Jaw Movement Tremor as a Predictor of Chewing Performance

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The purpose of this study was to investigate normal physiologic tremor in jaw movement as a factor that may influence chewing performance more directly than either muscle activity or jaw displacement. Chewing performance was defined in terms of the reduction in food particle size after 15 chewing strokes. Data on chewing particle size and electromyographic activity were available for 24 asymptomatic adults from an earlier study. Jaw movements during chewing were recorded using electrognathography, and velocity and acceleration in three planes were determined. Power spectrum for acceleration was calculated during opening and closing phases of the chewing cycle. The frequency of the peak amplitude in the power spectrum represented physiologic tremor of the jaw. Tremor frequencies during both opening and closing phases of the chewing cycle were strong predictors of chewing performance. A multivariate model composed of variables derived from acceleration, together with electromyographic and jaw movement variables, produced a multivariate model that was able to predict chewing performance with an adjusted R^2 *value of .78.*
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key words: chewing performance, jaw movement, physiologic tremor, acceleration

The process of chewing requires selection and placement of appropriate-size food particles and breakage of the particles between opposing teeth.[1] The forces necessary to break some test foods have been estimated by Slagter et al.[2] These authors concluded that maximum occlusal forces are not required for breakage, even when the available maximum force is much reduced, as it is in denture wearers. The reduced chewing performance of denture wearers has been attributed to an inability to sustain a chewing rhythm, rather than an absolute reduction in available occlusal force.[2] This view is supported by data that indicate that chewing performance is associated with coordination and timing of muscle contraction, rather than the peak levels reached during muscle bursts.[3] However, the reduced chewing performance of women, in comparison to men, could not be explained by gender differences in muscle activity.[3]

Forces developed during mastication are the resultants of reaction at the joint and a combination of tensile forces generated in masticatory muscles.[4] Osborn and Baragar[4] predicted that to produce an occlusal force of a particular direction and magnitude at the teeth, a combination of muscle groups would be recruited, which would collectively produce the resultant occlusal force most efficiently. Recent studies using multiple electrodes have revealed that within each muscle group there are subunits that can function independently.[5]

Although it is clearly desirable to record the activity of independently functioning units, estimation of the resultant force at the teeth becomes challenging. In view of the association between jaw movement patterns and chewing performance,[6] and the duel role of food selection and breakage in chewing,[7] it would be useful to estimate the forces on the mandible during all phases of the cycle. Changes in acceleration of the mandible during chewing may provide information about the collective result of complex patterns of muscle contractions.

Acceleration data may also be used to estimate the degree of physiologic tremor during movement. If a limb such as the arm is held outstretched against gravity, an invisible tremor occurs.[8] The frequency of this tremor can be calculated by recording the acceleration of the limb, at least 50 times a second, using a sufficiently sensitive device attached to the hand. The wave form of the recorded acceleration is then analyzed using a Fourier transform to determine the main frequency components of the wave. Peaks between 8 and 12 Hz have been found, with an amplitude several orders of magnitude higher than other frequencies. This band width constitutes the frequency range of normal physiologic tremors. The frequency range decreases as the hand is held outstretched for longer than 15 minutes or if weights are added to the hand.[8,9] The frequency of normal tremors is also altered by the nature of resistance to isometric contractions.[10]

The aims of the present study were the following: *(1)* to measure the acceleration of the jaw during the chewing cycle to compare acceleration and tremor at opening and closing phases of the chewing cycle; *(2)* to determine whether there are characteristic tremor frequencies associated with the output of masticatory activity, as reflected by chewing performance; and *(3)* to pursue an investigation of associated gender differences to have a better understanding of the determinants of chewing performance.

Materials and Methods

Sample

The subjects who participated in the present study are the same subjects who participated in earlier studies[3,6,11] 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 temporomandibular disorders.

Chewing Performance

Chewing performance for each subject was defined as the median particle size after the subject chewed a test food for 15 cycles. Details of the method used to measure particle size have been described in an earlier study on the same subjects.[11]

Electromyography

Electromyographic (EMG) recordings were made using surface electrodes over the posterior and anterior masseter, anterior temporalis, and anterior digastric muscles on each side of the jaws. The subjects chewed on a hard fruit gum for 15 seconds on the left first and then on the right side. The mean root mean square (RMS) values for masseter and temporalis muscle activity were calculated. The integrated EMG (iEMG) for the digastric muscle was subtracted from the iEMG of each adductor (temporalis and masseter) to reflect the level of digastric coactivation during closing (iEMGnet). The asynchrony in contraction between the ipsilateral and contralateral adductors was calculated for each closing phase and referred to as LAGipco.[3] The raw, unrectified data of the masseter EMG during opening were joined into trains of 2,048 data items. A fast Fourier analysis was performed, and the spectrum was analyzed in a band width between 1 and 40 Hz. The median power frequency was found.

Jaw Movement

Incisal movements were simultaneously recorded in three planes using electrognathography (EGN) (Sirognathograph, Siemens, Benheim, Germany). The signals were digitized at 300 Hz and converted to ASCII files using Bio-Pak equipment (Bio-Research, Milwaukee, WI). The following jaw movement variables were calculated from analysis of a frequency distribution matrix[12]: ANGLE was the angle between the most frequented approach to the region of maximal intercuspation and the horizontal plane; BIMODE was the frequency with which a bimodal pattern was found in the frequency distribution: the higher the percentage, the more separated would be the opening and closing pathways.

