC) and left-sided chewing (LTC) for session 0 (S0) and session 1 (S1).

4.2.8 The Lateral Range of Movement.

This parameter was calculated by adding together the maximum distance travelled by the mandible in the right and left lateral directions during the chewing cycle.

The mean for the 20 individuals of the study was 5.3 mm with a standard deviation of 1.9 mm. The range was between 1.1 mm and 10.7 mm (Appendix 9).

Some differences between means were evident with a change in the SESSION and RUN of the recording although changes in ACTION appeared to have a greater influence on mean differences (Appendix 11). The means calculated on the basis of FOOD gave very small differences in the recorded values (Appendix 10a and 10b). These were 5.6 mm for gum and 5.0 mm for nut.

The paired t-tests showed few significant differences between the means for food when compared according to SESSION (Table 4.8b). Only eight of a possible 120 values gave significant differences whilst chewing gum and 7 out of the 120 values gave differences whilst chewing nut. On the basis RUN, the chewing nut on the left side showed no significant differences and only 4% for all left sided chewing movements (Table 4.8b). On the basis of SESSION the left sided chewing movements again showed the least number of significant differences with the free choice chewing movements giving the second least number of significant differences.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	6	3	3	12
NUT (n=40)	2	2	0	4
TOTAL (n=80)	8	5	3	

Table 4.8a. The number of times there was a significant difference in the maximum lateral range of movement for the means calculated on the basis of the RUN for nut and gum according to the side upon which the food was chewed.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	2	3	3	8
NUT (n=40)	3	3	1	7
TOTAL (n=80)	5	6	4	

Table 4.8b. The number of times there was a significant difference in maximum lateral range of movement for the means calculated on the basis of the SESSION for nut and gum according to the side upon which the food was chewed.

The ANOVA comparisons indicated that on the basis of RUN, only 3 of 20 subjects showed any significant differences (Appendix 14). A total of 6 subjects showed significant differences on the basis of SESSION (Appendix 15). The incidence of significant differences occurring on the basis of FOOD and ACTION were 12 and 14 of the 20 subjects respectively (Appendices 16 & 17).

The scatter-plot of the means for each chewing movement for all the subjects (Figure 4.8), demonstrates a small standard deviation with most of the means falling within two standard deviations of the population mean. There was a significant difference between the means on the basis of FOOD with fewer differences found on the basis of ACTION .

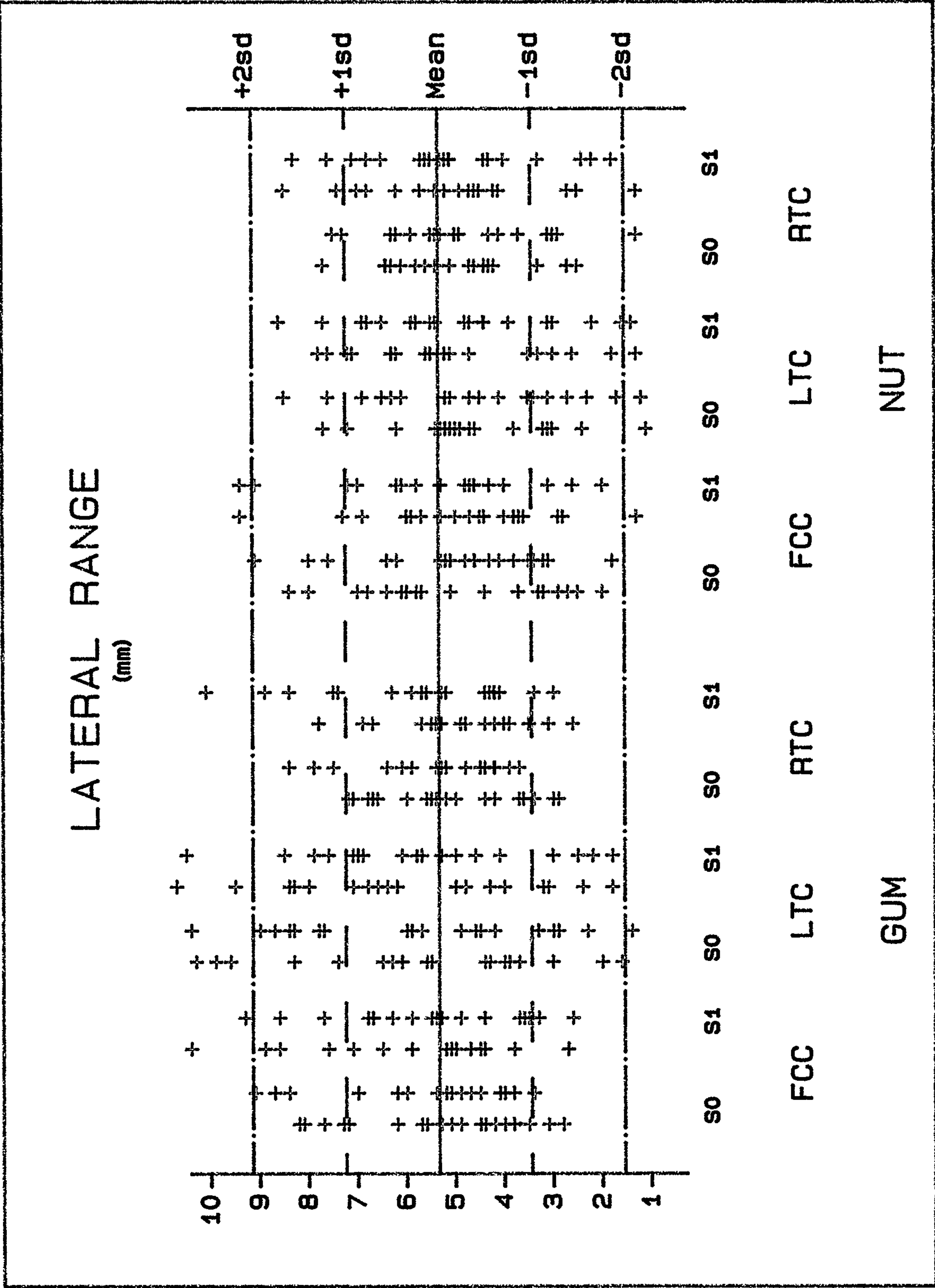


Figure 4.8 Scatter-plot to show individual mean values for lateral range of movement for 20 subjects for nut and gum. Values are given for free choice chewing (FCC), right-sided chewing (RTC) and left-sided chewing (LTC) for session 0 (S0) and session 1 (S1).

4.2.9 The Anteroposterior Range of Movement.

The anteroposterior range of movement was calculated as the sum of the distances travelled by the mandible anterior and posterior to the chewing movement.

For the 20 individual subjects, the mean for the maximum anteroposterior movement of 3.3 mm and a standard deviation of 1.2 mm. The range of the means for the subjects was between a minimum of 0.7 mm and maximum of 8.1 mm (Appendix 9).

The differences according to FOOD was minimal. The mean for gum was calculated at 3.3 mm and the mean for nut was calculated at 3.1 mm (Appendix 10a and 10b).

The overall means on the basis of SESSION, RUN, FOOD and ACTION were represented numerically (Appendix 11) with particular differences in means noticeable on the basis of ACTION .

The results of the paired t-tests on a sessional comparison showed no distinction in the significant differences between chewing on the right or chewing on the left sides with both parameters giving a value of 16 out of 80 possible results or 20% (Table 4.9a). There was little variation in the FOOD on a sessional comparison with 27 out of 120 values giving significant differences for gum and 24 out of 120 values giving significant differences for nut. On the intra-sessional basis the left chewing action gave the least significant differences with free choice movement showing the greatest number of significant differences (Table 4.9b).

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	6	8	6	20
NUT (n=40)	6	7	3	16
TOTAL (n=80)	12	15	9	

Table 4.9a. The number of times there was a significant difference in the maximum anteroposterior range of movement for the means calculated on the basis of the RUN for nut and gum according to the side upon which the food was chewed.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	9	9	9	27
NUT (n=40)	10	7	7	24
TOTAL (n=80)	19	16	16	

Table 4.9b. The number of times there was a significant difference in maximum anteroposterior range of movement for the means calculated on the basis of the SESSION for nut and gum according to the side upon which the food was chewed.

The variation in the results was greatly influenced by the FOOD (Appendix 16) and the SESSION (Appendix 15) according to the ANOVA. The number of significant differences occurring for these measurements were 17 and 16 of the 20 subjects respectively. The ACTION of the chewing movement and the RUN comparisons did not appear to be as important in the variation of the results (Appendix Tables 14 and 17).

The overall means for each individual were plotted on a scatter-plot (Figure 4.9) and this shows a wider standard deviation of means for the gum than for nut. There also appears to be greater consistency between individual means on an intra and inter-session basis than on the basis of FOOD or ACTION .

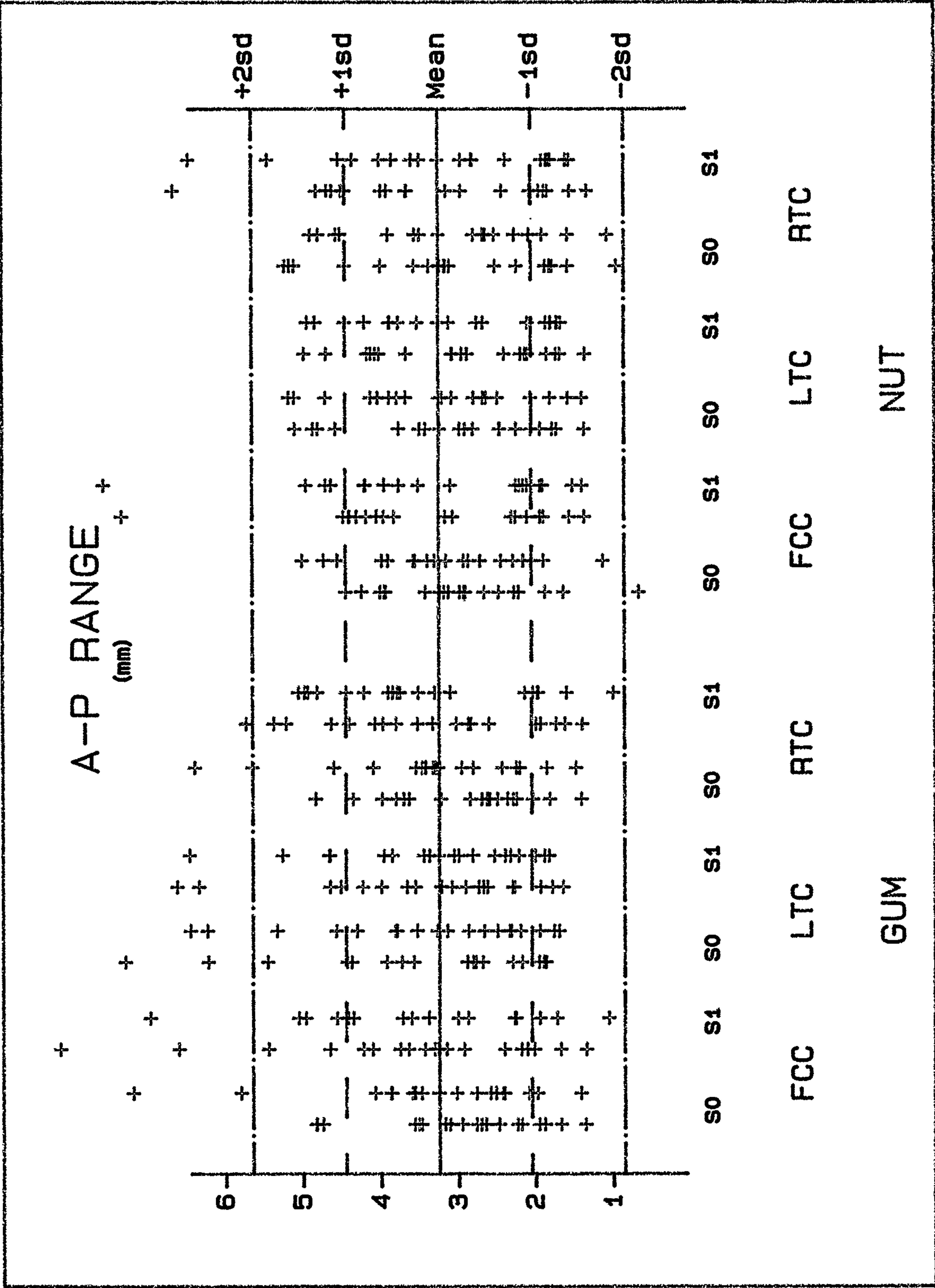


Figure 4.9 Scatter-plot to show individual mean values for A - P range of movement for 20 subjects for nut and gum. Values are given for free choice chewing (FCC), right-sided chewing (RTC) and left-sided chewing (LTC) for session 0 (S0) and session 1 (S1).

4.2.10 The Vertical Range of Movement.

This parameter was calculated as the maximum movement of the mandible in a vertical direction during the chewing cycle.

For all the individuals of the study an average value of 13.7 mm was calculated and the standard deviation was 2.4 mm. The range of the means varied between a minimum of 7.3 mm and a maximum value of 21.7 mm (Appendix 9).

The variation in these means was influenced by FOOD (Appendix 10a and 10b) as well as the ACTION and the SESSION of the recording (Appendix 11).

