TASK RELATED ELECTROMYOGRAPHIC SPECTRAL CHANGES IN THE HUMAN MASSETER AND TEMPORAL MUSCLES

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Task-related electromyographic spectral changes in the human masseter and temporalis muscles

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The masticatory muscles differ in their fiber type composition. It can therefore be expected that their electromyographic (EMG) power spectra will differ during the performance of different bite force tasks. In the present study, surface EMG activity was picked up from the masseter and from the anterior and posterior temporalis muscles of nine adult subjects. At a bite force level as low as 25 N, the mean power frequency (MPF) values of the posterior temporalis were significantly lower than those of the masseter and anterior temporalis. The MPF values of the masseter muscles decreased with an increase of bite force magnitude, whereas the MPF values of the anterior and posterior temporalis did not change significantly. The MPF values were significantly influenced by the direction of bite force. The observed changes of MPF are possibly related to the recruitment of different fiber types, and support the concept that the masticatory muscles behave heterogeneously.

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A number of factors determine the electromyographic (EMG) power spectrum of a muscle, including the duration and the shape of motor unit action potentials (1, 2) and the firing frequencies of each motor unit action potential train (3). Due to the obvious correlations between the features of action potentials and the diameter of muscle fibers (4, 5), quantitative changes of EMG spectra have been related to the fiber type composition of a muscle (6, 7). Although data about fiber type content of the masticatory muscles are scarce and ambiguous (8), they point to intermuscular and intramuscular differences. It can therefore be expected that muscle or muscle portions differ in their EMG spectra.

According to the size principle (9), type I motor units are recruited first in a motor task, whereas type II motor units are recruited when high velocities or forces are required. This would imply that the EMG power spectrum of the masticatory muscles would change with, for example, an increase of bite force magnitude. Furthermore, intramuscular EMG recordings have shown that the activity pattern of motor units in the jaw muscles is task dependent (10–12). This suggests that the power spectrum of the masticatory muscles may also depend on the nature of the task and will change as a function of, for example, the direction of exerted bite force.

In the present study we tested the hypothesis that the power spectrum of the masticatory muscles depends on the nature of the bite task. The specific questions to address were: (1) do different jaw muscles have different EMG frequency content, and (2) is there any change in their EMG power spectra upon varying bite force magnitude and direction?

Material and methods

Subjects

Nine young males were recruited from students of the Dental School of Amsterdam. All subjects gave an informed consent using a written form approved by the medical Ethical Committee of the Academical Medical Center of the University of Amsterdam. Their mean age (±SD) was 24.1±2 year. They had a complete natural dentition (with the exception of third molars) and were asymptomatic for craniomandibular disorders and orofacial pain (absence of jaw dysfunction, headache and muscle pain or soreness).

Bite force recording

Direction and magnitude of bite force were recorded using a three-component force transducer (Kistler, Type 9251 A, dimensions 24×24×10 mm, length×width×height; Kistler Instruments, Winterthur, Switzerland).

A detailed description of the transducer and the force registration method has been given elsewhere (13). The transducer was placed between two acrylic plates, creating two planes parallel to the maxillary occlusal plane, i.e. the plane through the mesio-buccal cusps of the first molars and the incisal ridges of the central incisors. The plates were made on dental casts, mounted in a Dentatus articulator

(Dentatus, Hägersten, Sweden). The center of the transducer coincided with a point defined by the midsagittal plane and a line through the cusps of mandibular canines. Interincisal distance with the transducer and acrylic plates in place ranged from 20 to 26 mm.

Using a feedback method, the subjects were allowed to perform static bite tasks of given magnitude and direction while looking at a computer screen (13).

Bite forces were exerted in the following directions: vertical (perpendicular to the occlusal plane), forward, backward, to the right and to the left of the subject. Non-vertical forces were kept at an angle of 15° from the vertical. Force levels of 25 N, 50 N, 100 N, and 200 N were exerted in each of the investigated directions.