The data for vertical displacement were used to define opening and closing points in the recorded data, and these data points were used to separate other jaw displacements and the EMG data into opening and closing phases of the chewing cycle.

Velocity and Acceleration

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

Velocity (v) and acceleration (a) were calculated in three-dimensional space using the data for vertical, lateral, and protrusive displacements of the midincisal point. Calculations for both of these vectors were made at each consecutive data point x, using a distance $x + 40$ equal to a time interval of 0.1 second. This interval was found to be a suitable time scale for observing the acceleration resulting from the more gross movements of the jaws and for eliminating signal noise.

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

$$vxyz_n = \frac{\sqrt{(x_n - x_{n+40})^2 + (y_n - y_{n+40})^2 + (z_n - z_{n+40})^2}}{s}$$

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

$$axyz_n = \sqrt{(ax_n{}^2 + ay_n{}^2 + az_n{}^2)}$$

The mean velocity during the opening and closing phases of chewing were calculated separately. The mean acceleration during opening and closing was calculated after rectifying the data to positive values. For the purpose of examining the frequency distribution of the unrectified acceleration data, trains of 2,048 consecutive data points were made by joining all opening data into one set and all closing data into another. A fast Fourier analysis was used to investigate the frequency distribution of the acceleration for each opening and closing set.[13] The median power frequency and the power frequency of the two highest amplitude peaks within a band width from 1 to 40 Hz was determined.

Statistical Analysis

A two-tailed Student's t test was used to investigate differences in velocity, acceleration, tremor frequency, and amplitude between opening and closing phases of the chewing cycle, and between men and women. A linear regression was used to find correlations between these variables and the logarithm of the chewing particle size of the same subjects. A stepwise multiple regression was applied to develop a model to predict particle size using variables derived from the velocity and acceleration data. A second model was derived using additional variables from EMG and EGN data. The effect of gender, as an indicator variable, was added to both models. Indicator variables help to show the main effects of a grouping of data in a regression model.[14] All data were analyzed using Statgraphics Plus software (Manugistics, Rockville, MD).

Results

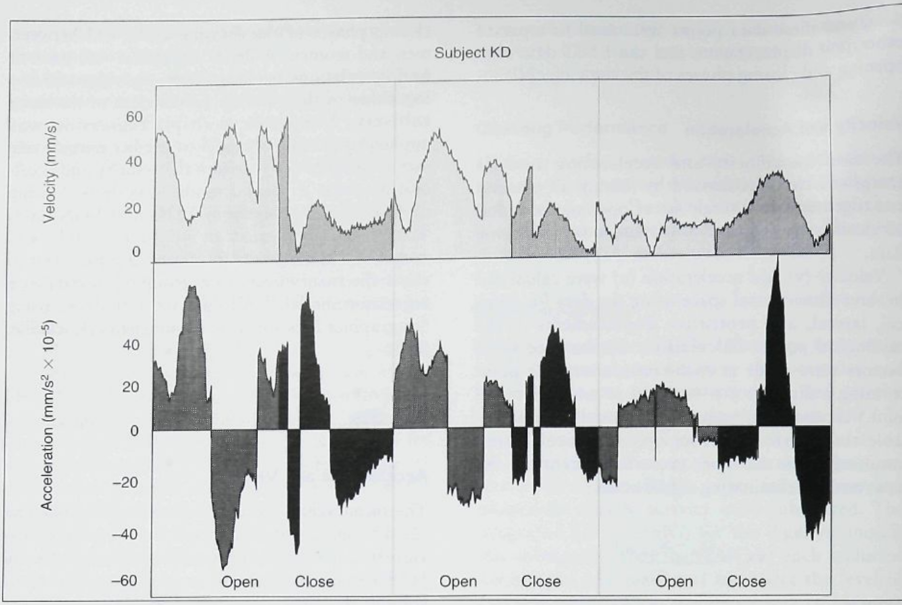
Acceleration and Velocity

The mean velocity for the sample during opening (22.19 mm/s, standard deviation [SD] 9.68) was significantly greater than that during closing (17.97 mm/s SD 8.08; $P < .01$), though in some subjects the reverse was found (Tables 1 and 2 and

Table 1 Mean Velocity, Acceleration, and Amplitude (and SD) of Three Highest Peaks of the Power Spectrum, With Relative Frequencies, for Opening and Closing Jaw Movements During Chewing

	Opening	Closing
Velocity (mm/s)	22.19 (9.68)	17.97* (8.08)
Acceleration (mm/s²)	33.13 (14.13)	30.87 (15.50)
Tremor amplitude (mm/s²)		
Peak 1	15.30 (6.85)	13.82 (8.13)
Peak 2	6.49 (3.04)	7.08 (3.87)
Tremor frequency (Hz)		
Peak 1	8.04 (2.83)	6.29** (2.33)
Peak 2	10.17 (4.62)	9.56 (3.56)
Median	11.26 (2.72)	10.74 (1.87)
EMG masseter frequency (Hz)		
Peak 1		6.08 (2.57)
Peak 2		8.17 (3.96)
EMG temporalis frequency (Hz)		
Peak 1		6.08 (2.57)
Peak 2		10.09 (7.04)

*$P < .05$.
**$P < .01$.



