Muscle Activity and Jaw Movements as Predictors of Chewing Performance

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Chewing performance can be defined in terms of the reduction in food particle size after 15 chewing strokes. In this study, the relationship between chewing performance and electromyographic activity was investigated to develop optimal values of electromyographic variables, based on their ability to predict chewing performance. Electrognathographic and electromyographic recordings from surface electrodes over the digastric (abductor), masseter, and temporalis (adductors) muscles were made from 24 subjects while they chewed a hard fruit gum. A moderate negative correlation was found between the food particle size and the root mean square calculation for masseter activity (–.48; P < .01). Weaker positive correlations were found between particle size and the asynchrony of ipsilateral and contralateral anterior temporalis muscles (.36; P < .05). A multiple regression model of electromyographic and electrognathographic variables was able to predict chewing performance with an R^2 value of .66. If chewing performance is used as an output measure of masticatory function, it may be possible to determine optimal ranges for electromyographic variables and jaw movements.
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key words: chewing performance, jaw movement, electromyography

Chewing requires two main processes: selection and breakage.[1] Selection involves the manipulation of unreduced food particles onto occluding tooth surfaces by movements of the tongue, jaws, lips, and cheeks. In monkeys, movement of the tongue and lips not only helps select food, but it also influences the shape of the chewing cycle.[2] Some aspects of jaw movement in humans are fair predictors of chewing performance.[3] Jaw movement is not produced by any single muscle, but it is affected by a variety of synergistic combinations of functioning units within several jaw muscles.[4] For any particular occlusal force and direction, there are certain combinations of muscles that generate the force most efficiently.[5] Therefore, the relation between muscle activity and jaw movement is complicated by the large number of distinct units in each masticatory muscle that can function independently of one another.[6] Although the occlusal force vector generated at a particular tooth by even the smallest physiologic unit can be determined theoretically, the number of possible interactions with other units makes it difficult to predict jaw movement on the basis of electromyographic (EMG) activity recorded with only a few surface electrodes. In spite of this complexity, associations have been found, for example between lateral grinding movements and contralateral jaw muscle activity.[7–9]

Claims[10–12] have been made for the value of EMG recordings in the diagnosis of dysfunctional movements and activity of temporomandibular disorders (TMD). In a review of the literature, Lund and Widmar[13] concluded that, as yet, the data from asymptomatic subjects are not adequate to support the use of EMG recording in the diagnosis of dysfunction. Diagnostic tests require a substantial baseline of both normative data and a reliable gold standard of disease to allow predictions to be made with acceptable levels of accuracy, precision, sensitivity, and specificity.[14]

The purpose of the present study was to determine whether chewing performance could be used to identify an optimal range of muscle activity. These data might define a useful baseline against which putative muscle dysfunction could be compared. In addition, evidence of an association between optimal muscle activity and optimal jaw movements derived from an earlier study[3] was sought.

Materials and Methods

Subjects

The subjects who participated in the present study are the same subjects who participated in earlier studies[3,15] of jaw movement and chewing performance. The sample comprised 12 women and 12 men with a mean age of 27.3 years. None of the subjects had signs or symptoms of TMD.

Chewing Performance

Chewing performance on the left and right sides of the dentition was determined using weighed whole almonds as a test food. Subjects chewed for 10 and then 20 times on either side. The food particle size and area were measured using digital image analysis.[15] The data were analyzed, and the median size category after 10 and 20 chewing strokes was calculated using the Rosin-Rammler function according to Olthoff et al.[16] The particle size was calculated for 15 chewing strokes using the function derived by Olthoff et al.[16]

Data Collection

Electromyographic recordings were made using surface electrodes over the posterior and anterior aspects of the ramus of the mandible, the region of the anterior temporal muscle, and under the chin over the region of the anterior belly of the digastric muscles on either side of the jaw. Although these regions of sampling may not represent the activity of muscles defined in anatomic terms, the electrical activity sampled from these regions is referred to for convenience as EMG of superficial and deep masseter, anterior temporalis, and anterior digastric muscles.

The subjects chewed on a hard fruit gum for 15 seconds on the left side first and then on the right side. Incisal movements were simultaneously recorded in three planes using a Sirognathograph (Siemens, Benheim, Germany). The signals were digitized at 300 Hz and were converted to ASCII files using Bio-Pak equipment (Bio-Research, Milwaukee, WI). The data for vertical displacement were used to separate the EMG data into a series of chewing cycles. The mean duration for each chewing cycle was calculated and is referred to as the cycle time.