Electromyography

Surface EMG activity was picked up bilaterally from the masseter, anterior temporalis and posterior temporalis muscles. Pairs of electrodes (sensor diameter, 3 mm) were applied at a fixed distance of 15 mm along the main direction of muscle fibers as determined by palpation during full effort. The subjects were asked to shave themselves accurately on the day of the experiment.

Before placement of electrodes, the skin was vigorously scrubbed with abrasive paper and ethyl alcohol (70%). The ground electrode was applied to the skin over the seventh cervical vertebra. The electrodes were filled with an electrode gel and attached to the skin with double-sided adhesive washers. EMG signals were amplified differentially (2000 times) and low-pass filtered with a cut-off of 1000 Hz.

Procedure

The subjects got acquainted with and trained about the whole procedure before the experiment. After the training, the subjects were allowed to rest for half an hour. The experiment comprised 20 trials (4 force levels × 5 directions); the sequence of required bite-force levels and bite-force directions was randomly determined for each individual. The duration of each trial was about 8 s. This time was considered long enough to allow the subjects to become accustomed to the bite task and short enough to avoid the occurrence of muscle fatigue throughout the recording.

In order to prevent the occurrence of muscle fatigue, the transducer and the acrylic plates were removed after each bite task, and the subjects were allowed to rest. The duration of the rest periods depended upon the level of bite force; it was 1, 1, 3, and 3 min after bites of, respectively, 25 N, 50 N, 100 N, and 200 N.

Data processing

The output of the force transducer and EMG amplifier was simultaneously recorded on a digital tape recorder (DTR-2602, Bio-Logic; Science Instruments, Claix, France). The sample frequency was set at 6000 Hz. Using the Bio-Logic DTR-GPIB, the signals were transferred to an Intel computer with a sampling frequency of 2000 Hz. Subsequent analyzes were performed by means of LabVIEW® software (National Instruments, Austin, TX). Since each force recording had an initial jump from 0 to the desired force, the first 2 s of each recording were always excluded from the analysis.

A period of 2 s was selected according to the following criteria: the force direction had to be within 5° of the specified one, and the force magnitude had to be within 10 N of the specified force level. Power spectra of the EMG signals were calculated from each selected period of 2 s by means of a standard fast Fourier algorithm. As the selected signals contained 4000 samples, each power spectrum contained the amplitudes of 2000 frequencies from 0 Hz to 1000 Hz. The spectra were smoothed using a moving average filter with a bandwidth of 20 Hz. From each spectrum, the mean power frequency (MPF) was calculated as an estimate of EMG frequency content. The mean rectified EMG activity of the selected period was also calculated. This was done by cutting the signals in periods of 20 ms and replacing every period by the average of that period. For each muscle, the mean rectified EMG activity was expressed as a percentage of the maximum EMG value (=100%) found during the complete experiment.

Statistics

Due to the presence of within-subject correlation, data collected were analyzed by means of a random intercept regression model (14, 15). The regression model can be summarized as follows:

$$Y_{ik} = \alpha + \mathbf{X}_i\beta + u_i + e_{ik}$$

where i labels the subject ($i = 1, \dots, n$), and k the observation within subject ($k = 1, \dots, n_i$). Y_{ik} is the dependent variable, $\mathbf{X}_i$ the explanatory variables vector, α is an overall intercept which does not vary from individual to individual, β is a vector of coefficients, u_i a random intercept, and e_{ik} is the error term. The random components e_{ik} and u_i are assumed to be mutually independent. A normal distribution with mean equal to 0 was assumed for the random intercepts and for the error terms with variance σ^2 and τ^2, respectively. MPF was considered as the response variable. Explanatory variables included into the model were: 'facial side' (right, left), 'muscle' (masseter, anterior temporalis, posterior temporalis), 'bite force magnitude' (25 N, 50 N, 100 N, 200 N), and 'EMG activity' (continuous variable). The factor 'bite force direction' was included into the model with the following levels: vertical, forward, backward, ipsilateral (i.e. to the right for the right-sided muscles and to the left for the left-sided muscles), and contralateral (i.e. to the left for the right-sided muscles and to the right for the left-sided muscles). Facial side, muscle, bite force direction and bite force magnitude were entered in the model using appropriate dummy variables. EMG activity was entered in the model as linear term. Significance of regression coefficients was tested by univariate and multivariate Wald tests. A Lagrangian multiplier test was performed to verify the hypothesis that $\sigma^2 = 0$. All the analyzes were carried out by means of commercial statistical software (STATA 6.0, Stata Corporation, College Station, TX). Statistical significance was accepted at $P < 0.05$.