Figs 1a (above) and 1b (above right) Velocity and acceleration of the midincisal point during three chewing cycles in subjects KD and CH. The opening phase of each cycle is represented by the lighter shading, compared to the shading of the closing phase. Variations in acceleration and velocity during opening and closing phases did not permit simple subdivision into fast and slow phases. *Subject KD* had a faster mean opening velocity compared to the mean closing velocity, a tendency found in the rest of the subjects. The actual mean closing velocity was low, as was the amplitude for acceleration (Table 2). *Subject CH* showed high peaks of closing velocity, which, in contrast to KD, were greater than peaks of opening velocity. CH had the highest chewing performance of all subjects. (Graph for KD is not drawn to the same scale as that for CH.)

Table 2 Mean Values and Values for Subjects (CH and KD) Selected From the Top and Bottom of the Range of Chewing Performance

	Particle size (mm)	Residual (mm)	Velocity closing (mm/s)	Tremor: Frequency opening (Hz)	Tremor: Amplitude peak 2 opening ($mm/s^2 \times 10^{-5}$)	Tremor: Amplitude peak 2 closing ($mm/s^2 \times 10^{-5}$)
Mean	2.10	0.00	17.9	11.2	6.5	7.1
CH	1.18	+0.01	41.5	22.9	13.0	17.7
KD	2.98	+0.45	16.9	11.4	5.9	4.9

The residual is the difference between the observed particle size and the size predicted by the multivariate model. CH had a high value for the median frequency of jaw tremor during opening, and high amplitudes for peak 2 during both opening and closing. These three variables were found to be good predictors of chewing performance.

Figs 1a and 1b). No statistically significant difference was found between the mean acceleration during opening and closing. Correlations were found between closing velocity and both opening and closing acceleration (coefficient .63 and .68; $P < 001$).

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

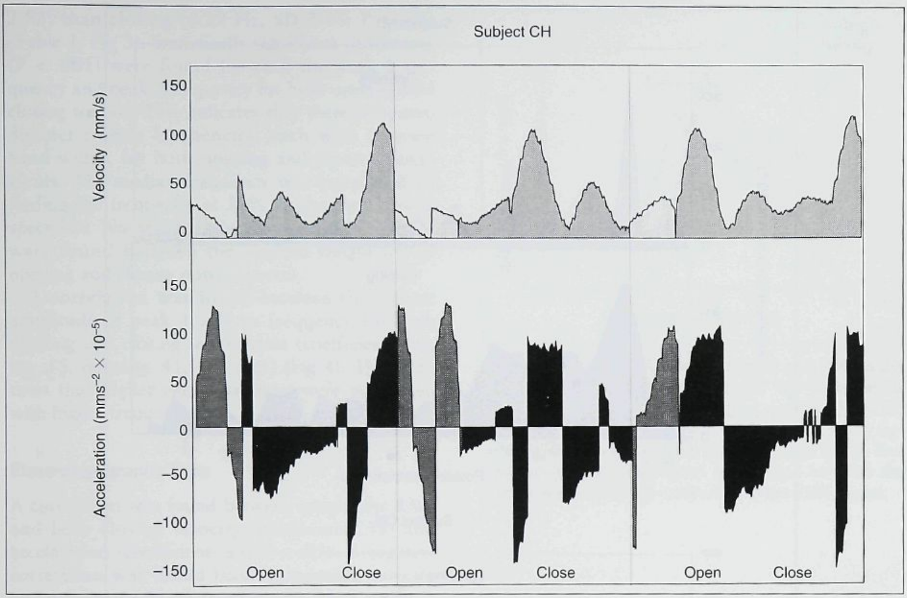


Fig 1b

Table 2 *continued*

Masseter					
RMS (μV)	iEMG net (μVs)	Temporalis LAGipco (s)	Cycle time (s)	ANGLE (degrees)	BIMODE (%)
39.7	27.0	−32.5	0.82	54.1	28.6
78.5	65.8	−111.4	1.13	53.8	67.6
17.0	6.7	64.5	0.52	75.6	51.4

opening and 13.82 mm/s^2 × 10^{-5} (SD 8.13) during closing. The mean value for the amplitude of the second highest peak (peak 2) was 6.49 mm/s^2 × 10^{-5} (SD 3.04) during opening and 7.08 mm/s^2 × 10^{-5} (SD 3.87) during closing. The mean amplitude of peak 1 was 67% of the combined amplitudes of peak 1 and peak 2 during opening and 67% during closing. This indicates that a well-defined peak amplitude tremor existed during both opening and closing (Fig 2).