The paired t-test comparisons showed the free choice chewing action for gum was the most reproducible on an inter-sessional basis with only 5 of the total 40 results giving significant differences (Table 4.10a). The left and right chewing of gum showed 9 and 10 out of 40 results respectively gave significant differences. The different chewing ACTIONS for the nut gave consistent results for the SESSION comparison. The reproducibility of the results according to the RUN showed that free choice and left chewing movements were the most reproducible with only 11% showing significant differences on the intra-sessional basis (Table 4.10b). The number of significant differences shown by nut compared to gum indicated that nut was more consistent by a factor of 3.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	8	9	5	22
NUT (n=40)	1	3	4	8
TOTAL (n=80)	9	12	9	

Table 4.10a. The number of times there was a significant difference in the maximum vertical range of movement for the means calculated on the basis of the RUN for nut and gum according to the side upon which the food was chewed.

FOOD	ACTION			
	FCC	RTC	LTC	TOTAL
GUM (n=40)	5	10	9	24
NUT (n=40)	7	6	7	20
TOTAL (n=80)	12	16	16	

Table 4.10b. The number of times there was a significant difference in maximum vertical range of movement for the means calculated on the basis of the SESSION for nut and gum according to the side upon which the food was chewed.

The ANOVA results showed that the change in FOOD was the most significant contributing parameter in the variation of the results with 18 out of 20 subjects showing significant differences (Appendix 16). The ACTION and SESSION of the chewing movement were the second most important causes of the variation with a 12 out of 20 people with significant differences (Appendix 15 and 17). Only one quarter of the recorded subjects showed any significant differences on the basis of RUN (Appendix 14).

The scatter-plot of the means for all the subjects (Figure 4.10) shows similar standard deviations for both gum and nut with a significant difference in the means for the two foods. Few differences were noted on the basis of RUN or SESSION.

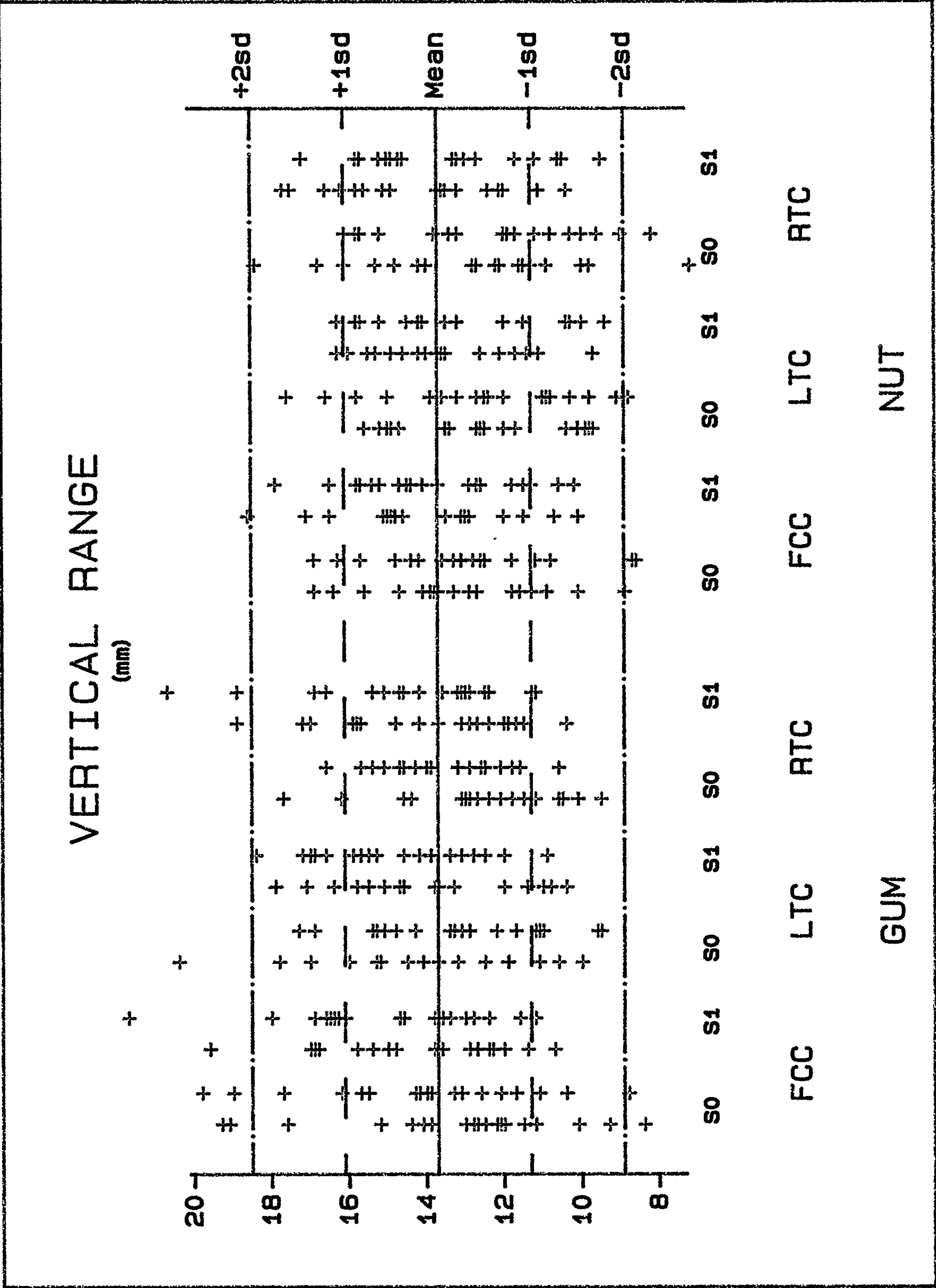


Figure 4.10 Scatter-plot to show individual mean values for vertical range of movement for 20 subjects for nut and gum. Values are given for free choice chewing (FCC), right-sided chewing (RTC) and left-sided chewing (LTC) for session 0 (S0) and session 1 (S1).

The overview of the results for the paired t-tests and the ANOVA indicate that the reproducibility of the results is greater on the basis of RUN and SESSION than on the basis of FOOD or the chewing ACTION. The use of the subject's preferred chewing action rather than unilateral chewing will also contribute to the reproducibility of the results. The measurement of 10 different parameters indicated that certain parameters produce more reproducible results than others. The time open, maximum opening velocity and lateral displacement tracings provide the most consistent recordings on the basis of RUN or SESSION.

5. DISCUSSION

The objectives of previous jaw movement analyses have been many and varied and a large proportion of the studies have focussed on assessments of mandibular movement during function with the use of different food materials. Most of these studies have been carried out using a single recording session on a group of subjects with no continuity of recordings over a specific time period.

5.1 SUBJECT GROUPS

The numbers of subjects used in jaw movement analyses have varied considerably from a group of three subjects (Atkinson and Shepherd, 1955) to a total of 552 (Proschel, 1987). Howell (1987b) used a group of 140 "normal" subjects. Documented evidence suggests that significant differences occur between different individuals (Jankelson et al. 1953; Kydd and Sandler, 1961; Bates et al. 1975a and Proschel, 1987) and between male and female subjects. Pullinger et al. (1987) implied that women have a greater mobility of the temporomandibular joint resulting in females opening wider than men and Posselt (1952) suggested that differences between males and females should be taken into ac-

count. A detailed study into the differences between the sexes was carried out by Howell (1987b), who showed that highly significant differences existed between men and women for the range of lateral movement, velocity of the movement and duration of the intercuspal pause. However, other studies have not given sexual differences of their subjects any consideration (Greenfield and Wyke, 1956; Mongini, 1986; Horio and Kawamura, 1989). Proschel and Hoffmann (1988) analysed jaw displacement data for 193 adults with a ratio of males to females of 3:1 and no differences between these groups was taken into account. No study was found where equal numbers of male and female subjects were selected. In light of the available evidence, equal numbers of males and females were chosen for this study to minimise differences that may exist between the sexes.

5.2 OCCLUSAL INFLUENCES

Several studies have compared the results of groups of subjects, with different occlusal schemes and it has been agreed that a change in occlusal scheme will affect mandibular displacement (Gillings et al. 1963; Beyron, 1964; Gibbs et al. 1971; Michler et al. 1987). Neill and Howell (1986) and Proschel (1987) both showed that a change in occlusal scheme gave significant differences in the jaw movement patterns for Class I and Class III occlusal relationships and a change in the incisor relationship was thought to be the most significant factor in altering the jaw movement pattern (Neill and Howell 1986). George (1983) stipulated that the standardisation of the occlusal scheme between subjects was imperative to ensure consistency of the results. The aim of this study was not to compare differences of occlusion within different groups but to assess changes shown by a single individual with no alteration to the occlusal scheme within the period of the recordings (section 3.7). However, all the subjects chosen in this study showed similarities in the occlusal scheme (section 3.7).

5.3 EXPERIMENTAL PROCEDURE.

In order to test for the reproducibility of jaw movement, the protocol carried out should be consistent on all occasions for all subjects. Each subject was examined and counselled, following an identical procedure and all recordings were carried out on the same day of the week and the same time of the day. Before recordings commenced, detailed and careful instruction was given to ensure that all subjects were relaxed in the clinical recording area and confident of the requirements which were to be met.

5.4 EXAMINATION OF RESULTS.

The analysis of data in this experiment required parametric statistical tests to be used. The statistical tests selected were the t-test and analysis of variance (ANOVA) tests. The Chi-Square or Mann Whitney-U tests were not considered for the analysis as they are only suitable for non-parametric tests or distribution free statistics.

Comparisons were made on a sessional basis to assess the changes in jaw displacement tracings. The variation between individual subjects has been identified in a number of different studies as one of the most critical factors in results (Jankelson, 1953; Kydd and Sandler, 1961; Bates et al. 1975a, and Proschel, 1987). Gibbs et al. (1971) noted that there was a larger variation in results because of a difference in individuals than there was because of a difference in food being eaten.

These effects were minimised in this study by each subject acting as his/her own control. The results were used to establish the response of a single person on two separate occasions, under standardised experimental conditions and to indicate the parameters

of each chewing cycle which could be applied in future studies for long term comparative measurements.

5.5 THE RECORDING OF JAW DISPLACEMENT.

The Siemens Sirognathograph, used to record jaw displacement data is a commercially available item of equipment and has been tested in the in the field of jaw movement research. In 1975, Jankelson et al. outlined the requirements of recording systems for the analysis of mandibular movement. These were:-

- a) Three dimensional measurement.
- b) Continuous data output.
- c) Maintenance of occlusal contacts.
- d) Preservation of lip competence.
- e) Quick and easy equipment set-up.
- f) Equipment accuracy within ± 0.1 mm
- g) Versatility.

The Sirognathograph and Kinesiograph both satisfy the above criteria and facilitate easy recordings of jaw displacement. The linearity of the Sirognathograph equipment has also been well documented (Lewin 1985) and is an essential feature for comparative studies. One restriction of the equipment is that it is only accurate within a limited field. This did not present a problem when recording mandibular movement within the normal functional range. Jankelson et al. (1975) stated that the accuracy of recordings which used the Kinesiograph were best in the lateral movements compared with a 3% discrepancy in the vertical channel and a 5.7% discrepancy in the antero-posterior channel. Similar changes in measurement have not been identified for the Sirognathograph, although both systems operate on comparable principles. This may give a reason why the

documented results from different centres appear to correlate closely to one another.

Many other types of recording equipment have been used for the assessment of jaw movement but they do not satisfy the above criteria which were vital considerations in the clinical use and accuracy with which recordings were made. The early photographic techniques used by Luce (1889) and Hildebrand (1931) only analysed jaw movement in two dimensions and the use of radiographic tracers (Sheppard, 1965) would certainly not be acceptable by current Ethical Review Committees. The Gnathic Replicator (Messerman 1967) and the Photoelectric Mandibulograph (Gillings, 1967) were bulky pieces of apparatus and the main head frames were much more cumbersome than the Kinesiograph and Sirognathograph.

The cineradiographic techniques used by Schweitzer (1961), Ahlgren (1961) and Watt et al (1976) and the light emitting diode technique used by Jemt et al. (1979) all required laborious and painstaking comparisons of radiographs and photographs to study the mandibular movement and this was time consuming and permitted human error. On the other hand, computerisation of raw jaw movement data and its analysis allows a large volume of information to be assessed with speed and consistency and will also facilitate its storage for future analysis. The necessity for using a computer system was endorsed by Hannam, De Cou and Scott (1980) and Michler et al. (1988). Certainly, the current study confirmed that the use of computer system is essential for satisfactorily recording and studying this type of data.

5.6 DATA COLLECTION.

The simultaneous recording of mandibular movement and EMG from jaw muscles required a complex recording system for data collection to take place satisfactorily.

Shannon's theorem states that the sampling frequency must be at least twice the maximum frequency required (Duxbury et al. 1974, Hannam, Scott and De Cou 1977; Michler et al. 1988). The expected frequency of muscle depolarisation from the muscles of mastication was 160 Hz (Hannam, Scott and De Cou 1977). The computer system used was capable of storing information at a rate of 1,000 samples per second. This compares with Hannam et al. (1980), Belser and Hannam (1986) and Mongini (1986), who sampled data at a rate between 1,000 hz - 1,600 hz. These values contrast with the earlier studies of Jankelson et al. (1953) and Waysenson and Salomon (1977) who used cinefluorographic techniques to measure mandibular movement with a films speed of 15 frames per second. Gibbs et al. (1981) used a sampling rate of 100 points per second with the Gnathic Replicator. If jaw movement only was recorded it would not be necessary to have recording equipment storing information at a very high rate. However, the simultaneous recording of jaw muscle activity, necessitates the use of fast recording levels. At a rate of 1,000 hz in this study, the recorded data was too large for easy analysis and the volume of data was reduced by one fifth for purposes of analysis to give an effective sampling rate of 200 Hz.