Results

General findings and differences of MPF between muscles

Descriptive statistics for MPF values are given in Table 1. A random intercept regression model including all the recorded explanatory variables and an interaction term between 'bite force magnitude' and 'muscle' was selected. The residual analysis showed 20 atypical observations that corresponded to MPF values obtained unilaterally from the posterior temporalis of one subject.

Table 1

Descriptive statistics for mean power frequency

	Mean	SD	Min	Median	Max
MPF	142.3	34.0	64.4	138.7	254.1
Muscle					
Masseter	142.4	26.0	67.6	140.4	254.1
Anterior temporalis	151.1	31.4	69.5	154.3	234.6
Posterior temporalis	127.3	37.0	64.4	120.2	244.2
Facial side					
Right	144.4	34.1	64.4	140.2	254.1
Left	140.2	33.9	69.5	136.6	234.6
Bite force magnitude					
25 N	141.3	33.1	64.4	140.4	254.1
50 N	142.1	33.5	67.6	138.5	240.5
100 N	144.0	33.7	69.4	137.7	244.2
200 N	141.7	33.7	82.1	134.9	239.7
Bite force direction					
Vertical	143.2	33.4	82.8	139.6	240.5
Forward	137.8	34.0	64.4	137.8	244.2
Backward	146.7	33.1	67.6	141.2	234.6
Ipsilateral	145.5	32.5	76.1	139.4	239.7
Contralateral	138.1	34.9	66.3	137.9	254.1

From a visual analysis performed on the original raw EMG signals, it could be argued that some problem with electrode connection had occurred throughout the experiment; consequently, the 20 atypical observations were removed from the model. The within-subject variance σ^2 was significantly different from 0 (Lagrangian test; d.f. = 1: $\chi^2 = 8426.0$, $P < 0.001$). The final estimation results are given in Table 2.

At a bite force level as low as 25 N, MPF values of the posterior temporalis were significantly lower than those of the masseter and the anterior temporalis. Although MPF values of the masseter tended to be lower than those of the anterior temporalis, the difference was not statistically significant (Table 2).

Effects of EMG activity and bite force magnitude on MPF

MPF was significantly influenced by the amount of muscle activation ('EMG activity') and the bite force magnitude; the statistical significance of the interaction between 'muscle' and 'bite force magnitude' (Wald test; d.f. = 6: $\chi^2 = 57.1$, $P < 0.001$) suggested that the effect of increasing bite force on MPF changed across the different muscles examined. With increasing bite force magnitude, a significant negative trend of MPF was found for the masseter muscle (test for linear trend; $z = -0.13$: $P < 0.001$), whereas MPF values of the anterior and posterior temporalis showed a tendency to increase, although not significant (Fig. 1).

Effects of bite force direction on MPF

MPF was significantly influenced by the direction of bite force (Wald test; d.f. = 4: $\chi^2 = 26.0$, $P < 0.001$). Lower values of MPF were expected when the bite force was exerted in a forward and in a contralateral direction. The first order interactions between 'bite force direction' and 'muscle', and between 'bite force direction' and 'bite force magnitude' were not statistically significant, indicating that the effect of various bite force directions on MPF did not change across muscles and across bite force levels.