The sample mean of the tremor frequency for peak 1 was higher during opening (8.04 Hz, SD

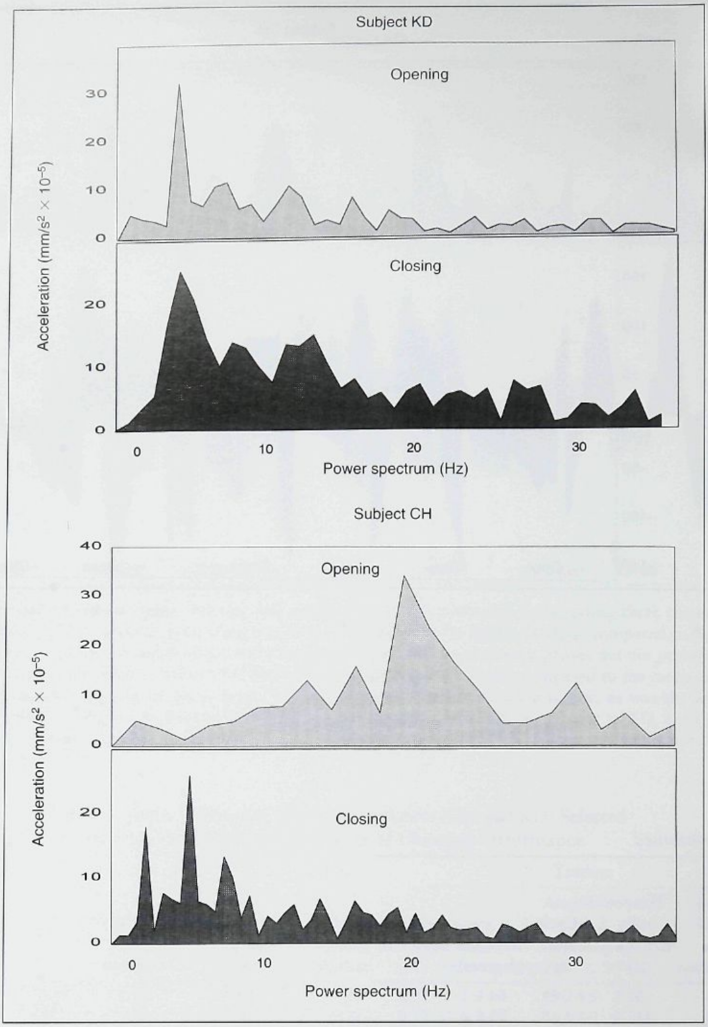


Fig 2 Power spectrum (1 to 40 Hz) for the acceleration measured at the midincisal point during opening and closing for subjects KD and CH. The two highest amplitude peaks were identified, and their respective frequencies were recorded. For *subject KD*, the low frequency of both peaks during opening contributed to the predicted poor chewing performance. For *subject CH*, the high amplitude of the second highest peak was found during closing, which was associated with improved chewing performance. The high median frequency during opening also contributed to the accurate prediction of a high chewing performance for this subject.

2.83) than closing (6.29 Hz, SD 2.33; $P < .01$) (Table 1, Fig 3). Statistically significant differences ($P < .001$) were found between the peak 1 frequency and peak 2 frequency for both opening and closing tremor. This indicates that there were two distinct tremor frequencies, each with its own band width, for both opening and closing movements. The median frequency was calculated by finding the frequency at 50% of the total power spectrum. No statistically significant differences were found between the median frequency of opening and closing power spectra.

A correlation was found between the tremor amplitude of peak 1 and its frequency for both opening and closing sets of data (coefficient closing .55, opening .41; $P < .001$) (Fig 4). This indicates that higher energy tremors were associated with higher frequencies.

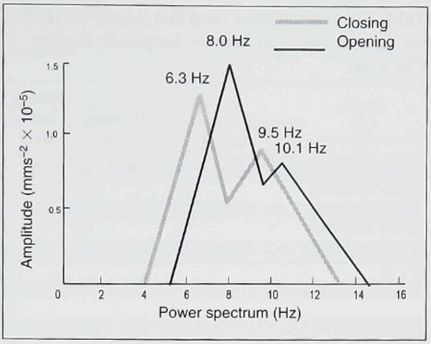


Fig 3 Mean frequencies of the highest two amplitudes of the power spectrum are illustrated. The mean tremor frequencies are represented as peaks, and their standard deviations are projected to the baseline. Statistically significant differences between the frequencies of the first and second peak amplitudes were found for both the tremor frequencies and oscillations in the EMG signal.

Electromyography Data

A correlation was found between temporalis RMS and both closing velocity (coefficient .38) and acceleration (coefficient .33; $P < .05$). A negative correlation was found between opening velocity and the digastric RMS (coefficient –.38; $P < .01$).

The mean frequency of the peak 1 amplitude for EMG power spectrum of the masseter was 6.08 Hz (SD 2.57), and the mean frequency for peak 2 was 8.17 Hz (SD 3.96) (Table 1). The difference between these two frequencies was statistically significant ($P < .01$). Equivalent values for the temporalis muscle were 6.08 Hz (SD 2.57) for the mean peak 1 frequency and 10.09 Hz (SD 7.04) for the mean peak 2 frequency ($P < .01$). These data suggest that there were at least two discrete sets of oscillation in the EMG signal, and it appears that these sets correspond with the two highest amplitude tremor frequencies in acceleration at the midincisal point. Significant correlations were found between the peak 1 tremor frequency during opening and the peak 1 frequency of both masseter (coefficient .85) and temporalis (coefficient .88) muscles (Fig 5). This suggests an association between oscillations in the EMG activity of the closing muscles and the tremor frequencies detected in jaw movement.