Electromyography

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

The difference between the iEMG for ipsilateral and contralateral adductors was calculated for each closing phase, and the mean was calculated (Fig 1). This variable is referred to as iEMGipco. A point found along the time axis during each muscle burst equally divided the area under the smoothed and rectified curve. This point was used to define the midpoint of the burst. The difference between the midpoints of ipsilateral and contralateral adductors was used to express the phase lag between contractions of the chewing and nonchewing sides and is referred to as LAGipco. From the manner in which the phase lag was calculated, a negative value indicated that the ipsilateral midburst point occurred earlier (lower time value) than did the contralateral midburst point. The difference between the integral of each adductor (temporalis and masseter) and the abductor (digastric) of the same side, during the adductor burst period, was calculated. This was done to represent the net adductor iEMG available for that muscle during closing (Fig 2). This variable is referred to as iEMGnet.

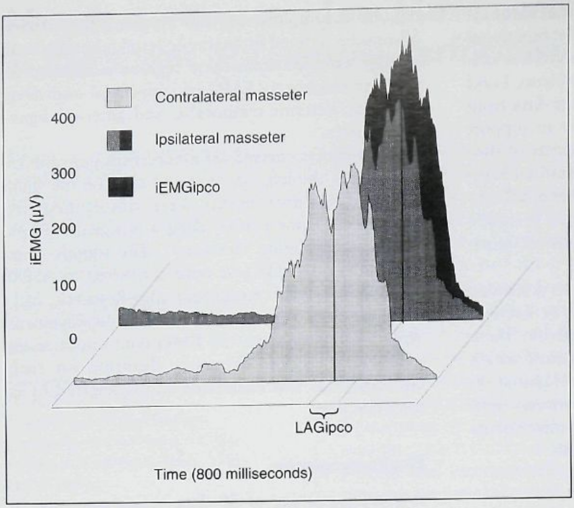

Fig 1 Rectified and smoothed EMG signals for one chewing cycle. The areas under the curve for the contralateral masseter EMG values are superimposed over the ipsilateral masseter EMG values. The variable iEMGipco represents the difference between these two areas. The time difference between the center of each area is represented by the variable LAGipco.

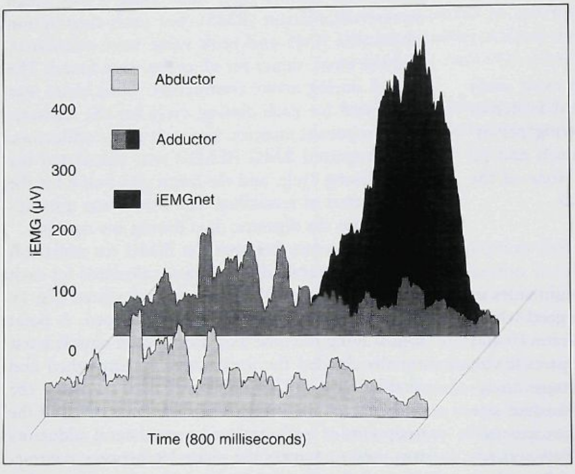

Fig 2 The area between the adductor (masseter and temporalis) and abductor (digastric) curves during the closing phase reflects the net adductor EMG and is represented by the variable iEMGnet.

In view of the potential for voltage reversals to describe some of the characteristics of an EMG wave form, the number of turns and the mean turn interval was calculated after the method described by Junge and Clark.[17]

Jaw Movement

Displacements in the frontal and sagittal plane of the midincisal point were transformed onto a grid of frequency distributions. The frontal grid consisted of a matrix 40 rows deep with 20 columns for each side of the midline. For every data record of displacement (x, y), a count was stored in the grid window that enclosed those coordinates. Statistical analysis of the frequency distribution of displacements was used to describe the characteristics of the most frequented pathways during chewing.[3] They included the following variables:

Table 1 Mean iEMG and SD for Ipsilateral and Contralateral Adductors and Digastric Muscles During Closing and LAGipco

	Masseter (μVs)		Temporalis (μVs)		Digastric (μVs)		LAGipco (ms)		
	Ipsilateral	Contralateral	Ipsilateral	Contralateral	Ipsilateral	Contralateral	Masseter	Temporalis	Digastric
Mean	48.5	34.1*	42.9	36.0	21.5	19.8	20.3	–32.5	–15.6
SD	29.8	24.8	25.0	24.7	8.87	8.48	37.6	42.6	26.2

*$P < .01$.
A negative value for LAGipco reflects an early contraction of the ipsilateral adductor.

1. ANGLE was the angle between the most frequented approach to the region of maximal intercuspation and the horizontal plane: the higher the angle near intercuspation, the flatter the chewing cycle would appear to be in the frontal plane.
2. BIMODE was the percentage of rows in which a bimodal pattern in the frequency distribution was found: the higher the percentage, the more separated would be the opening and closing pathways.

Statistical Analysis

A two-sample *t* test was used to investigate differences between ipsilateral and contralateral chewing sides and gender differences. A simple linear regression was used to test for correlations between particle size, EMG, and electrognathographic (EGN) variables. A stepwise multiple regression was used to develop a model to predict particle size, using variables derived from EMG data. A second model was derived using EGN- in addition to EMG-derived variables. All data were analyzed using Statgraphics Plus (Manugistics, Rockville, MD) software.