5.7 DATA ANALYSIS.

The computer programs used in this project have been developed and modified over many years to allow a wide variety of parameters and comparisons to be displayed and analysed. This facilitates the visual or numerical comparison of data. The computer processing of the data provides consistency in analysis of the results.

The raw EMG data were reduced to one fifth of the original size by calculating a mean value for five consecutive samples (section 3.6.2.1) and numerically filtered with a Butterworth filter with a cut - off frequency set at 20 Hz. The rate of data sampling

differed between studies. Michler et al. (1988) used a filtering range of between 20 Hz and 10 KHz, Mongini et al. (1984b) sampled jaw movement data at a rate of 50 Hz and EMG data at rate of 1.6 KHz and Hannam, Scott and De Cou (1977) used a sampling frequency between 1.5 Hz and 15 KHz. The filter used in this study created an integrated signal which was acceptable for comparison with data from other studies.

The jaw movement and EMG data were simultaneously displayed (section 3.6.4.1) as a continuous tracing which enabled correlations to be made between jaw movement and muscle activity. Although this was not extensively examined in this study it is a useful technique which has previously been used by other researchers (Ahlgren 1966, Hannam, Scott and De Cou 1977, Hannam, Scott, De Cou and Wood 1977 and Hannam and Wood 1977).

The jaw displacement was studied in detail and graphically represented in frontal, sagittal and horizontal planes as well as continuous traces of the whole chewing movement. The opening and closing strokes were distinguished from one another by using different coloured pens (section 3.6.4). The method of jaw movement display in three separate planes of analysis was used in a similar way by Jankelson et al.(1975), Gibbs et al. (1981), Hobo and Mochizuki (1983), Neill and Howell (1984), Mongini et al. (1984) and Howell (1987a). From this display, the distance of mandibular movement could be assessed and the consistency and shape of the envelope of function analysed for each chewing action. The numerical values for mandibular displacement, velocity and time of the chewing movement, were all obtained from the EXAMINE program (section 3.6.3). These are parameters which have been measured in other studies and provide essential comparisons between different centres (Gibbs et al. 1971; Lemmer et al. 1976 a; Mongini et al. 1986; Neill and Howell, 1986; Howell, 1988; Nishio et al. 1988; Hobo and Kawamura, 1989).

5.8 FOOD MATERIALS USED.

The consistency and homogeneity of the food bolus will affect the jaw movement. The use of two different food types (peanut and chewing gum) in this study allowed a comparison to be made of different mandibular functional envelopes due to the differences in the homogeneity and consistency of the materials. Both of these foods are available world-wide and chewing gum particularly is available as a standard sized stick which should produce a uniform bolus size. The standardisation of the food bolus is an important consideration where results from different recording sessions and recording centres are to be compared. Lewin (1985) and Horio and Kawamura (1989) suggested that an increase in the hardness of the bolus enlarged the deviation of mandible in the frontal plane and conversely, a softer bolus would result in a narrower mandibular movement. Horio and Kawamura (1989) performed tests of different food materials to test for differences in texture and consistency and related these to the results of mandibular displacement. Woelfel et al. (1963) and Stohler (1986) used beefsteak for the recording of jaw displacement and produced more consistent results with this homogeneous bolus than peanut, which would readily fragment. Gibbs et al. (1971) found that the reproducibility of mandibular movement was equally good with either hard or soft foods and this statement supported the use of two different food boluses in this study. As Lewin (1985) stated that muscle fatigue would increase irregularity in mandibular movements, only two test foods were chosen for this study. This reduced the possibility of a wide variation in the results which would complicate the final analyses.

5.9 ANALYSIS OF THE RESULTS.

A total of ten parameters was selected from numerous measurements which were available with the current computer programs. These were chosen to provide a comprehensive range of measurement and to provide cross-reference to previous studies (section 3.6.1). Although Proschel (1987) has carried out a detailed analysis of the chewing envelope, few studies have included an assessment of so many parameters for each chewing stroke. Notable exceptions are Neill and Howell (1984) and Howell (1987b).

Due to the number of subjects included in the study, the variation of chewing movements between individual subjects and the difference in chewing movements for a change in food bolus the recorded data base contained a large variety of different chewing strokes. For a comprehensive and accurate analysis to take place on such a large volume of data, a statistical analysis was required. Direct comparisons of mean values and standard deviation values alone were not adequate for the information recorded in this study. Paired t-tests were carried out although these were substantiated by the use of an ANOVA which reduced the possibility of the occurrence of false positive results. Previous studies with smaller sample sizes have not used statistical comparisons (Gibbs et al. 1971; Gillings et al 1973; Waysenson and Salomon 1977). Ahlgren (1966) used a statistical analysis on his data although he did not state the tests used. The t-test comparison has been commonly used by other researchers, (Moller, 1966; Howell, 1987; Neill and Howell, 1988; Horio and Kawamura, 1989), and the ANOVA procedure was used by Moller (1969) and Drago and Rugh (1984).

5.10 ANALYSIS OF TIME.

No previous results were found where detailed comparisons have been made of jaw tracking movements, between different recording sessions, for the same group of subjects. Klineberg (1980) stated that the composite envelope of a chewing sequence showed a 12-15% variation in area when repeated by one subject in a single recording session. Michler et al. (1987) did repeat jaw tracking recordings for one subject, one year after the initial recording, and claimed that there was consistency between the recordings on the two different occasions. There are no comparable figures for the same subject group over a period of time.

5.10.1 Total Time of Chewing Cycle.

The mean value for the total time for the chewing cycle was 920 msec, with a range of 568 msec to 1641 msec and agrees well with the results of Plesh et al. (1986) who found a range of 600 msec to 1400 msec for chewing gum. These values do appear to be slightly above the values for other studies. Proschel and Hoffmann (1988) gave a mean total time of 870 msec for chewing apple while Howell (1987) found a range of 748 msec to 821 msec for peanuts and chewing gum respectively. Ahlgren (1966) had a large sample group with a range of values for cycle time duration of 580 msec to 770 msec, for the chewing of gum and carrot. Howell (1987) and Ahlgren (1966) selected bolus types similar to those used in this study which should give comparable results for chewing cycle duration. Moller (1966) found a range of 580 msec to 680 msec for the duration of the chewing cycle for apple and bread, with longer chewing cycles for bread than for apple. The differences in the duration of these chewing cycles was due to changes in the time of the opening and not closing phases. Michler et al. (1987) had a wider range of cycle times of 500-800 msec for the single recording of an asymptomatic subject chew-

ing apple and gum. The fact that Michler et al. (1987) only recorded one subject makes valid comparisons with the data for this study, more difficult.

Mean Values for the Total Time of the Chewing Cycle

Ahlgren (1966)	580 - 770 msec (all foods).
Moller (1966)	580 - 680 msec (all foods).
Plesh et al. (1986)	600 - 1400 msec (gum).
Howell (1987)	748 - 821 msec (all foods).
Proschel & Hoffmann (1988)	870 msec (apple).
Present Study	568 - 1641 msec (all foods)

Jemt et al. (1979) deduced that the duration of the chewing stroke decreased with an increase in the number of chewing strokes completed. This may be caused by increased fatigue and agrees with Lewin (1985) who stated that there was a change in the duration of the chewing movement with an increase in muscle tiredness. The duration of the entire recording session for the current study was reduced to less than ninety minutes to reduce the possibility of fatigue. We checked this drop off of time versus stroke number and there was no correlation; ie it remains constant.

Several reports have been made on the rate of chewing which have been found for several different foods and are expressed as the number of chews per minute.

Shepherd (1960)	60 cycles/min (gum).
Beyron (1964)	60 cycles/min (beef).
Moller (1966)	88-104 cycles/min (apple, bread).
Ahlgren (1966)	78-104 cycles/min (gum, carrot).
Hedegard (1970)	58 cycles/min (toffee).
	73 cycles/min (bread).
Gillings et al. (1973)	73 cycles/min (peanut).
Bates et al. (1975b)	80 cycles/min (mean of foods)
Jemt et al. (1979)	19 cycles/min (gum).

The interpretation of the current results shows that the mean rate of chewing for gum was 61 cycles per minute and the mean rate of chewing for nut was 70 cycles per minute.

Although the current results are well within the range of values given in other studies, there are numerous different values for similar tasks by different investigators.

The ANOVA was used to identify the reproducibility of values for a single person on the basis of the run or session of the recording. There were few subjects who demonstrated reproducible results for the total time of the chewing action. The time total parameter is dependent upon the opening and closing times for its calculation, the latter of which is particularly vulnerable to variation of the values. This will contribute to the lack of reproducibility of this measurement.

5.10.2 Time of Opening Phase of Chewing Cycle.

The opening phase of the movement described (section 4.2.2) is not a parameter commonly quoted in other studies. Proschel and Hoffmann (1988) did measure this part of the chewing cycle for winegums and gave a mean value of 430 msec which compares favourably with the mean values of 296 msec for nut and 384 msec for gum which were found for this study. The slight differences noted between these figures may be accounted for by the difference in the consistencies of the foods used. Jemt et al. (1979) showed that the opening phase of the chewing movement, while eating white bread, was shorter than the closing phase of the masticatory cycle. His value for the mean duration of opening while eating white bread was between 700 - 1100 msecs. These values appear to be very large when compared to the present study despite the different food boluses used.

On the basis of run and session, the time open measurement showed good reproducibility of results for most subjects. There were significant differences in values for this parameter on the basis of food, although this may be explained by the fragmentation of the peanut bolus and the collection of food in the mouth. This causes difficulties in

creating consistent chewing movements.

5.10.3 Time of Closing Phase of Chewing Cycle.

The mean value for the closing time for chewing of nut and gum were 351 msec and 395 msec respectively with an overall mean of 373 msec. A value of 450 msec was obtained from results by Proschel and Hoffmann (1988) for the chewing of winegums, which is 20% more than the values for this study although the differences in the food bolus used may have caused the discrepancy between these results.

It might be expected that during the chewing of peanut, the closing phase of the chewing cycle would be shorter than the opening phase due to its fragmentation. This was not observed for any of the chewing strokes recorded. The opening stroke had a shorter duration than the closing stroke on an individual basis. The bolus fragmentation and movement of the mandible while closing into nut contrasts with gum, where bolus homogeneity allows a more consistent duration of closing and opening movements. The ANOVA results show poor reproducibility on the basis of food and the differences in the bolus types may be the most important contributing factor.

5.10.4 Time of Intercuspal Pause.

Graf and Zander (1963) stated that intercuspal pause would increase the length of the chewing cycle and Neill and Howell (1986) found that females have a longer intercuspal pause, or dwell time, than males.

The overall mean value for intercuspal pause was 206 msec with a range of 30 msec to 571 msec. The mean value for chewing gum was 209 msec and for chewing nut was 204 msec. The mean values for dwell time for men and women chewing peanut,

reported by Howell (1987) were 128 msec and 143 msec respectively. The comparable figures for gum for men and women were 139 msec and 156 msec respectively. There have been a wide range of values given for the intercuspal pause by several reporters using the same food bolus:-

Mean Values for the Intercuspal Pause

Shepherd (1960)	100 msec (gum).
Schweitzer (1961)	300 msec (gum).
Woelfel et al. (1962)	160 msec (gum).
Ahlgren (1967)	100 msec (gum).
Gillings et al. (1973)	180 msec (gum).
Plesh et al. (1986)	100 - 380 msec (gum).
Present Study (1989)	204 msec (gum). 209 msec (nut).

The values for the present study are a little larger than other studies although this is an overall mean for three different chewing actions. From the results (see section 4.2.4), it is noted that the right chewing movements show predominantly shorter intercuspal pauses than left or free choice chewing movements. The range of intercuspal pause values for chewing gum on the right side was between 169 msec and 174 msec and these values relate more closely to those found in previous studies. This may be true for the selected group of subjects where 60% of subjects preferred to chew on the right side. The possibility of subjects preferring to chew in a particular way is variable that has not been considered in previous studies.

The intercuspal pause phase showed the greatest consistency on the basis of run of the any of the ten measured parameters. This measurement is influenced by subconscious factors which are unlikely to change within a recording session unless the subject becomes stressed or fatigued. Both of these variables were reduced to a minimum by ensuring that all subjects were completely familiar with the procedure and that sequences of chewing movements were kept short and with a sufficient rest period between in order to avoid muscle fatigue.

5.10.5 The Movement Time of Chewing Cycle.

The duration of the active component of the chewing cycle is believed to be important in the diagnosis of temporomandibular joint dysfunction syndrome with an increase in this value correlating with an increase in symptoms (Besette et al 1971, Helling and Klineberg 1983, Chong-Shan and Hui-Yun, 1989a,b). The movement time is obtained by adding the opening time and the closing time. The overall mean value was 713 msec with the mean values for gum and nut, 780 msec and 648 msec respectively. No other studies were found to identify this measurement as a separated entity. However, in the light of the comparisons of this study and others with respect to the opening and closing phases, it would be expected that the values of this study are comparable to other results.

The reproducibility of the movement time is compromised by the summation of opening and closing times to determine its value. The variation of either of the component parameters will change the reproducibility of the results for time move.

5.12 ANALYSIS OF VELOCITY.

5.12.1 Time of Maximum Opening Velocity.

The literature shows a wide range of values for the maximum opening velocity according to different tested variables. Neill and Howell (1986) stated that men eat faster than women and Lucas and Luke (1983) and Horio and Kawamura (1989), showed that harder foods required slower chewing than softer food materials. The mean maxi-

mum velocity for nut in the present study, was 91 mm/sec and the value for gum was 75 mm/sec, showing a significantly faster rate for the harder food. There were marked differences between the two foods for all recordings, although there were no differences on the basis of session or run which showed good reproducibility.