No statistically significant differences were found between the frequencies of the first and second highest amplitude peaks of the power spectrum for the digastric muscle during opening. A correlation was found between the peak amplitude of the digastric power spectrum and the tremor frequency of the peak 1 amplitude during opening (coefficient .62, $P < .001$).

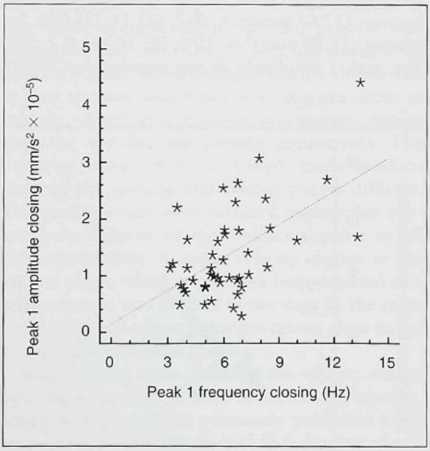


Fig 4 Regression between the tremor frequency of peak 1 closing with amplitude of peak 1 (coefficient .55, $P < .001$).

Table 3 Mean Values (and SD) ($mm/s^2 \times 10^{-5}$) for Acceleration and Tremor Amplitude During Chewing

	Men (n = 12)	Women (n = 12)	Significance level
Acceleration at opening	37.64 (11.32)	28.80 (10.41)	*
Tremor amplitude, peak 1, opening	17.40 (7.74)	13.30 (5.30)	*
Tremor amplitude, peak 2, closing	8.30 (4.55)	5.91 (2.69)	*

*$P < .05$.

Table 4 Correlation Coefficients for Particle Size, Jaw Movement, and EMG Variables

	Logarithm, particle size	Velocity close
Logarithm, particle size		**
Velocity closing	–.46	
Acceleration open	–.38	.63
Acceleration close	–.41	.68
Tremor frequency median open	–.64	.41
Tremor amplitude peak 2 open	–.26	.48
Tremor amplitude peak 2 close	–.63	.76
Masseter RMS	–.48	.01
Temporalis RMS	–.41	.37
Temporalis LAGipco	.42	.21
BIMODE	–.35	.50
Cycle time	–.40	.16

*$P < .05$.
**$P < .01$.
***$P < .001$.
****$P < .0001$.

Gender Differences

The mean acceleration during opening was higher for men (37.64 $mm/s^2 \times 10^{-5}$, SD 11.32) than for women (28.80 $mm/s^2 \times 10^{-5}$, SD 10.41; $P < .05$). The peak 1 amplitude during opening was higher for men (17.40 $mm/s^2 \times 10^{-5}$, SD 7.74) than for women (13.30 $mm/s^2 \times 10^{-5}$, SD 5.30; $P < .05$) (Table 3). The peak 2 amplitude during closing was also higher for men (8.30 $mm/s^2 \times 10^{-5}$, SD 4.55) than for women (5.91 $mm/s^2 \times 10^{-5}$, SD 2.69; $P < .05$).

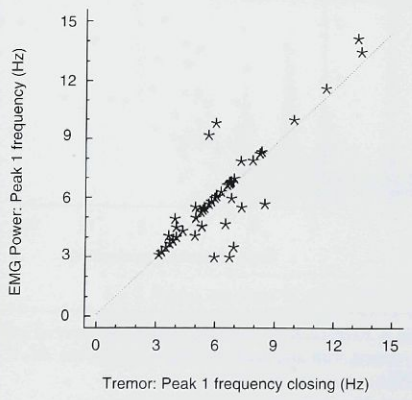


Fig 5 Regression between the frequency of peak 1 closing with frequency of the peak amplitude between 1 and 30 Hz of the power spectrum of masseter EMG ($r = .85$, $P < .0001$).

Correlations Between Particle Size, Velocity, and Acceleration

A negative correlation was found between the logarithm of particle size and the closing velocity of each subject (coefficient –.46; $P < .01$) (Table 4). No correlation was found with the opening velocity, but there was a correlation between mean opening acceleration and particle size (coefficient –.38; $P < .05$). Negative correlations with the logarithm of particle size were found with the peak 1 frequency during opening (coefficient –.51; $P < .01$), the median tremor frequency during opening (coefficient –.64; $P < .001$), and with the amplitude of peak 2 during closing (coefficient –.63; $P < .001$). This indicates that higher frequency tremors during opening and higher amplitude tremors during closing were associated with small particle size, or improved chewing performance.

The acceleration during closing was correlated with the asynchrony of ipsilateral and contralateral temporalis contraction (LAGipco) (coefficient .36; $P < .05$), and the jaw movement variable BIMODE (coefficient .37; $P < .01$).