Results

The sample mean for the masseter EMG (RMS) during its active burst was 145.4 μV (standard deviation [SD] 60.8), and for the temporalis anterior it was 133.6 μV (SD 55.7). The mean value for the digastric RMS during the opening phase of movement was 53.8 μV (SD 21.3). No statistically significant difference was found between the superficial and deep masseter RMS; thus, these values were combined for analysis.

The iEMG values for ipsilateral and contralateral chewing sides were compared, and a statistically significant difference was found between their sample means for the masseter muscles ($P < .001$), but not for the temporalis or digastric muscles (Table 1). The sample mean for the phase lag between ipsilateral and contralateral masseters midburst was 20.3 milliseconds (SD 37.6), which indicates that the masseter burst on the contralateral side usually occurred before that on the ipsilateral side. The sample mean for the phase lag for the temporalis muscle (–32.5 milliseconds, SD 42.6) indicated that for the temporalis muscle, the ipsilateral midburst usually occurred before that of the contralateral side. A pattern similar to that of temporalis muscles was found for the digastric muscles, with a lag between the ipsilateral and contralateral sides of –15.6 milliseconds (SD 26.2).

The sample mean for iEMGnet was 27.0 μVseconds (SD 24.2) for the masseter and 21.4 μVseconds (SD 20.5) for the temporalis. The mean duration of the burst period was 149.2 milliseconds (SD 100.9) for the masseter muscles and 133.1 milliseconds (SD 77.5) for the temporalis muscles. The sample mean for the average turn interval was 160.9 μV (SD 45.1) for the masseter muscles and 155.9 μV (SD 45.4) for the temporalis muscles.

Gender Differences

The mean iEMG for the temporalis muscle was higher in women (51.1 μVseconds, SD 22.2) than in men (34.8 μVseconds, SD 25.4) ($P < .02$). The mean for iEMGnet (temporalis) for women (98.0 μV, SD 30.7) was higher than for men (72.9 μV, SD 37.2) ($P < .02$) (Table 2).

Correlations Between Variables

Several EMG variables were found to correlate negatively with particle size. These included the RMS values for the masseter, temporalis, and digastric muscles, and the masseter turn frequency. The

Table 2 Sample Means (and SD) for iEMG (μVs) in Temporalis Muscle During Chewing in Men and Women

	Men (n = 12)	Women (n = 12)	
Mean iEMG	34.8 (25.4)	51.1 (22.2)	*
Mean iEMGnet	72.9 μV (37.2)	98.0 μV (30.7)	*

*$P < .05$

Table 3 Correlation Coefficients for Particle Size, EGN, and EMG Variables

	Particle size	Masseter RMS	Masseter iEMG	Masseter iEMGnet	Masseter iEMGipco	Temporalis LAGipco	Digastric iEMG	BIMODE	ANGLE	Cycle time
Particle size		***	*	*	*	*	*	*	**	*
Masseter RMS	–.48		****	****	***	*	**		*	**
Masseter iEMG	–.33	.94		****	***	**	****		**	*
Masseter iEMGnet	–.30	.92	.91		***	**	**	*	*	*
Masseter iEMGipco	–.31	.53	.54	.49		*	**			
Temporalis LAGipco	.36	–.38	–.44	–.42	–.36		*		****	
Digastric iEMG	–.32	.62	.71	.42	.45	–.33			*	*
BIMODE	–.41	.27	–.22	–.32	.04	–.26	.03		*	
ANGLE	.46	–.42	–.44	–.43	–.17	.53	–.33	–.48		
Cycle time	–.34	.39	.37	.33	.24	.00	.32	.11	.04	

*$P < .05$
**$P < .01$
***$P < .001$
****$P < .002$

highest correlation was found for masseter RMS (coefficient –.48, $P < .01$). The variable iEMGipco for masseters also had a negative but weaker correlation with particle size (coefficient –.31, $P < .05$) (Table 3). A positive correlation between particle size and the LAGipco for temporalis muscles was found (coefficient .36, $P < .05$). The sample mean value for this phase lag was negative, indicating that the ipsilateral temporalis burst usually occurred before the contralateral burst.

A negative correlation between particle size and cycle time was found (–.34, $P < .01$). A positive correlation between ANGLE and particle size was found (.46, $P < .001$). Correlations were found between ANGLE and several EMG variables; the most significant was with LAGipco for temporalis (.53, $P < .002$) (Table 3).

No correlations were found between the RMS peak values for adductors and particle size. A strong correlation of .91 ($P < .001$) was found between the turns interval for masseter and masseter RMS.