Woelfel et al. (1963) suggested that a homogeneous food bolus, such as rubber, gave more regular maxima for velocity than an inconsistent food bolus, such as peanut, which showed a wide range of velocity values during trituration. In the current study, the maximum opening velocity was between 38 - 150 mm/sec for chewing peanut and the corresponding values for gum were between 35 - 137 mm/sec, with the values for chewing peanut showing slightly more inconsistent results than gum.

Bates et al. (1975 b) stated that unilateral movement gave a reduced velocity compared to bilateral function. An increase in the number of strokes completed, while eating bread, increased the velocity of the movement (Jemt et al. 1979). My results (Appendix Table 5) indicate that the right-sided chewing movements had a slightly slower chewing rate, which may be explained by the fact that 60% of the subjects in the chosen group preferred to chew on the right side and carried out a more deliberate chewing movement under instruction. However, the left-sided chewing movement appeared to show faster chewing movements for all foods which may be due to the majority of subject being unused to chewing on this side. The bilateral chewing movement was generally slightly slower and could be caused by the movement of the food bolus from one side of the mouth to the other.

A smaller food bolus will increase the velocity of the chewing movement, suggesting that standardisation of the bolus volume is important in the reproducibility of the jaw recording (Lucas et al. 1986). Gum was used as a test food in this study because it is available worldwide and in a standard package size and this allows more accurate com-

parisons with other studies to be made.

Ahlgren (1966) and Bates et al. (1975 b) found that the position of the maximum opening velocity was at the beginning of opening and closing movements. This was different from Mongini and Tempia-Valentia (1984) who maintained that the acceleration of the jaw movement was in the middle third of opening stroke and the last third of the closing stroke, although some of these results related to a group of dysfunction subjects. Jemt et al. (1979) found a notable decrease in the velocity towards the end of the closing movement for eating of white bread.

Values for Maximum Opening Velocity

Ahlgren (1966)	64 mm/sec (gum). 75 mm/sec (carrot).
Gillings et al. (1973)	54 mm/sec (peanut).
Jemt et al.	102-113 mm/sec.
Neill and Howell (1986)	128-148 mm/sec (gum). 147-170 mm/sec (peanut).
Proschel (1988)	65 mm/sec (winegums).
Present Study (1989)	91 mm/sec (peanut). 75 mm/sec (gum).

Overall Mean Value for Velocity

Rudd et al. (1969)	95 mm/sec (peanut).
Bates et al. (1976)	64-135 mm/sec (all foods).
Feine et al. (1988)	95-286 mm/sec (gum).
Michler et al. (1987)	60 mm/sec (all foods).

It is widely accepted that measurements for different foods will be vary and this is apparent from the values shown above. Ahlgren (1966) found that opening velocities for gum and carrot were 56 mm/sec and 75 mm/sec respectively. Neill and Howell (1986) gave a velocity range of 124 - 146 mm/sec for gum which was almost three times the figures given by Ahlgren (1966)! The range of values found by Neill and Howell (1987), for peanut were 144 - 168 mm/sec. The mean velocity value for this study for gum was 75 mm/sec and for nut 91 mm/sec which are closer to the values shown by Ahlgren (1966) and Proschel and Hoffmann (1988).

These factors suggest that there are a number of variables which influence the velocity and the standardisation of these is important in experimental design. The differences in these figures may be due to dissimilarities in recording equipment, analysis procedures, subject group or the food bolus selected.

There was good reproducibility of the maximum opening velocity on the basis of run and session but poor reproducibility on the basis of food or action. The velocity of chewing movement is controlled by habitual chewing movements and influenced by changes in food bolus. It would be expected that run or sessional changes were less than those due to food or chewing actions.

5.12.2 Maximum Closing Velocity.

In contrast to the number of different factors which influence opening velocity for various foods, the same criteria have not been identified in literature for closing velocity. However, it may be suggested that similar variations could be expected. Ahlgren (1966), stated that there was no difference in the values for the closing velocities for gum or carrot and for both foods, the maximum velocity was noted at the beginning of the closing stroke.

The mean value for the maximum closing velocity for the current study was 79 mm/sec with a range between 56 – 121 mm/sec. The mean maximum closing velocity for gum was 76 mm/sec and the value for peanut was 82 mm/sec. There were significant differences in the values obtained for gum and nut although these were not as dramatic as those differences observed for the maximum opening velocity.

Comparisons of the results obtained on the basis of session and run, showed very little variation between the recorded values. Differences due to the chewing action

showed an increase in the maximum closing velocity for the right side chewing for both foods, similar to the maximum opening velocity. A comparison of these figures based on the chewing action has not been made in other studies but those found in the literature show a wide range of figures as follows:-

Mean Values for the Maximum Closing Velocity

Ahlgren (1966)	60 -64 mm/sec (gum,carrot).
Gillings et al. (1973)	52 mm/sec (peanut).
Bates et al. (1976)	64-135 mm/sec (all foods).
Hannam and Wood (1977)	110 mm/sec (gum).
Neill and Howell (1986)	127-148 mm/sec (gum).
	130-151 mm/sec (peanut).
Proschel and Hoffman (1988)	80 mm/sec (winegums).
Present Study (1989)	76 mm/sec (gum).
	91 mm/sec (nut).

The means calculated for this investigation fall within the range of values for other studies, although they do not exactly correspond to any one study. The variations between the foods chewed and the sample sizes used in the studies are all factors which may influence dissimilarities in the values recorded. The way in which the food is triturated is not a factor which is considered by other investigators. Hannam, Scott et al. (1977) Hannam and Wood (1977) and Howell (1987 a,b) used a Kinesiograph for their recordings whilst the Sirognathograph which was used in this project. Differences in the rate at which the information is collected and the computer analysis procedure may influence the discrepancies observed between the values from different centres.

There was good reproducibility of the maximum closing velocity according to the run or session of the recording. The changes in the food bolus and difficulties in the control of unilateral chewing movements caused a greater variation in the maximum closing velocity with little reproducibility of these results noted. The programming of chewing movements by individual learning processes may contribute to the consistency of the results on a sessional and run basis.

5.13 ANALYSIS OF RANGE OF MOVEMENT.

5.13.1 Lateral Range of Movement.

Hildebrand (1931) and Bates et al. (1975a) suggested that functional lateral movements were half that of maximum lateral movements. Schweitzer (1961), however, claimed that functional movements were only one half to one third of maximum movement. Harder or more chewy foods have been found to cause larger lateral movements than softer or less chewy foods (Schweitzer, 1961; Neill and Howell, 1986; Howell, 1987b). Michler et al. (1987) gave a mean value for functional lateral movement to the right side of 5 mm and to the left side 7 mm. This compares well to the value of 5.3 mm, given by Proschel and Hoffmann (1988) for chewing winegums. Howell (1987b) gave a range of values for the mean lateral mandibular displacement during function of 5.4 mm to 6.0 mm and also showed that lateral movements were larger for male subjects than female subjects. Differences between the sexes were not studied in this particular study and most other projects do not give their results according to the sex of their subjects.

The mean value for this study was 5.36 mm which is well within the range of these other projects. The increase in lateral movement during the chewing of gum, compared with nut, is consistent with these previous reports.

Mean Lateral Range of Mandibular Displacement

Beyron (1964)	10 mm (peanuts).
Ahlgren (1966)	5.3 mm (carrot).
Gillings et al. (1973)	8.5 mm (peanuts).
Hannam, Scott and De Cou (1977)	7.2 mm (gum).
Howell (1987b)	5.8- 6.2 mm (peanuts).
Proschel (1988)	4.7 mm (winegums).
Present Study (1989)	5.6 mm (gum). 5.0 mm (nut).

There was good reproducibility of the results on the basis of run and session for the majority of the subjects recorded. This maybe due to the influence of tooth contacts in the guidance of mandibular movement. The difference in the food bolus contributed to the variation in measurements on the basis of food.

5.13.2 Antero-posterior Range of Movement.

The antero-posterior range of movement is not commonly quoted in the literature although ranges of movement in the lateral and horizontal planes are quoted more often.

The mean value for the antero-posterior movement in this current study was 3.2 mm, with a range from 1.3 mm to 5.9 mm. This was found true for both the foods examined. The mean value for peanut was 3.1 mm and the mean value for gum was 3.3 mm. The mean values given by Howell (1987b), fall within a similar range as those of the current study. These values were 2.7 mm for nut and 3.6 mm for gum. The differences in the mean values maybe explained by the way in which the calculations were carried out.

Howell (1987b) extrapolated the results further to show a variation in the mean values between males and females. The mean value for gum for men was 2.7 mm and for women was 3.3 and for peanuts for men was 3.3 mm and for women was 3.6 mm. This comparison was not carried out in this study.

However, the current results were compared on an intra and inter-sessional basis, with little variation observed between either of these parameters. Also there was little difference in the means calculated according to the way the food was chewed.

It is known that a 10^0 movement in the headframe position will cause a distortion of 1 mm of the recordings in the antero-posterior plane. A more accurate system for the sequential repositioning of the headframe might improve the accuracy of the recordings. The ANOVA showed little reproducibility on for the antero-posterior measurement which may have been caused by headframe movement.

5.13.3 Range of Vertical Movement.

The range of vertical movement quoted in the literature varies widely with the type of subject studied and the food material chosen. Horio and Kawamura (1989) suggested that the vertical mandibular displacement during function increased while chewing harder foods, although Shepherd (1960) stated that maximum mandibular opening changes with age and the number of natural teeth present. In this current study, there was a change in vertical displacement when chewing the softer food (eg gum) and a smooth movement while chewing peanut. This appears to be contradictory to the previous reports.

Proschel and Hoffmann (1988) published a mean value of 15.5 mm for chewing winegums and Howell (1987B) found mean values of 15.5 mm and 17.5 mm for chewing of gum for women and men respectively. Howell (1987b) quoted figures of 15.8 mm and 17.2 mm for women and men respectively, for the chewing of peanuts. This compares with Ahlgren (1966) who gave a value of 19.1 mm for chewing of carrot.

Range of Maximum Vertical Movement

Beyron (1964)	17 mm (peanuts).
Ahlgren (1966)	19.1 mm (carrot).
Gillings et al.(1973)	13 mm (peanuts).
Hannam, Scott and De Cou (1977)	19.3 mm (gum).
Lucas et al. (1986)	9-19 mm (peanuts).
Plesh et al. (1986)	15-21 mm (gum).
Michler et al. (1987)	16-20 mm (apple, gum).
Howell (1987b)	15.5-17.5 mm (gum).
	15.8-17.2 mm (peanuts).
Proschel (1988)	15.6 mm (winegums).
Horio and Kawamura (1989)	12-18 mm (all foods).
Present Study	14.0 mm (gum).
	13.3 mm (nut).

The overall mean value of 13.7 mm was calculated for the vertical mandibular displacement in this study. The range varied from 9.8 mm to 17.9 mm for both foods. The mean maximum vertical displacement of the mandible for gum was 14.0 mm and the mean displacement for nut was 13.3 mm. This value compares well with the other studies quoted above.

The range of maximum vertical movements of the mandible during function are larger for male subjects than female subjects (Neill and Howell 1986, Howell 1987b). This range is between 14.5 mm and 18.7 mm. These figures are significantly less than Michler et al. (1987) who quoted values between 16 mm and 20 mm. Pullinger et al. (1987) found that for passive and active jaw opening, females had a larger mandibular opening than men which implied that women have a greater temporomandibular joint mobility. He discounted the possibility that these variations could be due to a disparity in the size of the mandible between the two groups. This variation between the sexes, may have a large influence on the range of the values noted above being dependent upon the relative numbers of males and females within the subject groups. The current study examined equal numbers of male and females to try and reduce these effects. When comparisons of the results are made according to the time when the recordings were made, there did not seem to be any significant difference in the results. While comparing

the current results on the basis of the action of the chewing movement, there appeared to be little change in the vertical displacement of the food according to the way in which the bolus was triturated.

5.14 SUMMARY OF DISCUSSION

The aim of this study was to test the reproducibility of recording jaw displacement using the Sirognathograph. This was carried out for a group of twenty asymptomatic subjects who were chosen on the basis of similar occlusions and because none of them had received dental treatment during the experiment or for six months prior to the recordings. In all experimental techniques there are several sources of error which have to be identified and reduced to a minimum. This was done on the basis of previous studies and the documented evidence was applied to this end.

The first source of error might have been the recording equipment used. Documented evidence does not show sufficient inaccuracies to affect the reproducibility of the result. Michler et al. (1987) and Maruyama et al. (1984) performed bench tests on the Sirognathograph to examine the reliability and reproducibility of the equipment, found that a movement of the magnet did not change the continuous recording, although a 10° rotation of the magnet did cause a 1 mm deviation of the movement traces from the axis origin. Alteration in the base line position due to head movement was reduced by ensuring that the subject maintained a fixed gaze on a point immediately ahead. Lewin (1985) confirmed that the Sirognathograph has superior linearity to the Kinesiograph and this is an important feature if multiple comparisons were to be made. The use of computer programs to prepare and analyse the results would eliminate operator bias in the preparation and computation of the results.

The variation of recorded values between male and female subjects has been identified by Pullinger et al. (1987) and Howell (1988) as significant. The aims of this study was not to identify "sexual dimorphism" (Howell 1987b), but to measure the reproducibility of measurements for a single individual between two recording sessions. The assurance that the subjects chosen included equal numbers of males and females, each acting as their own control, did help to eliminate such diversity. Few of the previous investigations on jaw displacement, have used a subject group of larger than twelve people; notable exceptions being Howell (1987b) and Proschel and Hoffmann (1988). Although the current group of twenty subjects is not extensive, it was felt to be sufficient to monitor the trends of the factors studied.