Table 4 *continued*

Acceleration open	Acceleration close	Tremor frequency median	Tremor amplitude peak 2 open	Tremor amplitude peak 2 close	Masseter RMS	Temporalis RMS	Temporalis LAGipco	BIMODE	Cycle time
**	**	****		****	**	**	**	*	*
****	****	**	**	****		*		**	
	****	***	****	****		*	*		
.82			***	****		*	*	*	
.49	.19		**	**		**		**	*
.76	.67	.42		***			*		
.71	.80	.42	.62						
–.05	.10	.24	–.07	.13		**	*		*
.08	.33	.41	.26	.32	.45		*		*
.36	.39	–.28	.30	.18	–.37	.01			
.37	.39	.44	.26	.40	.00	.31	.10		
.03	.12	.30	.22	.22	.37	.39	–.04	.17	

Multivariate Models

A model was derived from acceleration data that were used to predict particle size, with an adjusted R^2 value of .63 (Table 5 and Fig 6). No improvement in this model was achieved by including the indicator variable gender. The three major components of this model were the median tremor frequency during opening and the tremor amplitudes of peak 2 during both opening and closing. With the addition of EMG and EGN variables, the accuracy of the model increased to an adjusted R^2 value of .78. The EMG variables were masseter RMS and iEMGnet, and temporalis LAGipco. The EGN variables were cycle time, BIMODE, and ANGLE. The adjusted R^2 value of the model was increased to .82 by adding the indicator variable gender.

Discussion

Velocity

Jaw movement was divided into only two phases in the present study—opening and closing. Hiiemae[15] proposed the use of four phases in chronologic order: *(1)* fast closing (FC); *(2)* slow closing (SC) as the bolus was engaged; *(3)* slow opening (SO); and *(4)* fast opening (FO). More recently, Hiiemae et al[16] confirmed the value of these phases in correlating tongue movement with jaw movement. The transition from SO to FO and from FC to SC was determined as the intersection on a graph of two best-fit lines. The authors of that study acknowledged that this process was subjective, and sometimes it was not possible to detect a distinct phase change. Figure 1 shows that at least one and sometimes more changes occur in velocity, as well as reversals in acceleration, during both the opening and closing movements. The irregular nature of these changes made subdivisions of the opening and closing phases difficult. This problem may have occurred because we analyzed the velocity of the midincisal point in all three dimensions. A single velocity change in the sagittal plane, which might have been detected as a phase change, was masked in our data by the combined effects of velocity changes taking place in the horizontal and frontal planes.

We found the mean values of the velocity during opening were higher than those during closing, which merely confirms previously published work on humans and mammals.[15,17–19] A number of our subjects, however, showed a reversal of this pattern, with faster closing than opening (Fig 1 [subject CH]). A correlation was found between closing velocity and RMS for the temporalis muscle, but not for the masseter RMS. This finding may be related to the difference in the mechanical advantage of the two muscles. Throckmorton and Dean[20] calculated that the mechanical advantage of the anterior temporalis muscle was less than

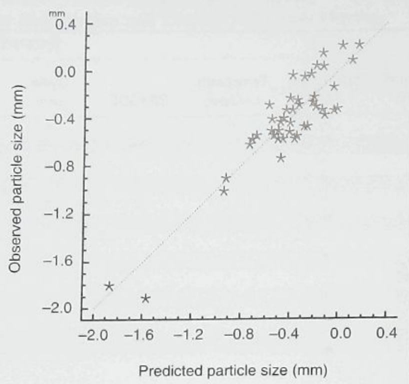


Fig 6 Observed particle size versus particle size predicted using the multivariate model comprising variables derived from velocity, acceleration, EMG, and jaw displacement during chewing. The adjusted R^2 value for this model was .78 without the indicator variable of gender.

Table 5 Components of Multivariate Model

	Independent variables	Influence	R^2
Tremor	Median tremor frequency (opening)	----	
	Tremor, amplitude peak 2 opening	+	
	Tremor, amplitude peak 2 closing	----	
			.63
EMG	Masseter RMS	--	
	Masseter iEMGnet	++	
	Temporalis LAGipco	++	
EGN	Cycle time	−	
	BIMODE	−	
	ANGLE	+	
			.78

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

that of the masseter muscle. Thus, the temporalis muscle has the greater velocity ratio of the two muscles. Therefore, its activity affects closing velocity more directly than does the masseter muscle. A correlation was also found between closing velocity and the prevalence of a bimodal pathway of movement, a pattern of jaw movement found to be associated with improved chewing performance[6] (see Table 4). Closing velocity was negatively related to particle size (see Table 4).

Acceleration

The relationship between a static vertical occlusal force at the first molar and agonist muscle activity has been shown.[21,22] Forces generated during the remainder of the cycle are difficult to estimate from EMG activity. This may be because the data derived from a few surface electrodes do not represent the complex synergies of all of the agonist and antagonist muscle groups involved in dynamic jaw movement. However, force may be represented by acceleration, provided other factors such as tissue viscosity and jaw mass are constant. Accelerometers have been used to estimate the forces occurring at the joints of a compound pendulum[23] and at the lumbar spine during the lifting and lowering of weights.[24] We have not been able to estimate forces being applied to the joint or the teeth because we did not have the morphometric data necessary for making such estimations. Furthermore, our acceleration data were not comprehensive. The version of the Sirognathograph we used is accurate in representation of translations in all three planes and rotations in the sagittal and horizontal planes, but it does not reflect rotations in the frontal plane.[25]