Multivariate Models

A stepwise multiple regression was used to generate a number of models using EMG data as the dependent variables. It was possible to predict 44% of the variance of the vertical dimension of jaw opening from EMG variables (Table 4, Fig 3). The masseter, temporalis, and digastric RMS, iEMG, and iEMGnet had powerful influences in the model. A model constructed to predict chewing cycle time had an adjusted R^2 value of .48 and was dominated by masseter iEMG and the duration of the temporalis burst. The relationship between EMG variables and jaw movement patterns was revealed in a model in which ANGLE was the dependent variable. The components of the model for ANGLE were dominated by variables representing temporalis muscle activity.

The logarithm of the particle size was predicted with an adjusted R^2 value of .51 using EMG variables. The masseter RMS, the iEMG, and the temporalis LAGipco were the dominant adductor variables. The model also included the digastric iEMG.

A model containing both EGN data and EMG variables provided a more accurate prediction of particle size than either group on its own. This combined model had an adjusted R^2 value of .66 (Table 5, Fig 4). The EMG components of the model included most of those selected for EMG

Table 4 Components of Multivariate Models With EMG Data as Independent Variables

	Opening max $R^2 = .44$	Cycle time $R^2 = .48$	ANGLE $R^2 = .46$	Log particle size $R^2 = .51$
Masseter				
RMS	+ +			– – –
iEMG	+ + + +	+ + + +	–	– – –
iEMGnet	– – – –			–
Temporalis				
RMS			– –	
iEMG		+ +		
LAGipco			+ +	+ + + +
Burst time		– – –	– –	
iEMGnet	+	– –		
Digastric				
iEMG	– – – –	– –		– –

For each model, the influence of each component is indicated by either + or – signs. The number of signs reflects the F factor for adding or removing the variable from the model (one sign = 4 factor units).
R^2 values are adjusted.

Table 5 Components of a Multivariate Model With Both EMG and EGN Data as Dependent Variables, With the Logarithm of Particle Size as the Dependent Variable

Independent variables	Influence*
ANGLE	+ +
BIMODE	– – –
Cycle Time	– – –
Masseter RMS	– – –
Masseter iEMG (log)	+ +
Masseter iEMGnet	+
Temporalis LAGipco	+ +

R^2 adjusted = .66.
R^2 adjusted = .75, including indicator variable (gender).
*For each model, the influence of each component is indicated by either + or – signs. The number of signs reflects the F factor for adding or removing the variable from the model (one sign = 4 F factor units).

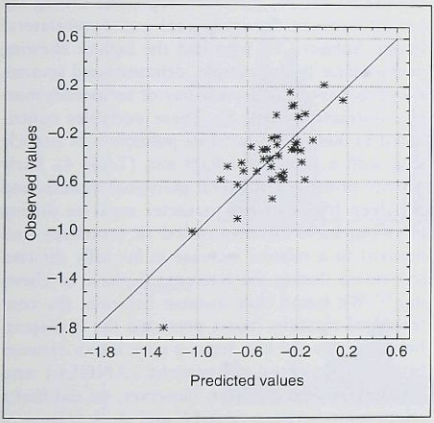

Fig 3 Predicted values for particle size calculated from the EMG model (Table 4) and the observed values for particle size. Both scales are logarithmic. The R^2 value of the multivariate model was .51.

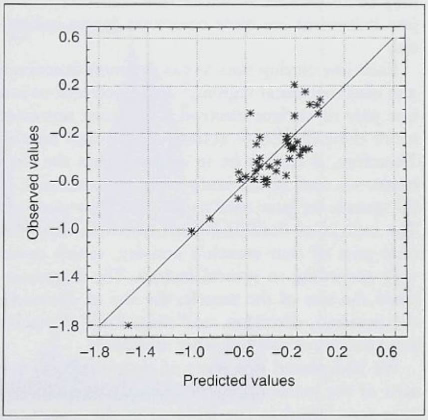

Fig 4 Observed values for particle size and those calculated from the EMG and EGN model, excluding the indicator variable gender (Table 5). The R^2 value of this model was .66.

alone and those listed in Table 4. The EGN variables all had high coefficients in the model. A model consisting of just the three EGN variables, ANGLE, BIMODE, and chewing time, had an adjusted R^2 value of .53.

The addition of gender as an indicator variable raised the predictive accuracy of the combined EGN/EMG model to an adjusted R^2 value of .75. Indicator variables help to show the main effects of a grouping of data in a regression model.[18]

Discussion

A tough variety of fruit gum was chosen so as to make the chewing task challenging enough to bring out characteristics of muscle activity that may not have emerged if a test food that required little effort, such as chewing gum, were used instead. The test food that was used to measure chewing performance in a previous study of the same subjects was almonds. This choice was made because nuts fracture cleanly into particles whose size can be measured. Unfortunately, neither fruit gum nor nuts are ideal for both purposes. Some variables of jaw movements, particularly vertical dimension, are reduced when nuts are chewed in comparison to tougher food.[19] However, chewing patterns and muscle activity were found to be similar when either hard or soft gum was chewed, provided the chewing rate remained constant.[20] In an earlier study,[21] significant differences were not found in jaw movements as bolus consistency changed during progressive chewing on the same food, which may be an indication that certain characteristics of jaw movement are quite consistent for an individual.