There was a possibility that the recorded values may show a variation as result of the time of day or week on which they were taken. No previous study has looked at the possible effects of time differences on the recording of jaw displacement. The fact the jaw movement sequences were recorded minutes apart or two weeks apart, did not change the reproducibility of the recordings for the same subject.

The two food materials used in the study, peanut and chewing gum, were chosen as they have been extensively used in other projects and are valid in comparisons with similar investigations. They also provided different types of food bolus allowing a wide range of mandibular movement to be monitored. It was anticipated that the recordings made with two food materials would show differences, although the reproducibility with which a single person triturates the bolus, was a factor that had not been previously investigated. The homogeneity of chewing gum allowed improved reproducibility of results by comparison with peanut which was readily fragmented and more difficult to masticate reproducibly. These results allow the recommendation that chewing gum is the preferential food to use when assessing the reproducibility of the chewing action.

Bates et al. (1975b) identified changes in chewing action according to the way in which the bolus was triturated although extensive comparisons of unilateral or bilateral chewing actions have not been routinely used in previous studies. The reproducibility of the results recorded showed that the free choice chewing movement gave increased reproducibility in comparison with unilateral chewing on the right or left sides. The command of specific chewing actions creates more variation in the results and this should be avoided in future studies.

A total of ten parameters were selected for comparison for each chewing movement on the basis that they have been used world wide in different studies and provide a means of comparing information with other studies. They also provided a wide measure of the variation in the characteristics of the chewing cycle to be monitored. The majority of parameters show few differences in mandibular displacement during function on an intra- or inter- sessional basis. This implied that there was a minimal effect on jaw displacement as a result of "learning" during the recordings and there was little difference in the mandibular movements of a single person from one week to the next where the subject group had no clinical symptoms relating to temporomandibular joint dysfunction or myofascial pain. It was concluded that jaw displacement recordings, following the described standardisation techniques, would produce reproducible results on the basis of time.

6. SUMMARY

The simultaneous recording of mandibular movement and EMG from jaw muscles requires a complex and accurate recording system for data collection. Such a system has been developed and used in this study to measure muscle activity and jaw movements on a group of twenty subjects (10 males and 10 females).

The equipment was easily used and set-up on each of the subjects and has been shown to give a linear output for the recording of jaw displacement. The computerisation of the results, enabled the efficient handling of a large volume of data with the assurance that the information would be assessed in a standard way.

Ten parameters were selected to test the recordings for intra- and inter- sessional reproducibility. The results measured range, velocity and time of movement of individual chewing cycles. The mean values recorded for these parameters were comparable with those previously published. Due to the inevitable variability in the values of the parameters describing jaw displacement, each subject was used as his or her own control and all results were confirmed using an ANOVA.

All subjects showed a large variation in the values of each of the measured parameters calculated according to the food that was eaten although generally there were fewer variations when gum was used. Greater variability was observed during directed, unilateral chewing movements than the free choice chewing side or sides. The parameters describing the time of the jaw movement generally show few differences on an intra- and inter-session basis. The opening time (timeopen) and the intercuspal pause (timedwel) for gum and nut, showed good reproducibility on the basis of session but the closing time (timeclos) exhibited a greater variability. The combination of opening and closing times later gave rise to poor reproducibility of the total time measurement, a parameter more commonly quoted in the literature. Both the maximum opening and closing velocities showed wide variations between recording sessions with both food types. Lateral movements were significantly more consistent than either the vertical or antero-posterior movements which was true on the basis of session, run and of the food chewed. The marked variability in the measurements of the antero-posterior and vertical measurement suggest that they are not suitable for routine use in comparative studies.

The response of the subject to operator instructions during chewing, shows an increase in the variation of the displacement recorded. Masticatory movements are not normally consciously controlled and the introduction of a deliberate action would require thought and precipitates variation in the individual response.

7. CONCLUSIONS

1. Multiple comparisons for the same individual over a period of time, require that the choice of chewing movements be left to the subject.
2. The preferred food is gum. The fewer variations shown during the chewing of gum may be due to the homogeneity of the bolus during chewing and consistency of bolus size. This compares with the easy fragmentation of peanut and the greater variation in bolus size.
3. The values for opening time, intercuspal pause time and lateral mandibular displacement gave reproducible results and are to be recommended for future studies.
4. The other seven parameters examined were less consistent and could not be recommended for comparative purposes. This includes the total time of the chewing cycle which is commonly quoted in the literature.
5. If this recording technique is to be used in the treatment and follow-up of symptomatic patients, then criteria for comparison must be established. It is hoped that the results of this study will provide the guidelines for such investigations.

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9. APPENDIX

Cumberland Area Health Service



CONSENT FOR RESEARCH

Title . . . Family Name		M.R.N.	
Given Names		C.M.O.	
Address	Street	Age	Sex
Suburb		Postcode	H.I.S.
		Adm. date.	

Title of Project:

Study of the Human Masticatory System

Name(s) of Chief Investigator(s):

Dr. Sally Ellis & Professor I. Klineberg.

Purpose: To use EMG and jaw tracking to study the effects on jaw muscle and jaw joint function of dental treatment involving changes in occlusion of the teeth.

Methods and Demands: You will be asked to attend the clinical research unit on two occasions for a period of approximately two hours each time. Recordings will be made from jaw muscles to study their behaviour and associated jaw movement, while you chew peanuts and then gum and also whilst moving the jaw in certain ways such as open, close, to the right to the left. These procedures are not painful and will be no more inconvenient than routine dental treatment. Recordings will be made using electrodes either attached to the skin surface with an adhesive or as small hooks for muscles within the hair line, and sometimes for deep muscles, needles will be used to place fine wires in position. The application of surface electrodes is entirely painless. The placement of hook electrodes causes slight discomfort and when using needle electrodes a surface anaesthetic spray will be used to avoid discomfort.

Risks, Inconveniences and Discomforts Which May Occur:

The skin is prepared for electrode attachment by removing oil and grease with alcohol wipes, and in males, fine abrasive paper may be necessary if the skin is particularly thick and tough. This is a routine procedure and will not involve any risk of damage to or infection of the skin or underlying tissues. The skin preparation is necessary to reduce skin impedance to allow the recording of underlying muscle activity, and when surface electrodes are used an electrode jelly is added to improve the conductivity of the recording electrode. If you are wearing complete dentures a simple adjustment of the lower denture is necessary and will be corrected immediately after the study with no ill effects to the fit or comfort of the denture.

All procedures and equipment used will be fully explained to you before beginning. The projects involves the recording of electrical impulses from muscles and does not involve any electric stimulation to the muscles.

I have been asked to participate in the above research study and give my consent by signing this form on the understanding that:

1. The research study will be carried out in a manner conforming with the principles set out by the National Health and Medical Research Council
2. The general purposes, methods and demands and the possible risks, inconveniences and discomforts which may occur during the study have been made known
3. Refusal to take part in this study will not affect the treatment of my condition.
4. I am volunteering to take part in this study and I may withdraw at any time
5. This research has been approved by the Cumberland Area Health Service Research and Human Ethics Review Committees.

Signature: _____ Date: _____
(By subject, if over 18 years, otherwise by guardian or next friend)

Witnessed by: _____ Project Approval No: _____
of: _____

Appendix 1. The form used for all subjects to obtain written consent for the recordings to commence.

The Parramatta Hospitals



Westmead Hospital
Dental Clinical School

Title MS		Family Name		D.R.N.	
Given Name A. H.				D.O. 03-10-35	
Address		Street		Age 53	Sex F
Suburb		Postcode		H.I.S. Adm. Date	

CLINICAL EXAMINATION:

Date.	18-10-88									
1. T.M. JOINTS	R	L	R	L	R	L	R	L	R	L
Pain — lateral	0	0								
Pain — posterior	0	0								
Clicking	0	0								
Crepitation	0	0								
Limited movement	0	0								
Subluxation	0	0								
Inflammation	0	0								
Score	0	0								

2. JAW MUSCLE PALPATION	R	L	R	L	R	L	R	L	R	L
Temporal ant.	0	0								
Temporal post.	0	0								
Temporal tendon	0	0								
Masseter origin	0	0								
Masseter body	0	0								
Masseter insertion	0	0								
Masseter deep	0	0								
Pterygoid med.	0	0								
Pterygoid lat.	0	0								
Digastric ant.	0	0								
Digastric post.	0	0								
Sternomastoid origin	0	0								
Sternomastoid body	0	0								
Sternomastoid insertion	0	0								
Trapezius origin	0	0								
Trapezius insertion	0	0								
Tongue	0	0								
Submandibular gp.	0	0								
Score	0	0								
Total Score	0	0								

3. MANDIBULAR MOVEMENTS	mm	Pain localisation and degree	Clicking point mm Hard/Soft	Provocation test Pain/fatigue at bruxofacet location	Deviation open — close	Deviation open — close
Opening Max. incisor dist. 2.1/3.1	38				R	L
Vertical overbite	3					
Horizontal overbite	3					
Max. laterotrusion R	10					
Max. laterotrusion L	7					
Max. protrusion	5					
Score pain						
Date.						
MANDIBULAR MOVEMENTS REASSESSMENT	mm	Pain	Click mm	mm	Pain	Click mm
Opening Max. incisor dist.						
Max. laterotrusion R						
Max. laterotrusion L						
Max. protrusion						
Score pain						

DR-10

Appendix 2. A copy of the Orofacial Pain and Dysfunction form used in the examination of each subject before recordings commenced.

4. OCCLUSAL ANALYSIS

Type of jaw relationship: ant. post vertical transverse

MOP—RP—

all teeth

12345678

87654321

12345678

87654321

all teeth

12345678

87654321

12345678

87654321

Slide: RP-IP distance ant-post.: 1 mm
vertical: 0 mm
lateral displacement: 0 mm to R/L

Laterotrusion R—

12345678

87654321

12345678

87654321

Laterotrusion L—

12345678

87654321

12345678

87654321

Protrusion —

12345678

87654321

12345678

87654321

Bruxofacets—

12345678

87654321

12345678

87654321

Partial denture

satisfactory

not satisfactory

Complete denture

satisfactory

not satisfactory

Degree of attrition

inc

can

prem

mol

open bite

Soft tissue trauma:

Tongue/cheek biting

Deviant swallow

Vertical dimension*

Initial lateral guidance

Max. tooth

inclined

distal

Mucosal ridging

Tongue ridging

severely reduced

optimal ☒ reduced ☐ severely reduced ☐

Score. MOP: RP: Lat. R: Lat. L: Pro: Brux: Attrition:

DATA CODE.

T M Joint lateral palpation:

1 - mild discomfort; 2 - moderate discomfort/pain (palpebral reflex); 3 - severe pain; 4 - very severe.

Muscle palpation: 1 - mild discomfort; 2 - moderate discomfort/pain; 3 - severe pain; 4 - very severe.

Mandibular movement pain: 1 - mild discomfort; 2 - moderate discomfort/pain; 3 - severe pain; 4 - very severe.

Code "IP", "RP" etc: Circle tooth with black for contact, red for interference.

Attrition:

0 - nil; 1 - only enamel; 2 - dentine; 3 - dentine extensively; 4 - dentine and secondary dentine involved

5. RADIOGRAPHIC SURVEY AND SPECIAL TESTS

(Summary of radiographic analysis and other special tests)