Table 2

Summary of the regression model[a]

	Coefficient	S.E.	z	*P*-value
(Intercept)	142.6	4.9	29.2	0.000
Muscle				
Masseter	–	–	–	–
Anterior temporalis	1.4	3.1	0.4	0.656
Posterior temporalis	−35.3	3.2	−11.0	0.000
Facial side				
Right	–	–	–	–
Left	2.5	1.3	2.0	0.050
Bite force magnitude				
25 N	–	–	–	–
50 N	−3.7	3.1	−1.2	0.224
100 N	−9.1	3.1	−2.9	0.004
200 N	−23.6	3.4	−6.8	0.000
Bite force direction				
Vertical	–	–	–	–
Forward	−5.8	2.0	−2.9	0.003
Backward	2.5	2.0	1.3	0.208
Ipsilateral	1.2	2.0	0.6	0.563
Contralateral	−4.4	2.0	−2.2	0.029
EMG activity	0.2	0.03	5.5	0.000
Muscle: Bite force magnitude				
AT: 50	7.7	4.4	1.8	0.075
PT: 50	4.5	4.4	1.0	0.307
AT: 100	15.0	4.4	3.4	0.001
PT: 100	13.3	4.4	3.0	0.002
AT: 200	27.4	4.3	6.4	0.000
PT: 200	26.4	4.5	6.0	0.000

[a]The estimated coefficients were referred to the differences with the expected values of MPF in the "reference" categories. These reference categories were fixed as being: masseter muscle, vertical direction, bite force level equal to 25 N, and right facial side.

Discussion

The differences of MPF between the muscles investigated appear consistent with previous observations that the fiber type content of a muscle or a motor unit affects the EMG spectra (7, 16). In general, in limb and trunk muscles the fast contracting type II fibers have larger diameters than the slow contracting type I fibers (17). Therefore, type II fibers produce action potentials with faster depolarization than type I fibers, thus leading to an increase of high frequency components of the EMG spectrum (18). In human masticatory muscles, type I fibers have larger cross-sectional areas than type II fibers (19–21). It can therefore be expected that, in muscles (or muscle portions) with a relatively high proportion of active type II fibers, the MPF is lower, and, reversibly, that in muscle portions with a relatively high proportion of active type I fibers the MPF is higher.

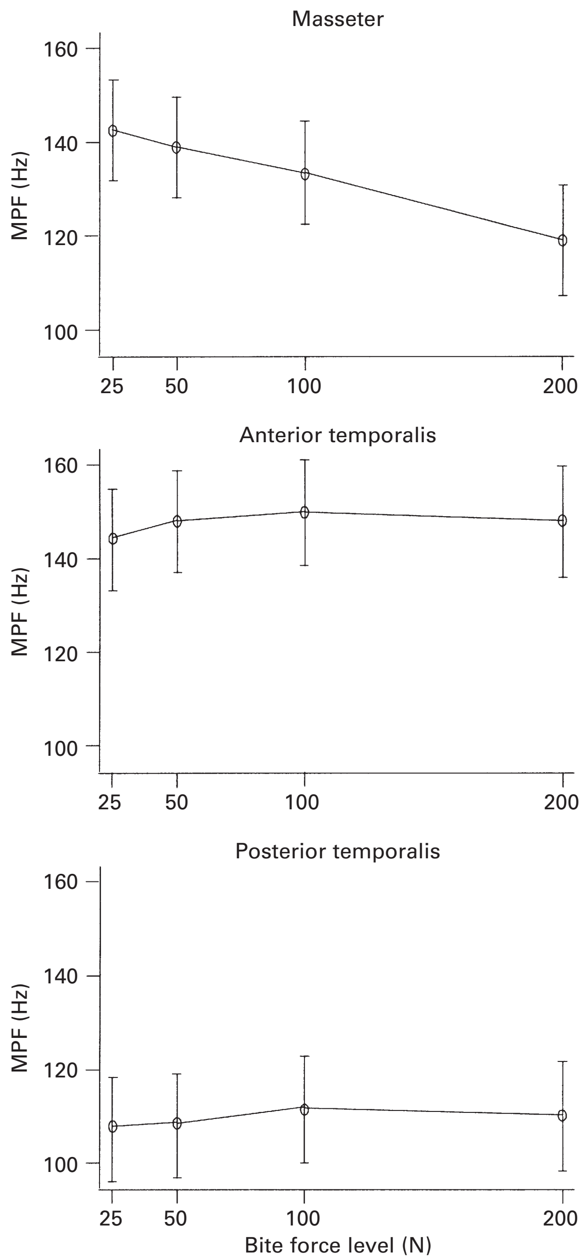

Fig. 1. Relationship between MPF and bite force magnitude in each muscle investigated. Dots and vertical bars indicate the expected values of MPF and 95% confidence interval.