Each jaw closing muscle has different functional and electrophysical regions.[8] The placement of just one pair of surface electrodes does not represent more than the EMG activity of a small region. Therefore, it cannot be in assumed that the electrodes we used in this study were representative of the muscle we have used to describe their position. The individual data from each electrode represent only part of that muscle's activity, which could vary according to several factors. The factors include the size of the muscle; the site of electrode; the position, direction, and magnitude of occlusion; and the activity of other muscles.[21]

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

Asymmetry Between Ipsilateral and Contralateral Sides

Differences in the EMG activity between chewing and nonchewing sides have been reported by a number of authors.[7,9,22–24] We found a positive correlation between the variable iEMGipco for masseters and particle size (see Table 3). Thus, small differences in integrated EMG of ipsilateral and contralateral muscles were associated with small particle size. These differences were expressed as a working/balancing ratio by Hylander et al,[25] who found that as the ratio approached 1.0, the amount of overall occlusal force during chewing increased.

Asynchrony Between Ipsilateral and Contralateral Sides

Differences in the midburst time of the ipsilateral and contralateral adductors have been reported.[7,23,25] Our results confirm that the contralateral masseter reaches its midburst point usually before the ipsilateral muscle (LAGipco is negative, Table 1). However, the midburst point of the ipsilateral temporalis muscle usually occurred before that of the contralateral side (LAGipco positive), an asynchrony also observed by Moller[23] and reported for the posterior temporalis by Takada et al.[26] We found a negative correlation between the asymmetry of masseter muscles (iEMGipco) and the asynchrony of temporalis muscles (LAGipco, Table 3). It is necessary to recall that LAGipco values were mostly negative; the lowest values, therefore, represent a long lag period between the ipsilateral and contralateral bursts. Subject CH, who had the highest chewing performance in the sample, demonstrated symmetry of masseter and asynchrony of temporalis muscle contractions (Fig 5). These variables contributed to making an accurate prediction of particle size, with a residual of 0.09 mm (Table 4). Early activity of the contralateral pterygoid muscles and the deep fibers of the masseter muscles during chewing have corresponded in monkeys and humans to a relative increase in laterally directed movement during the intercuspal phase of chewing.[8,9] We found that in most subjects, the contralateral masseter burst preceded the ipsilateral burst, but we did not detect a correlation between laterally directed movement (ANGLE) and LAGipco for the masseter. However, we did find a relationship between ANGLE and the LAGipco of the temporalis. This positive correlation (.53) indicated that lower angles of approach to intercuspation (ANGLE) were associated with an early ipsilateral contraction of the temporalis muscle. An additional predictor of ANGLE was the ipsilateral temporalis burst time (see Table 4). In an earlier study by Wilding and Lewin,[3] ANGLE was found to be a strong predictor of chewing performance; it remained an influence in the statistical model containing both EMG and EGN variables (see Table 5). These results suggest that asynchronous contraction of the anterior temporalis muscle contributes to a longer intercuspal period with improved chewing performance.