NO ABNORMALITIES DETECTED

6. ASSESSMENT

SUMMARY OF SUBJECTIVE AND OBJECTIVE FINDINGS

1. Joints: WITHIN NORMAL LIMITS

2. Muscles: NO ABNORMALITIES DETECTED

3. Jaw Movements: FLUENT

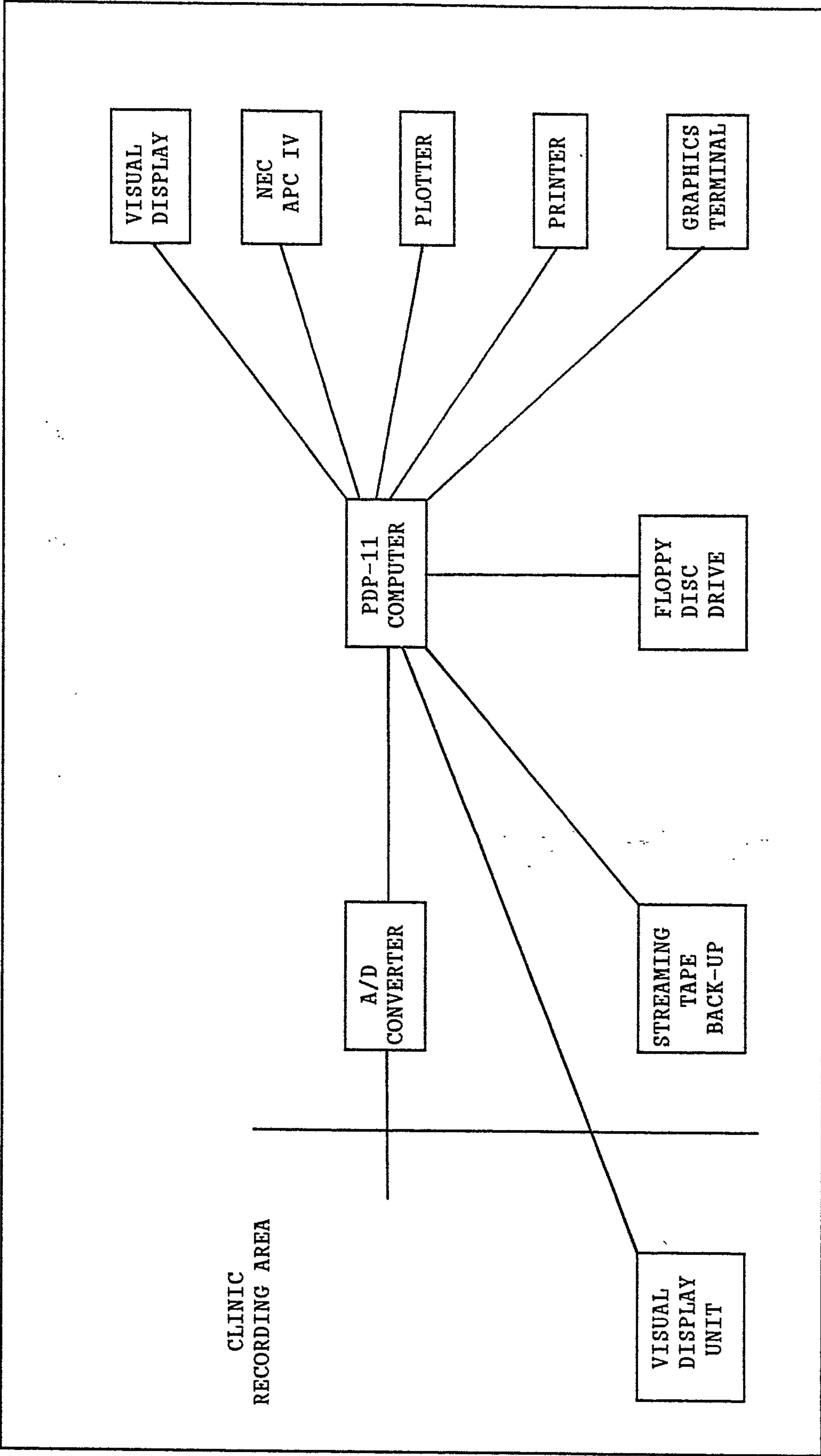
4. Occlusal Features: STABLE BILATERAL CONTACTS, MINIMAL WEAR

5. Parafunction: NONE EVIDENT

6. Psychological Profile: STABLE

DIAGNOSIS: ROUTINE DENTAL TREATMENT

TREATMENT PLAN: ENG AND JAW TRACKING RECORDINGS



Appendix 3. Hardware components and their connections.

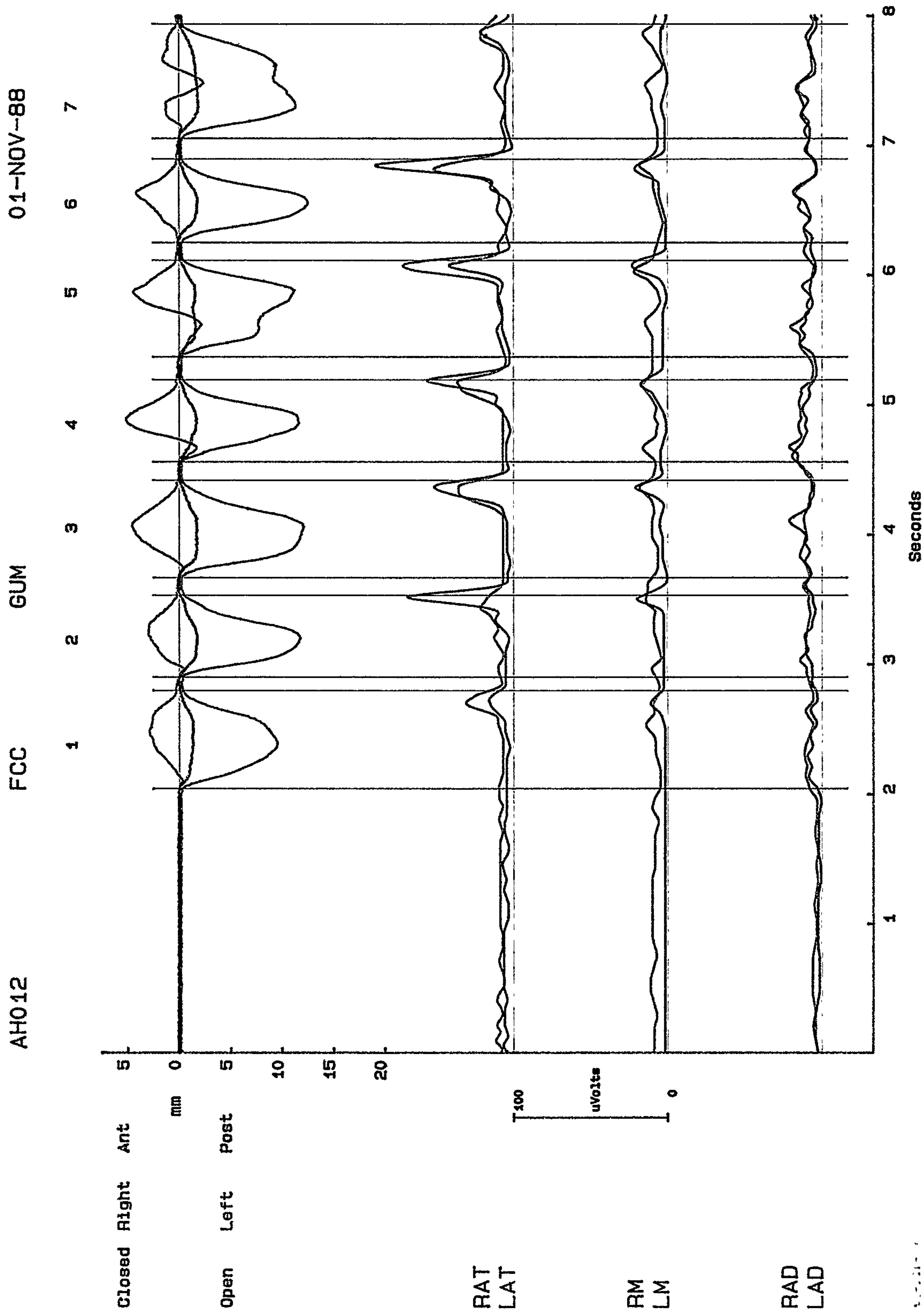
NAME	AGE	SEX	O'BITE (mm)	O'JET (mm)	NO. TEETH	PREF CHEW
SAB	45	M	3	3	27	L
SA	35	M	0	0	25	L
TC	22	M	3	2	28	R
GC	50	F	3	3	28	R
CE	23	M	3	2	28	L
SE	28	F	2	2	28	R
AH	53	F	3	3	25	R
JH	62	M	3	2	24	R
RH	35	M	3	3	28	L
SH	35	F	2	2	30	R
IG	32	M	3	2	28	L
MJ	56	M	2	2	24	R
HK	32	F	1	1	25	R
DL	31	F	3	3	28	R
AM	20	M	3	2	31	L
SM	22	F	2	2	32	R
SMU	26	F	3	2	26	R
RS	18	M	1	1	32	R
MS	44	F	0	1	22	R
GZ	46	F	2	2	28	R

Appendix 4. A Table to Show the Age, Occlusal Relationship and the Preferred Chewing Side of the Subjects Included in the Study.

Date recorded: 01-NOV-88
 Comments: 1ST RECORDING MDS PROJECT
 Raw data file: AH012.RAW
 Action recorded: FCC
 Food or comment: GUM

Units : times in milliseconds, displacements in millimetres, velocities in millimetres per second.																										
Stk No.	Total Time	Zmax	Time	Clos	Dwel	Max	Ant	Max	Pos	Max	Lt	Max	Rt	Max	Opn	Min	Vmax	Open	Vmax	Clos	VmxO	Time	VmxC	Err Code	Rej Usr	Stk No.
1	860	345	405	110	0.0	-1.4	-0.3	2.9	-9.5	-0.1	52	52	95	245	0000	R	1									
2	770	300	330	140	0.1	-1.8	-0.6	3.0	-11.7	-0.1	90	90	100	130	0000		2									
3	890	395	350	145	0.0	-1.8	-0.4	4.6	-12.1	-0.1	92	92	115	115	0000		3									
4	810	300	330	180	0.1	-1.8	-1.7	5.2	-11.6	-0.1	71	71	145	140	0000		4									
5	880	510	230	140	-0.0	-1.8	-2.2	4.4	-11.2	-0.1	71	71	110	95	0000	R	5									
6	805	315	330	160	0.0	-1.9	-0.0	4.1	-12.5	-0.1	85	85	130	130	0000		6									
7	1005	260	620	125	0.0	-2.0	-2.5	1.6	-11.4	-0.2	81	81	125	520	0000	R	7									
8	795	355	280	160	0.0	-1.8	-0.1	4.1	-12.2	-0.1	78	78	115	100	0000		8									
9	930	390	365	175	0.0	-1.9	-0.1	4.5	-12.8	-0.1	80	80	125	125	0000		9									
10	885	315	310	260	0.0	-1.8	0.0	3.8	-12.0	-0.1	81	81	100	140	0000		10									
11	730	210	275	245	0.0	-1.8	-0.0	3.2	-10.9	-0.1	89	89	140	160	0000		11									
12	945	375	295	275	-0.0	-1.9	-0.3	3.6	-12.2	-0.2	66	66	140	145	0000		12									
13	855	320	285	250	-0.0	-1.9	-0.2	3.1	-12.0	-0.2	68	68	130	135	0000		13									
14	1255	775	280	200	-0.0	-1.6	-0.3	3.6	-9.5	-0.2	36	36	50	85	0000	R	14									
15	835	385	330	120	-0.1	-1.9	-1.5	1.1	-10.1	-0.2	71	71	140	115	0000	R	15									
16	1165	390	610	165	-0.1	-2.1	0.2	3.0	-12.3	-0.2	68	68	130	495	0000	R	16									
17	705	265	295	145	-0.0	-1.8	0.2	2.7	-11.0	-0.2	72	72	105	190	0000	R	17									
18	760	275	315	170	-0.0	-1.8	0.2	3.1	-12.0	-0.2	67	67	140	90	0000	R	18									
19	845	320	330	195	-0.0	-2.1	0.2	3.4	-14.4	-0.2	73	73	100	115	0000	R	19									
20	815	325	320	170	-0.0	-2.1	0.0	3.1	-12.8	-0.2	68	68	165	110	0000	R	20									
21	905	275	320	310	-0.0	-2.0	0.0	5.1	-13.0	-0.2	90	90	115	140	0000	R	21									
22	1060	515	230	315	-0.0	-2.1	-2.0	4.5	-12.5	-0.3	68	68	125	95	0000	R	22									
23	2000	1070	635	295	-0.1	-2.1	0.3	2.4	-13.2	-0.3	76	76	150	110	0000	R	23									
N =	10																									
Mean	842	328	315	199	0.0	-1.8	-0.3	3.9	-12.0	-0.1	80	80	124	132			72									
S.D.	71	55	31	52	0.0	0.1	0.5	0.7	0.5	0.0	9	9	16	17			10									
Min	730	210	275	140	-0.0	-1.9	-1.7	3.0	-12.8	-0.2	66	66	100	100			54									
Max	945	395	365	275	0.1	-1.8	0.0	5.2	-10.9	-0.1	92	92	145	160			87									
Rnge	215	185	90	135	0.1	0.2	1.7	2.2	1.9	0.1	26	26	45	60			33									

Appendix 5. The output from the program EXAMIN. This gives specific data for each chewing stroke.



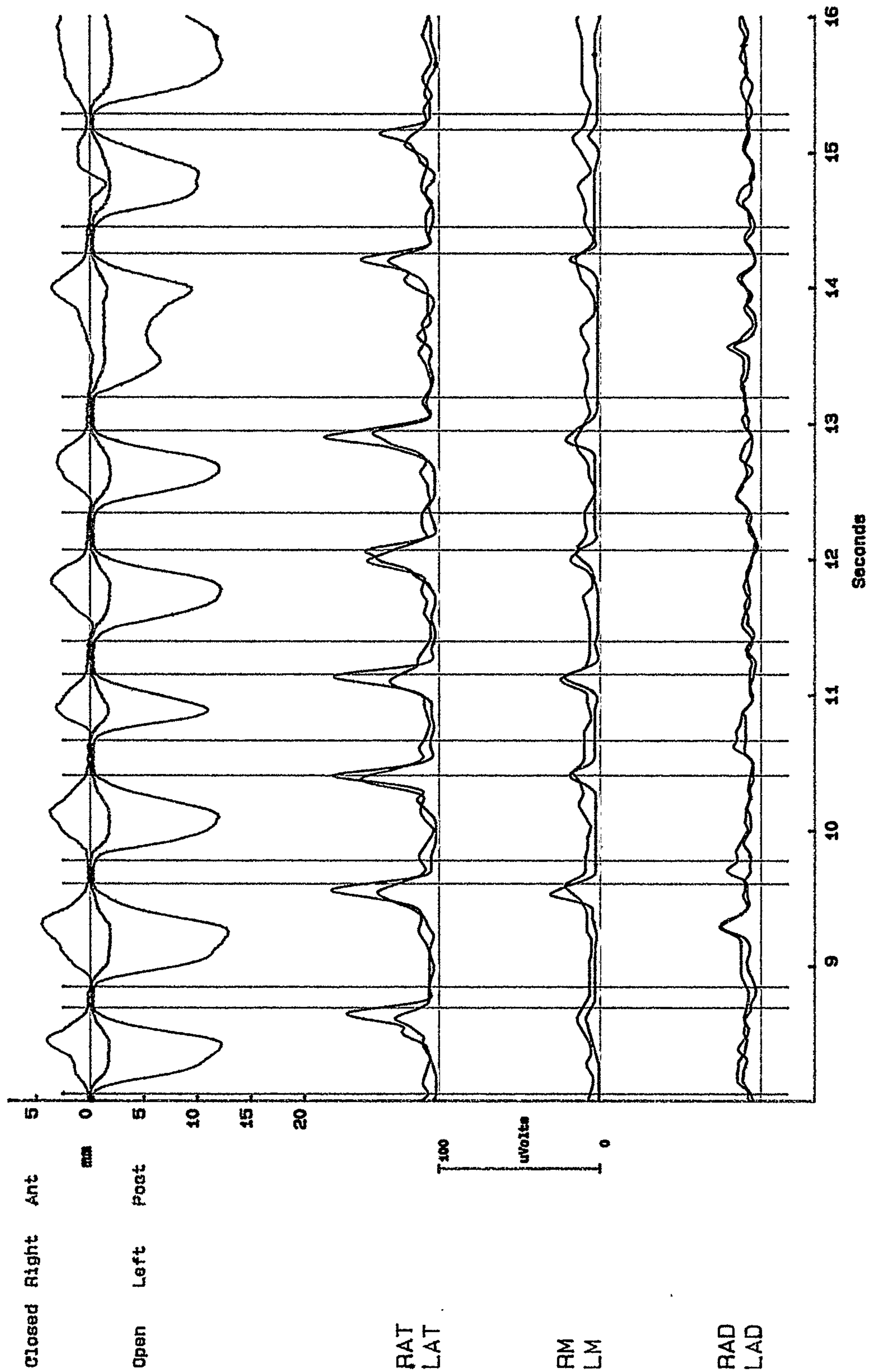
Appendix 6. A plot to show the tracings obtained for the displacement data (x=sagittal, y=lateral, z=frontal) and EMG data for right & left anterior temporal (RAT, LAT) right & left masseter (RM, LM) and right & left anterior digastric muscles (RAD, LAD).