The mean acceleration was calculated after rectifying all acceleration data to positive values. It thus reflects the resultants of forces applied to the mandible from both bolus resistance, muscles tension, and joint reaction. Acceleration during closing had a negative correlation with particle size and positive correlations with closing velocity and temporalis muscle RMS, but not with masseter muscle RMS (see Table 4). The absence of a correlation with the masseter muscle suggests that the magnitude of the jaw acceleration is more dependent on changes in velocity and direction (perhaps a function primarily of the temporalis muscle) than on the development of high occlusal forces, which appears to be a feature of masseter activity.[20]

Tremor

Although it was difficult to divide the chewing cycle into rhythms of slow and faster movement, a spectral analysis of acceleration revealed a periodicity of movement that was related to time rather than to the chewing cycle. The power spectrum for acceleration was used by Salzer[26] to measure tremor in the lower arm, the hand, and the finger. Salzer reported several reproducible peaks, indicating more than one main tremor frequency. We found dominant peaks within a range of 2 to 15 Hz in our study. This range is wider than the band width of 8 to 12 Hz, which has been considered characteristic of normal physiologic tremor.[9] However, Sakamoto et al[27] found two distinct frequency peaks at 10 and 25 Hz in their evaluation of finger tremor in typists, and Viitasalo et al[10] reported that 90% of the power spectrum for acceleration was to be found within a band width of 7 to 20 Hz. The circumstances under which these tremors were recorded include a variety of ballistic and feedback influences, which are different and may explain the range of what has been termed physiologic tremor.

Burne et al[9] investigated the probable origins of hand tremor. They concluded that it was not of central origin, or of a ballistic nature, but the result of resonance in the firing of motor neurons. This resonance is caused by oscillations set up in the feedback loop of muscle stretch receptors. We found a strong correlation between the frequency of the peak amplitude tremor and the frequency of the peak amplitude of the EMG power spectrum for both masseter and temporalis muscles (see Fig 3). These data are consistent with the role muscle activity appears to play in generating tremors. Sakamoto et al[27] suggested that separate feedback loops would generate two different frequencies of oscillation and may explain the frequency peaks they observed. The component of the lower frequency was thought to originate from the central nervous system as a long loop, and that of the higher frequency originated from the muscle–spinal cord loop system as a short loop.

A statistically significant difference existed between the frequencies of the two highest tremor amplitudes, which suggests that there were two distinct tremor frequencies in our subjects. The peak 1 tremor frequency was lower during closing than during opening, but there was no statistically significant change in the amplitudes. The frequency of the second amplitude peak, however, was similar for both opening and closing tremors. There may be similar origins for these two second amplitude peaks, while the frequencies of peak 1 have different origins related to the different feedback pathways during opening and closing. Gresty and Buckwell[28] pointed out that two apparently separate frequency peaks may not represent independent oscillators but may be a result of amplitude and frequency fluctuation of one essential oscillating pathway.

Changes in the tremor frequency during various tasks have been reported by a number of authors.[9,10,29] In all of these studies, tremor frequency decreased during tasks that required skilled movement and coordinated muscle activity. However, the absolute values for limb tremor are not comparable with jaw movement tremor in view of the differences in the length of the feedback loops in forearms, fingers, and jaws. Changes have also been observed in jaw tremor frequency as feedback was altered.[30] The tremor frequency of jaw movement was found to increase after blocking periodontal feedback.[31] In this study,[31] this increase in frequency was considered to result from the shorter feedback loop of jaw muscle spindles, unmodified by the longer loop of periodontal feedback. This conclusion was based on the assertion that input from muscle spindles is calibrated by periodontal afferents.[32]

In view of the suggested reasons for a decrease in tremor frequency during fine movement, we would have expected low closing frequencies to have been associated with chewing performance, but no such association was found. There was, however, a strong correlation between particle size and the amplitude of the second peak tremor during closing with a coefficient value of .63 (see Table 4). The amplitude of peak 2 was also strongly associated with both opening (coefficient .71) and closing (coefficient .80) acceleration and with closing velocity (coefficient .76), each a variable, which on its own, had significant correlations with particle size. The amplitude of peak 2 appeared, on its own, to contain more information relevant to chewing than did the other three variables. In contrast to the peak 2 amplitude, the peak 1 amplitude and its frequency showed little direct association with chewing performance in our study. The difference between the associated amplitudes of these two peaks does, however, suggest that the two frequencies may be caused by separate oscillations and separate feedback pathways, one of which has greater influence on chewing activity than does the other.

Although no association was found between the closing tremor frequency and particle size, correlations between the opening tremor frequencies and particle size were found. The peak 1 tremor frequency during opening correlated with the peak amplitude of the digastric power spectrum. The opening frequencies are thus related to digastric muscle activity. Digastric iEMG was found to correlate weakly with chewing performance in an earlier study.[3]

Gender Differences

Gender differences in acceleration and in some aspects of tremor were found (see Table 3). The closing velocity and opening acceleration were greater for men than for women. In an earlier study,[6] vertical and lateral dimensions of the chewing cycle were found to be greater for men than for women. Gender differences in EMG activity have also been reported.[3,20,33] Some authors[20,33] conclude that to achieve the same occlusal force as men, women have to compensate for their reduced muscle mass by greater muscle activity. The difference in tremor amplitude found in the present study may be a reflection of its association with opening and closing acceleration, which in turn, is related to muscle activity.