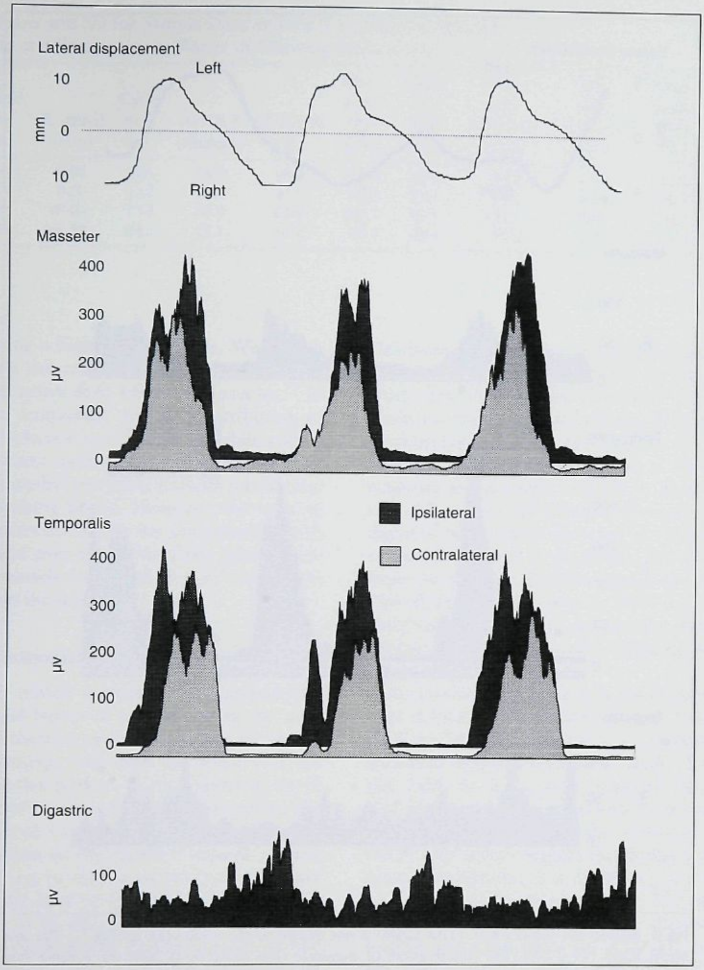

Fig 5 Rectified and smoothed EMG signals for the ipsilateral and contralateral adductor muscles during three chewing strokes on the left side for subject CH. The lateral displacement in the frontal plane of the midincisor point is included. The difference between ipsilateral and contralateral masseter curves (iEMGipco = 112 μVseconds) and the phase lag between ipsilateral and contralateral temporalis muscles (LAGipco = –17.2 milliseconds) contributed to accurately predicting the superior chewing performance of this subject (Table 6).

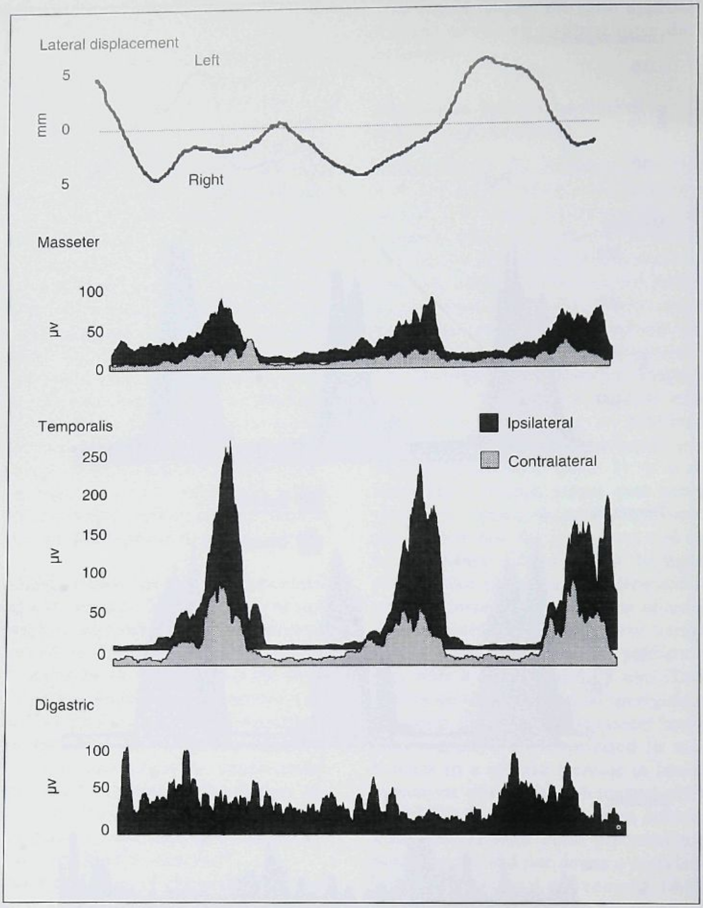

Fig 6 Results for subject KD. (This figure is not drawn to the same scale as Fig 5.) The low mean RMS (65.0 µV), the coactivation of digastric (low iEMGnet), and the reverse synchrony of temporalis muscles (LAGipco = 9.8 milliseconds) contributed to accurately predicting the inferior chewing performance of this subject (Table 6). The reversed sequence of the first two chewing cycles, which approach intercuspation from the nonchewing side, were reflected by a more vertical approach to intercuspation (ANGLE = 75 degrees).

The relative significance of temporalis activity as a determinant of chewing performance was suggested by Thexton and McGarrick,[4] who found that the temporalis muscles in the cat were particularly active at a time late in jaw closure after tooth contact with the bolus. Takada et al[26] found that a longer duration of the posterior temporalis was a feature of chewing harder food. These observations, together with our findings, confirm the suggestion made by Moller[23] that a primary role of asynchronous temporalis contraction is to move the jaws through the intercuspal zone without nec-

Table 6 Means and SD for Sample Data and for Two Subjects Selected From the Top and Bottom of the Range of Chewing Performance