01-NOV-88

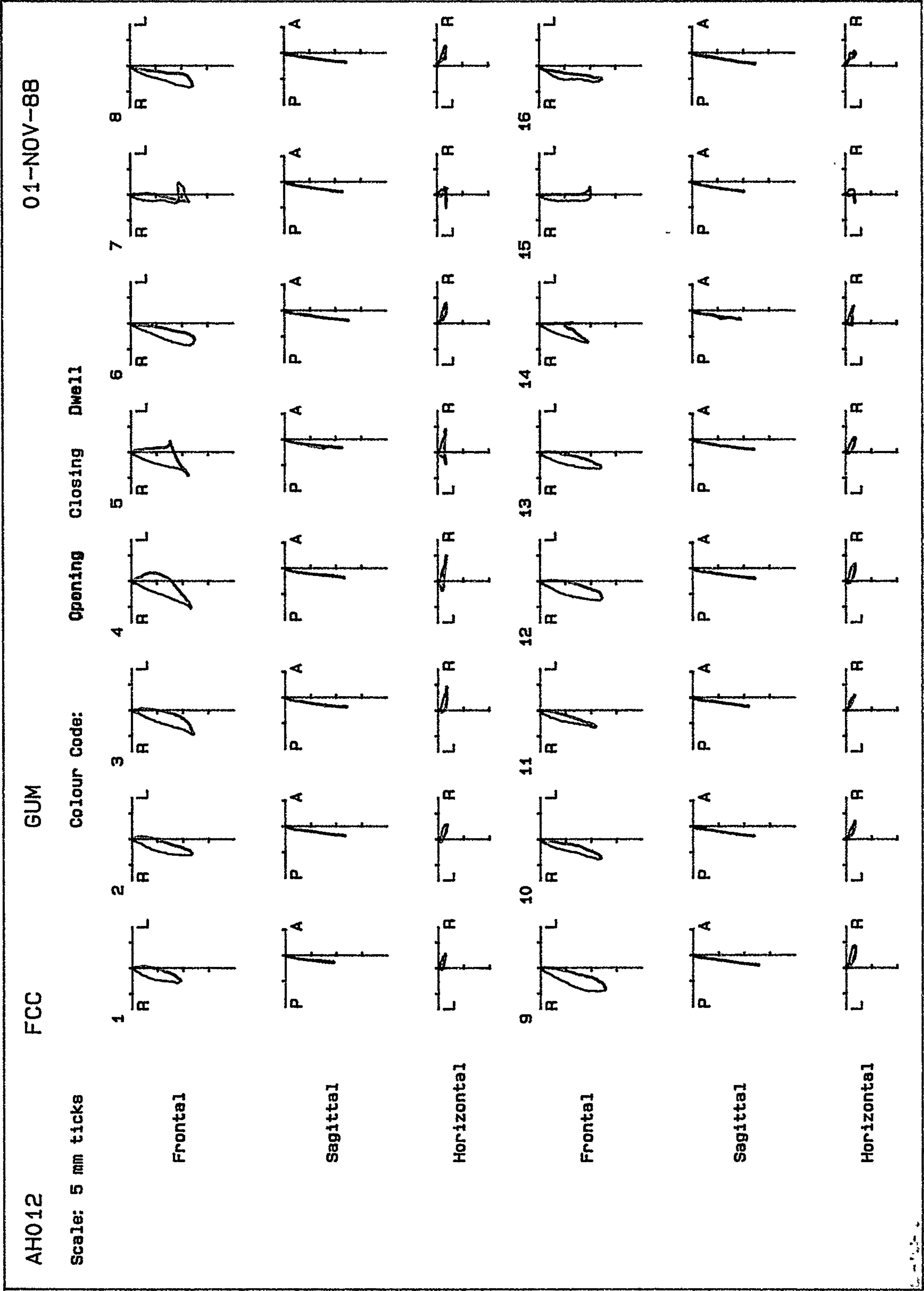
GUM

FCC

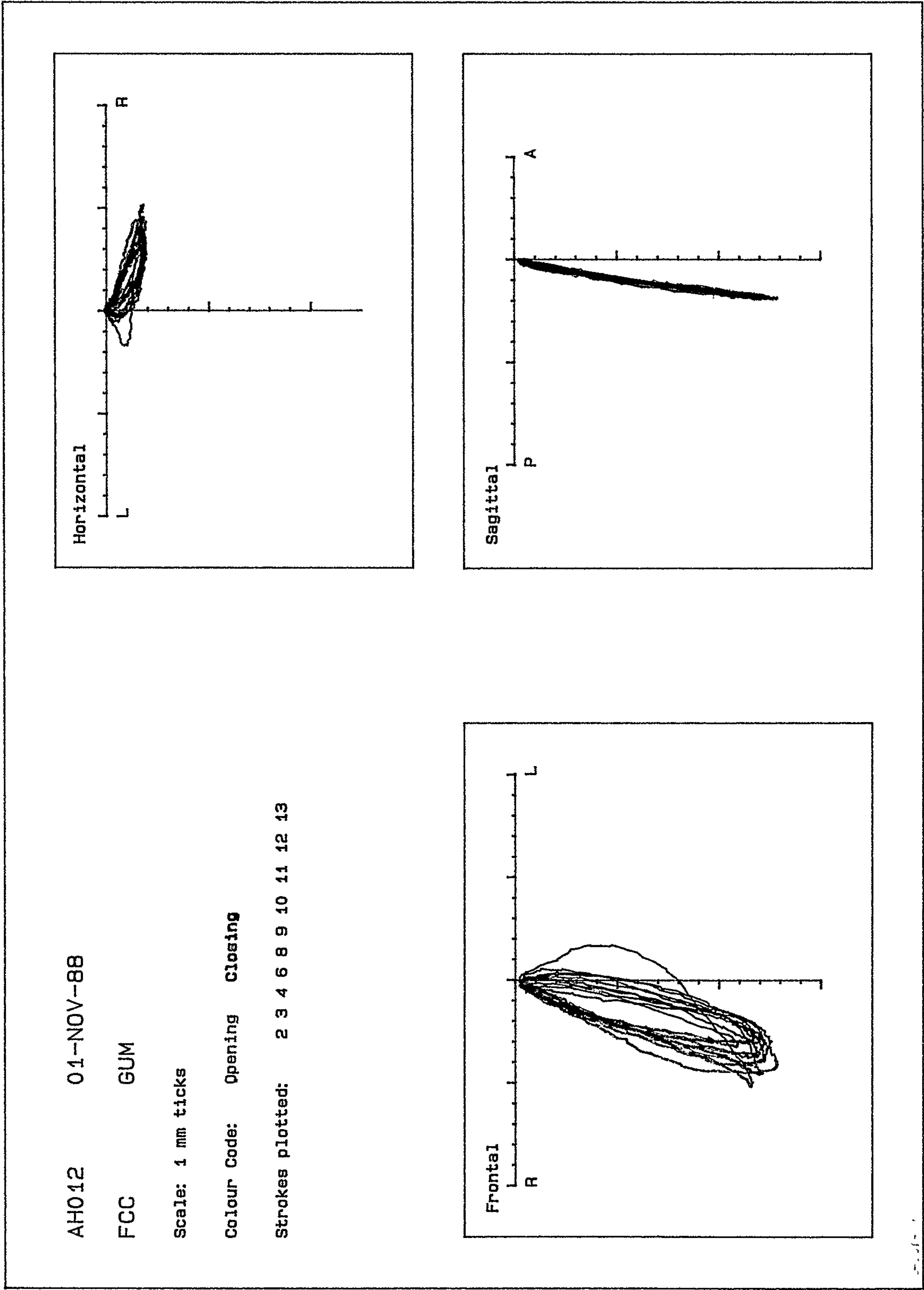
AH012



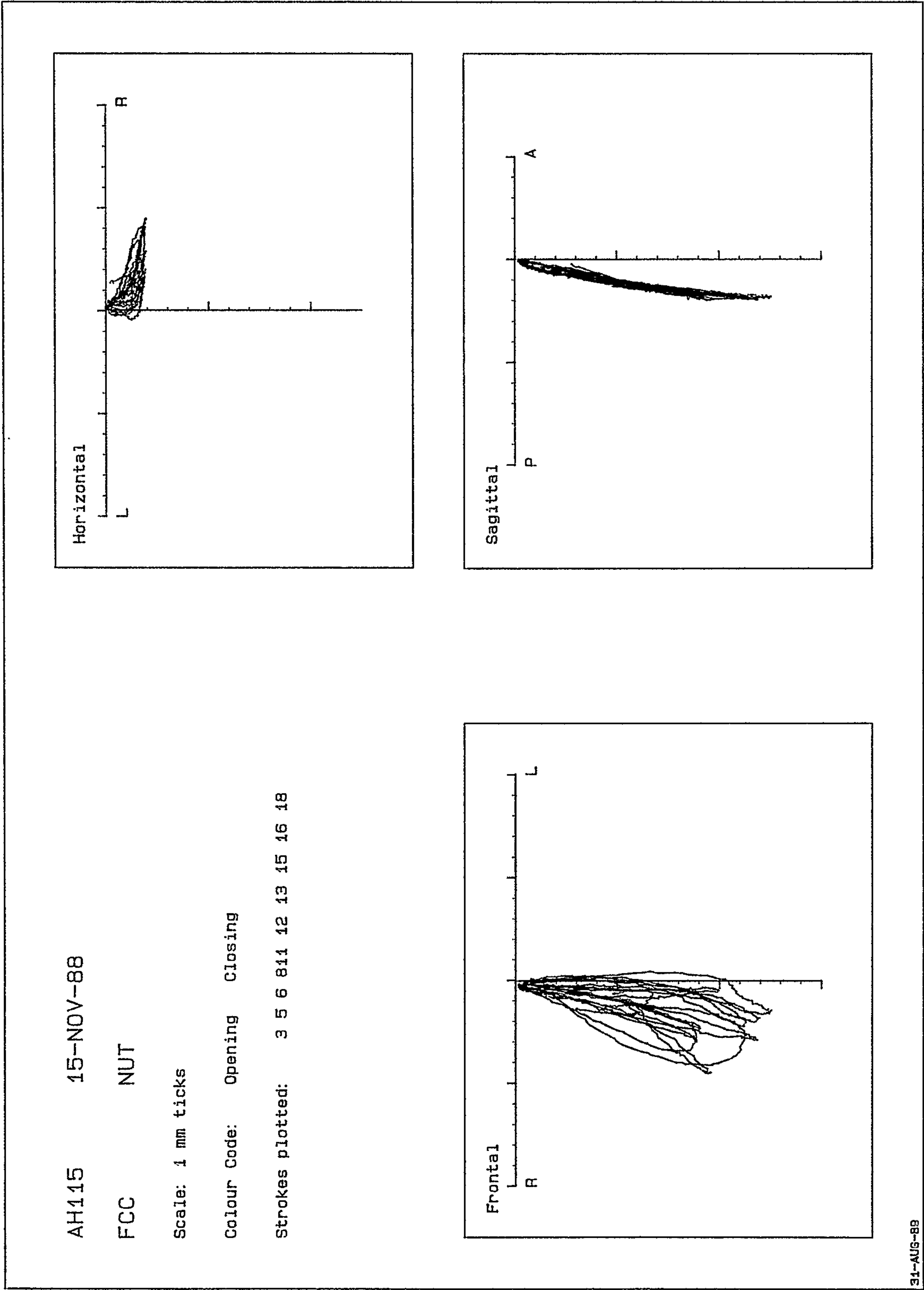
Appendix 6. (continued)



Appendix 7. STROKE. A plot to show the individual chewing strokes for free choice chew (FCC) of gum, for subject AH, illustrated in the frontal, sagittal and horizontal planes.