In a previously published study,[6] men were found to have a chewing performance superior to that of women, but no satisfactory explanation for this difference was given. In an earlier model[3] used to predict particle size, the use of an indicator variable, gender, improved the predictive accuracy of the model. In the first model that we used in the present study, the indicator variable did not improve the prediction of the model. This may have been because one of the two variables, peak 2 amplitude, already reflects gender differences. There was little effect on the final model, which included EMG and EGN data by including the indicator variable, gender.

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

Multivariate Model

The model used to predict chewing performance in the present study is less complex and more powerful than those that have been developed in other studies.[3,6,34] Three variables (the opening median frequency, and the peak 2 amplitudes during both opening and closing) collectively account for 63% of the variance in the particle size data. Although they are weakly related to each other, the two amplitude variables are strongly related to the variables of velocity and acceleration. None of them correlate with masseter RMS, and they have weak correlations with jaw movement variables. The model which includes EMG and EGN variables, is certainly more accurate, but the dominant weight of the tremor variables in this model is still apparent (see Table 5).

We have not been able to identify the exact point at which contact with the bolus is made during closing; therefore, we have no means of separating the chewing process into the separate stages of food selection and breakage.

The present study confirms others that suggest that movement tremor is somehow associated with a skilled task; additional study is required to understand the role of tremor as a predictor of chewing performance. We have no data to explain the association of peak 2 tremor during closing with chewing performance, or to explain the absence of association of peak 1 tremor with chewing. The roles of both peak 1 and peak 2 tremors require an understanding of the different origins of these two tremor frequencies, which also require further study. The association of movement tremor during opening suggests that food selection may be a skilled process that requires feedback and, hence, generating tremor, but we are unable to explain the absence of two distinct tremor frequencies during opening movement in contrast to the two frequencies found during closing.

Future studies will determine the influence of altered feedback on the tremor frequencies we have recorded. We will also pursue the possibility that distinct differences in tremor frequency may be found in edentulous patients and those with muscle pain and dysfunction. Our longer-term goals are to contribute to the development of research diagnostic criteria in patients with temporomandibular disorders to enable discrimination between diagnostic subpopulations, as advocated by Widmar.[35]

Conclusions

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

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Resumen

Temblor en el movimiento mandibular como un factor para la predicción del desempeño masticatorio

El propósito de este estudio fue el de investigar el temblor fisiológico normal en el movimiento mandibular como un factor que puede influenciar el desempeño masticatorio mas directamente, que la actividad muscular o el desplazamiento de la mandíbula. El desempeño masticatorio se definió desde el punto de vista de la reducción del tamaño de la partícula de comida después de masticar 15 veces. Se tenia disponible la información recolectada en un estudio previo, en cuanto al tamaño de la partícula de comida y la actividad electromiográfica de 24 adultos asintomáticos. Los movimientos mandibulares durante la masticación fueron registrados por medio de la electrognatografía, y se determinó la velocidad y aceleración en tres planos. Se calculó el espectro para la aceleración durante las fases de apertura y cierre del ciclo masticatorio. La frecuencia de la amplitud máxima en el espectro de potencia representó el temblor fisiológico de la mandíbula. Las frecuencias de los temblores durante las fases de apertura y cierre del ciclo masticatorio fueron factores favorables utilizados para la predicción del desempeño masticatorio. La utilización de un modelo multivariado compuesto de variables derivadas de la aceleración, junto con las variables de la electromiografía y de los movimientos mandibulares, produjeron un modelo multivariado que fue capaz de predecir el desempeño masticatorio con un valor R2 ajustado de 0,78.

Zusammenfassung

Kieferbewegungstremor als vorhersagender Faktor der Kauleistung

Das Ziel dieser Studie war, den normalen physiologischen Tremor in der Kieferbewegung als Faktor zu untersuchen, welcher die Kauleistung direkter beeinflusst als Muskelaktivität oder Kieferverlagerung. Die Kauleistung wurde definiert in Zeitabschnitte der Zerkleinerung der Nahrungspartikelgrösse nach 15 Kaueinheiten. Daten über die Partikelgrösse und elektromyographische Aktivität waren für 24 asymptomatische Erwachsene aus einer früheren Studie vorhanden. Kieferbewegungen während des Kauens wurden mittels Elektrognathographie aufgezeichnet, und Geschwindigkeit und Beschleunigung wurden in drei Ebenen bestimmt. Das Leistungsausmass für die Beschleunigung wurde während der Öffnungs- und Schliessphasen des Kauzyklus berechnet. Die Frequenz der Spitzenamplitude im Leistungsspektrum stellt den physiologischen Tremor des Kiefers dar. Tremorfrequenzen während beider Öffnungs- und Schliessphasen des Kauzyklus sind srenge vorhersagende Faktoren der Kauleistung. Ein multivariables Modell zusammengesetzt aus Variablen hergeleitet aus Beschleunigung, zusammen mit elektromyographischen und Kieferbewegungsvariablen, war in der Lage, die Kauleistung mit einem geeichten R2-Wert von .78 vorherzusagen.