	Particle size (mm)	Residual (mm)	Cycle time (s)	ANGLE (degrees)	BIMODE (%)	Masseter RMS (μV)	Digastric RMS (μV)	Masseter iEMGnet (μVs)	Masseter iEMGipco (μVs)	Temporalis RMS (μV)	Temporalis LAGipco (ms)
Mean	2.10	0.00	0.81	54.8	28.6	145.5	53.9	88.4	2.74	133.6	–5.43
SD	0.53	0.00	0.12	15.8	21.2	60.9	21.3	39.0	6.81	55.8	7.48
CH	1.18	+0.09	1.10	53.9	67.6	262.1	82.1	164.1	9.40	274.1	–17.21
KD	2.98	+0.53	0.52	75.1	51.4	65.7	39.4	56.4	4.27	157.6	9.82

essarily exerting a high occlusal force. When high occlusal forces are required, the masseter muscles become more active than temporalis muscles.[27] In this role, the temporalis may be contributing to food particle selection and placement, while adductors with greater mechanical advantage such as masseter and medial pterygoid muscles provide the necessary breaking forces. However, the roles of adductor muscles are clearly not circumscribed and are able to take over a secondary role when necessary. If one muscle is "knocked out," others are recruited to do the work.[28]

Digastric Coactivation

The adductor muscle activities were characterized by well-defined bursts of activity during the closing phases of chewing cycles and during relaxation phases of opening. Although the activity of the digastric muscles peaked during opening, there was considerable sustained activity throughout the cycle (Figs 5 and 6). Miles and Madigan[29] found that coactivation of the digastric muscle always occurred during isometric mastication but was modified by the level of force being generated by the adductors or by the expectation that the resistance to jaw closing may suddenly yield. It has been suggested that the coactivation of digastric muscles during closing is the result of a separate pool of motor neuron activity concerned with control, rather than primary opening.[5] We found the digastric iEMG to be negatively correlated with particle size, indicating that increased digastric activity during opening was associated with improved chewing performance. Digastric iEMG was selected in the process of generating some multivariate models, in particular, in the prediction of maximum opening (see Table 4).

The method we used in the present study to quantify digastric coactivation (iEMGnet) was not adequate because the masseter and digastric muscles have different masses, origins, and lines of action. Therefore, subtracting electrical activity from their two surface electrodes (of uncertain position) may not represent any functional relationship between these two muscles. It would have been preferable to use the timing of the activity of masseter and digastric muscles to detect coactivation. However, the absence of a clearly defined digastric burst makes the onset of contraction and relaxation difficult to determine. The data derived from the variable iEMGnet must nevertheless be viewed with some suspicion. With this caveat, we cautiously suggest that interactions that emerged between iEMGnet and other variables are of passing interest.

An inverse correlation was found between masseter iEMGnet and particle size (see Table 3). The iEMGnet also was selected as a component in the statistical model developed to predict particle size (see Table 4). It has been suggested that coactivation of digastric muscle provides some stiffness to the jaw movement, and this stiffness is protective.[29] Our results suggest that if this protection is more than optimal (low iEMGnet), it is inhibitory to chewing performance. Subject KD, who had a high median particle size (poor chewing performance) and a low value for iEMGnet, may reflect the influence of excessive coactivation (Table 6, Fig 6). Multivariate models for maximum opening and cycle time are both influenced by the iEMGnet for masseter and temporalis muscles, respectively (see Table 4).

Gender Differences

No gender differences in the variables of masseter muscles were found, but the iEMG value for temporalis muscles was significantly higher in women than in men; this may have accounted for the increase in value for temporalis iEMGnet in women (see Table 2). This increase in activity is consistent with the observations made that women use more muscle power to achieve the same occlusal force as men.[21,30] Gender differences in chewing performance were reported in a previous study[3]: the median particle size after 15 chewing strokes was significantly larger in women than in men. This appears to be in spite of significant increases in the temporalis muscle activity of the same women who volunteered for the present study. However, maximum occlusal forces are well in excess of those required to chew even hard test foods, and so it is likely that the occlusal forces available to women are more than adequate to achieve food breakage.[31] Slagter et al[31] suggested that a smooth uninterrupted chewing cycle may make greater demands on muscle power than food breakage. There is some evidence in our study and in other studies[7,25,28,29] to suggest that the temporalis muscle plays a greater role than does the masseter muscle in directing lateral jaw movement (ANGLE, Table 4). The gender differences we found in temporalis muscles, rather than in masseter muscles, suggest that it may be movement rather than occlusal force for which women use greater muscle activity. These data still do not account for the observed gender differences in chewing performance.

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

Multivariate Models

The model selected to predict chewing performance from multiple EMG variables was moderately accurate (R^2 = .51, see Table 4, Fig 3). The major determinants derived from the masseter muscle activity were the RMS and iEMG variables. Notably absent from this model was the peak muscle activity, which confirms the suggestions of Slagter et al[31] that food breakage does not depend on maximum occlusal force. The major contribution of temporalis activity to the model was the asynchrony of ipsilateral and contralateral contraction.