Appendix 8a. An OVERLA plot to show the composite tracing for subject AH on the second session for the free choice chewing (FCC) of gum as shown in the frontal, sagittal and horizontal planes.



PARAMETER MEASURED	MIN VALUE	MAX VALUE	MEANS OF PEOPLE	STANDARD DEVIATIONS
TIME TOTAL (MSEC)	568	1641	920	200
TIME OPEN (MSEC)	141	613	340	89
TIME CLOSE (MSEC)	234	680	373	76
TIME DWELL (MSEC)	30	571	206	82
TIME MOVE (MSEC)	418	1196	714	146
MAX OP VEL (MM/SEC)	35	150	83	24
MAX CL VEL (MM/SEC)	41	153	79	19
AP RANGE (MM)	0.7	8.1	3.3	1.2
LAT RANGE (MM)	1.1	10.7	5.3	1.9
VERT RANGE (MM)	7.3	21.7	13.7	2.4

Appendix 9. The mean and standard deviations for the ten parameters calculated for the population PEOPLE.

Food = GUM				
Variable	Min	Max	Mean	S.D.
TIMETOTL	700	1639	983	197
TIMEDWEL	30	572	204	86
TIMEOPEN	240	613	384	79
TIMECLOS	259	680	395	78
TIMEMOVE	530	1197	780	135
APRANGE	1.0	8.1	3.3	1.3
LATRANGE	1.5	10.7	5.6	1.9
VERRANGE	8.5	21.7	14.0	2.4
MAXOPVEL	35	137	75	21
MAXCLVEL	41	153	76	18

Appendix 10a.

Food = NUT				
Variable	Min	Max	Mean	S.D.
TIMETOTL	567	1641	857	183
TIMEDWEL	55	525	209	79
TIMEOPEN	141	583	296	76
TIMECLOS	234	585	351	68
TIMEMOVE	418	1115	648	126
APRANGE	0.7	7.6	3.1	1.1
LATRANGE	1.2	9.4	5.0	1.8
VERRANGE	7.3	18.6	13.3	2.3
MAXOPVEL	38	150	91	25
MAXCLVEL	41	145	82	19

Appendix 10b.

Appendix 10a & 10 b The mean, maximum, minimum and standard deviation for the ten parameters used to describe chewing movements calculated on the basis of the food eaten (nut and gum).

					T	T	T	T	T	A	L	V	M	M
					I	I	I	I	I	P	A	E	A	A
					M	M	M	M	M	R	T	R	X	X
					E	E	E	E	E	A	R	A	O	C
					T	O	C	D	M	N	A	N	P	L
					O	P	L	W	O	G	N	G	V	V
					T	E	O	E	V	E	G	E	E	E
					L	N	S	L	E				L	L
SESSION 0	RUN 0	G	F	1040	399	405	236	804	2.9	5.4	13.3	69	68	
			L	1048	402	429	216	832	3.4	5.8	14.0	71	71	
			R	934	377	386	171	763	2.9	5.8	12.4	70	72	
		N	F	885	311	372	203	683	3.0	5.0	13.4	85	79	
			L	876	293	355	228	649	3.1	4.7	12.6	85	75	
			R	829	301	344	183	645	3.2	5.0	13.0	87	82	
	RUN 1	G	F	999	392	397	211	789	3.3	5.7	14.0	75	75	
			L	1002	378	399	225	777	3.4	5.8	13.3	72	71	
			R	907	369	370	169	739	3.4	5.5	13.7	79	79	
		N	F	854	297	341	216	638	3.2	5.1	13.2	91	83	
			L	871	299	339	234	638	3.3	4.9	12.6	85	78	
			R	803	283	325	195	608	3.1	5.0	12.5	91	83	
SESSION 1	RUN 0	G	F	1058	409	418	2330	827	3.6	5.9	14.6	73	73	
			L	1033	400	406	227	806	3.9	6.0	14.2	74	75	
			R	888	353	361	174	713	3.4	5.2	14.1	79	80	
		N	F	884	299	377	208	675	3.3	5.1	13.9	92	80	
			L	886	302	363	221	664	3.0	5.2	13.5	90	81	
			R	806	292	330	183	623	3.4	5.1	14.0	96	92	
	RUN 1	G	F	985	387	393	205	780	3.5	5.7	14.9	78	79	
			L	988	379	403	206	782	3.4	5.8	14.8	78	79	
			R	915	369	373	174	741	3.4	5.8	14.6	82	87	
		N	F	873	295	361	217	655	3.4	5.3	13.9	96	85	
			L	874	300	352	221	653	3.1	5.0	13.4	91	81	
			R	848	230	357	202	646	3.2	5.2	13.9	97	86	

Appendix 11. The mean values for PEOPLE for each of the ten selected parameters for each recorded chewing stroke, on the basis of FOOD, ACTION, RUN and SESSION.

SESSIONAL COMPARISON PARAMETER MEASURED	FOOD = GUM			TOTAL
	FCC	RTC	LTC	
NUMBER	40	40	40	120
TIME TOTAL (MSEC)	8	8	11	27
TIME OPEN (MSEC)	4	4	4	12
TIME CLOSE (MSEC)	4	4	8	16
TIME DWELL (MSEC)	4	6	4	14
TIME MOVE (MSEC)	7	7	10	24
MAX OP VEL (MM/SEC)	3	5	4	12
MAX CL VEL (MM/SEC)	4	6	5	15
AP RANGE (MM)	9	9	9	27
LAT RANGE (MM)	2	3	3	8
VERT RANGE (MM)	5	10	9	24
TOTAL	50	62	67	

Appendix 12a. The number of times paired T-test values, for chewing of gum according to the SESSION of the recording, were significant >0.01 level for the ten parameters measured on the basis of the side on which the gum was chewed.

SESSIONAL COMPARISON PARAMETER MEASURED	FOOD = NUT			TOTAL
	FCC	RTC	LTC	
NUMBER	40	40	40	120
TIME TOTAL (MSEC)	7	10	10	27
TIME OPEN (MSEC)	4	6	5	15
TIME CLOSE (MSEC)	4	6	5	15
TIME DWELL (MSEC)	1	7	4	12
TIME MOVE (MSEC)	4	7	6	17
MAX OP VEL (MM/SEC)	8	5	5	18
MAX CL VEL (MM/SEC)	6	2	6	14
AP RANGE (MM)	10	7	7	24
LAT RANGE (MM)	3	3	1	7
VERT RANGE (MM)	7	6	6	20
TOTAL	54	59	56	

Appendix 12b. The number of times paired T-test values, for the chewing of nut according to the SESSION of the recording, were significant >0.01 level calculated for the ten parameters measured on the basis of the side on which the nut was chewed.

RUN COMPARISON PARAMETER MEASURED	FOOD = GUM			TOTAL
	FCC	RTC	LTC	
NUMBER	40	40	40	120
TIME TOTAL (MSEC)	6	17	13	36
TIME OPEN (MSEC)	2	6	5	13
TIME CLOSE (MSEC)	2	10	6	18
TIME DWELL (MSEC)	2	7	4	13
TIME MOVE (MSEC)	3	15	9	27
MAX OP VEL (MM/SEC)	9	10	4	23
MAX CL VEL (MM/SEC)	5	8	6	19
AP RANGE (MM)	6	8	6	20
LAT RANGE (MM)	6	3	3	12
VERT RANGE (MM)	8	9	5	22
TOTAL	49	93	61	

Appendix 13a. The number of times paired T-test values, for the chewing of gum according to the RUN of the recording, were significant >0.01 level calculated for the ten parameters measured on the basis of the side on which the gum was chewed.

RUN COMPARISON PARAMETER MEASURED	FOOD = NUT			TOTAL
	FCC	RTC	LTC	
NUMBER	40	40	40	120
TIME TOTAL (MSEC)	6	8	4	18
TIME OPEN (MSEC)	4	2	0	6
TIME CLOSE (MSEC)	6	1	1	8
TIME DWELL (MSEC)	4	2	1	7
TIME MOVE (MSEC)	5	3	1	9
MAX OP VEL (MM/SEC)	7	8	1	16
MAX CL VEL (MM/SEC)	7	7	5	19
AP RANGE (MM)	6	7	3	16
LAT RANGE (MM)	2	2	0	4
VERT RANGE (MM)	1	3	4	8
TOTAL	48	43	20	

Appendix 13b. The number of times paired T-test values, for the chewing of nut according to the RUN of the recording, were significant >0.01 level calculated for the ten parameters measured on the basis of the side on which the nut was chewed.

Appendix 14. A diagram to show the incidence of significant differences greater than 0.01 on the basis of RUN according to an ANOVA.

A Table To Show The Incidence of Significant Differences Greater Than 0.01 on the Basis of RUN According To an ANOVA.																						
Subject	AH	AM	CE	DL	GC	GZ	HK	IG	JWH	MJ	MS	RH	RS	SAB	SA	SE	SH	SM	SMU	TC	Total	
TIME TOTAL	*	*	*	*	*						*	*	*	*	*				*		10	
TIME OPEN	*	*			*						*	*	*	*	*	*			*		9	
TIME CLOSE	*						*				*		*	*				*			6	
TIME DWELL					*						*	*		*				*			3	
TIME MOVE	*	*		*	*						*	*	*	*	*			*			9	
MAXOPVEL	*		*		*				*		*			*		*		*			8	
MAXCLVEL	*		*						*	*	*				*		*	*			6	
LATRANGE									*	*	*	*					*				3	
APRANGE												*	*								1	
VERRANGE			*			*							*	*	*				*		5	
TOTAL (n=10)	6	3	4	2	5	1	0	1	3	1	6	5	1	5	4	2	1	4	6	0		

A Diagram To Show The Incidence of Significant Differences Greater than 0.01																						
Occuring on the Basis of SESSION According To An ANOVA.																						
Subject	AH	AM	CE	DL	GC	GZ	HK	IG	JWH	MJ	MS	RH	RS	SAB	SA	SE	SH	SM	SMU	TC	Total	
TIME TOTAL	*	*		*	*	*		*	*	*		*	*	*	*			*		*	14	
TIME OPEN				*	*	*			*			*	*	*				*		*	9	
TIME CLOSE	*	*		*	*	*		*	*			*	*	*	*	*		*	*	*	13	
TIME DWELL		*		*	*		*		*	*		*	*	*	*		*	*	*	*	13	
TIME MOVE	*	*	*	*	*	*		*	*			*	*	*	*			*	*	*	14	
MAXOPVEL		*		*	*			*						*			*	*	*	*	8	
MAXCLVEL	*		*	*	*			*					*			*	*				8	
LATRANGE							*	*			*		*	*		*					6	
APRANGE		*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	16	
VERRANGE	*			*			*	*	*		*	*	*	*	*		*	*	*	*	12	
TOTAL (n=10)	5	6	3	9	8	5	4	6	7	3	3	7	8	9	5	2	5	8	6	4		

Appendix 15. A diagram to show the incidence of significant differences greater than 0.01 on the basis of SESSION according to an ANOVA.

Appendix 16. A diagram to show the incidence of significant differences greater than 0.01 on the basis of FOOD according to an ANOVA.

A Table To Show The Incidence of Significant Differences Greater than 0.01 Occuring On the Basis of FOOD According to an ANOVA.																					
Subject	AH	AM	CE	DL	GC	GZ	HK	IG	JWH	MJ	MS	RH	RS	SAB	SA	SE	SH	SM	SMU	TC	Total
TIME TOTAL	*	*	*		*	*	*	*	*	*	*		*	*	*			*	*		15
TIME OPEN	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	19
TIME CLOSE		*	*		*	*		*	*	*	*			*	*	*	*	*	*		13
TIME DWELL		*	*	*	*	*	*	*	*		*	*		*	*	*	*	*	*	*	17
TIME MOVE	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	19
MAXOPVEL	*	*		*	*	*	*	*	*	*			*	*	*	*		*	*	*	16
MAXCLVEL			*	*	*	*		*			*		*			*		*		*	10
IATRANGE	*	*	*	*		*	*				*			*	*		*		*	*	12
APRANGE	*	*				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	17
VERRANGE	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	18
TOTAL (n=10)	7	8	7	7	8	10	8	8	9	7	9	4	7	9	9	7	6	7	8	8	8

A Table To Show The Incidence of Significant Differences Greater than 0.01 Occuring

On the Basis of ACTION According to An ANOVA.

Subject	AH	AM	CE	DL	GC	GZ	HK	IG	JWH	MJ	MS	RH	RS	SAB	SA	SE	SH	SM	SMU	TC	Total
TIME TOTAL			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	16
TIME OPEN								*	*		*	*	*	*	*	*	*	*	*	*	7
TIME CLOSE		*	*		*		*	*	*		*	*	*	*	*	*	*	*	*	*	12
TIME DWELL	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	17
TIME MOVE		*	*		*		*	*	*		*	*	*	*	*	*	*	*	*	*	12
MAXOPVEL		*				*	*	*			*	*	*	*	*	*	*	*	*	*	11
MAXCLVEL		*		*		*	*	*			*	*	*	*	*	*	*	*	*	*	13
LATRANGE	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	14
APRANGE	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	15
VERRANGE	*	*	*		*	*	*	*			*	*	*	*	*	*	*	*	*	*	12
TOTAL (n=10)	5	8	7	4	4	7	8	9	7	4	7	10	7	10	6	5	4	8	4	5	

Appendix 17. A diagram to show the incidence of significant differences greater than 0.01 on the basis of ACTION according to an ANOVA.