When both EMG and EGN variables were used to predict chewing performance, the accuracy of the model was better than with either factor alone. Wilding and Lewin[3] described a model to predict chewing performance based only on jaw movement. In that model, an indicator variable was found to increase the accuracy of prediction from an R^2 value of .40 to .79. It was suggested that this missing variable, which was subject dependent, might be related to muscle activity. This prediction appears to have been partly correct, because the accuracy of our model, without any indicator variable, now accounts for 66% of the variance in the observed level of chewing performance. In the present study, we noted that the inclusion of an indicator variable—gender—further improved the predictive accuracy of the model. There appears to be a gender-related characteristic that influences chewing performance and, therefore, requires further investigation.

Optimal Values

It is likely that the characteristics of muscle activity and jaw movement that are associated with improved chewing performance are more effective and perhaps more efficient than patterns of muscle activity associated with poor chewing performance. Therefore, such effective patterns of movement and muscle activity may be described as *optimal*, or most likely to produce the desired effect. By this definition, optimal masticatory movements are characterized by a prolonged chewing cycle time that moves in an open loop, with a lateral approach to and from positions of tooth contact. Optimal muscle activity would be characterized by adequate masseter activity, minimal coactivation between opening and closing muscles, and asynchrony of the anterior temporalis muscles. None of these observations is new to the literature on mastication: their collective presence in this study merely serves to validate their role. They are naturally quite restricted observations, confined by the limited movement and EMG data recorded in the present study; therefore, a host of other aspects of chewing that promote optimal performance are not excluded. It must be stressed that all these data are derived from clinically asymptomatic subjects, and so there appears to be a wide range of values for jaw movement and EMG that is compatible with health. Additional studies may determine whether there is a wide overlap between these suggested optimum patterns and subjects diagnosed with TMD.

The combination of muscle activity and incisal displacement suggests that an investigation into the acceleration of the midincisal area might reflect both movement and muscle activity. Acceleration data not only reflect forces acting on the mandible but also reveal the rhythmic oscillations of physiologic tremor. In view of the association between tremor and efficient skilled tasks such as handwriting, we are currently investigating the role of jaw tremor as a predictor of chewing performance.[32]

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Resumen

La Actividad Muscular y los Movimientos Mandibulares como Factores de Predicción del Desempeño Masticatorio

El desempeño masticatorio puede definirse en términos de la reducción en el tamaño de la partícula de comida después de masticar 15 veces. En este estudio, se investigó la relación entre el desempeño masticatorio y la actividad electromiográfica para desarrollar unos valores óptimos de las variables electromiográficas, basadas en su habilidad para predecir el desempeño masticatorio. Se efectuaron grabaciones electrognatográficas y electromiográficas de los electrodos de la superficie sobre los músculos digástrico (abductor), masetero, y temporal (aductores) en 24 personas, mientras que ellas masticaban una goma de fruta dura. Se encontró una correlación negativa moderada entre el tamaño de la partícula de comida y el cálculo de la raíz cuadrada media de la actividad masetera (−0,48; $P < 0,01$). Se encontraron correlaciones positivas mas débiles entre el tamaño de la partícula y el asincronismo de los músculos temporales ipsolateral y contralateral anterior (0,36; $P < 0,05$). Por medio de un modelo de regresión múltiple de variables electromiográficas y electrognatográficas, fue posible predecir el desempeño masticatorio con un valor R^2 de 0,66. Sí se utiliza el desempeño masticatorio como una medida de rendimiento de la función masticatoria, puede ser posible determinar los límites óptimos para las variables electromiográficas y los movimientos mandibulares.

Zusammenfassung

Muskelaktivität und Kieferbewegungen als Voraussagungen der Kauverrichtung

Die Kauverrichtung kann definiert werden in Zeitabschnitte der Verkleinerung von Nahrungspartikelgrösse nach 15 Kauzyklen. In dieser Studie wurde die Beziehung zwischen der Kauverrichtung und der elektromyographischen Aktivität untersucht, um optimale Werte von elektromyographischen Variablen zu entwickeln, welche auf deren Fähigkeit, die Kauverrichtung vorauszusagen, basieren. Elektrognathographische und elektromyographische Aufzeichnungen von Oberflächenelektroden über den Digastricus- (Abduktor), Masseter- und Temporalismuskeln (Adduktoren) wurden bei 24 Personen gemacht, während sie einen harten Fruchtgummi kauten. Eine mässige negative Korrelation wurde zwischen der Nahrungspartikelgrösse und der mittleren Quadratwurzelberechnung für die Masseteraktivität (-.48;.P < .01). Schwächere positive Korrelationen wurden zwischen der Partikelgrösse und der Asynchronität von ipsilateralen und kontralateralen anterioren Temporalismuskeln (.36; P < .05). Ein multiples Regressionsmodell von elektromyographischen und elektrognathographischen Variablen war in der Lage, die Kauverrichtung mit einen R2 Wert von .66 vorauszusagen. Wenn die Kauverrichtung als ein Leistungsmass der mastikatorischen Funktion verwendet wird, mag es möglich sein, optimale Bereiche für elektromyographische Variablen und Kieferbewegungen zu bestimmen.