Histochemical and immunohistochemical studies (19–22) point to differences in fiber type composition across muscles and muscle portions. Although the results of these studies show a large variability, the relative proportion of type II fibers is, in general, larger in the posterior than in the anterior temporalis, and larger in the superficial than in the deep masseter. Furthermore, the average fiber type compositions of the anterior temporalis and the masseter are fairly similar. These findings might explain why, at low bite force magnitude, the MPF of the posterior temporalis is lower than that of the masseter and anterior temporalis.

When the bite force was increased, the MPF of the masseter decreased significantly, whereas the MPF of the anterior and posterior temporalis did not change. During increasing voluntary contractions, motor units are activated in an orderly fashion (9) with the type II units being recruited after the type I units. An orderly recruitment of motor units has also been observed in the masticatory muscles (23, 24). Because of the principle of Henneman *et al.* (9), more type II fibers are recruited at high bite force levels than at low force levels. It can therefore be expected that an increase in bite force leads to a relative decrease in MPF, with the amount of decrease being dependent on the ratio of the number of active type I and type II fibers. It should also be noted, that (because of the Henneman principle) at lower bite force levels the deep masseter (with less type II fibers and further away from the registering electrodes) is preferentially activated, and that at higher levels relatively more activity of the superficial masseter (with more type II fibers and closer to the electrodes) is added. This might be a factor that could possibly explain the relative strong decline of the masseter MPF with an increase of force. Furthermore, in the masseter type II, fibers are extremely small (Korfage and Van Eijden; unpublished observations). This observation would imply an additional strong effect on the decrease of the MPF of the masseter with an increase of bite force.

The EMG signals can be low-pass filtered by the skin-layer underlying the electrodes (25) and by the muscle tissue itself (26).

When the force level is increased, the muscle tissue filtering decreases, as more units near the surface of the muscle are recruited (26). While this effect cannot explain the shift towards lower frequencies of the MPF values of the masseter muscles, it may have contributed to suppress (at least in part) the lower frequency content of the anterior and posterior temporalis spectra across increasing force levels. This observation might also explain why the MPF of the anterior and posterior temporalis showed a slight tendency to increase.

The finding that MPF varies with different directions of bite force has not been previously reported for any muscle; it could not be ascribed to variation in the relative mean rectified EMG activity, because this variable was also included in the regression model as a covariate. The relationship between MPF and bite force direction may indicate that the motor strategy of motoneuron pools for purposes of achieving specific biomechanical actions is more complex than is predicted by Henneman's principle. Indeed, a limitation of this principle is that it restricts the central nervous system to a single degree of freedom in the control of any group of motor units. Additional degrees of freedom can be gained by a separation of the motor units into groups. The task groups represent a selective activation of motor units within the motoneuron pool for the performance of a specific motor task (27). Orientation of bite forces towards forward or contralateral directions represent activities infrequently performed by the masticatory system. It may be possible that in such cases more type II fibers would be recruited. The additional recruitment of type II fibers would yield lower frequency content of the EMG spectra. This hypothesis is also supported by other EMG studies in masticatory muscles (11, 12, 28).

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References

1. Hägg GM. Interpretation of EMG spectral alterations and alteration indexes at sustained contraction. *J Appl Physiol* 1992; **73**: 1211–1217.
2. Seki K, Narusawa M. Relation between the size of motor units and the spectral characteristics of their action potentials. *Electroencephal Clin Neurophysiol* 1998; **109**: 436–443.
3. Fuglsang-Frederiksen AF, Rønager J. The motor unit firing rate and the power spectrum of EMG in humans. *Electroencephalogr Clin Neurophysiol* 1988; **70**: 68–72.
4. Arendt-Nielsen L, Mills KR. The relationship between mean power frequency of the EMG spectrum and muscle fibre conduction velocity. *Electroencephalogr Clin Neurophysiol* 1985; **60**: 130–134.
5. Gath I, Stålberg E. Frequency and time domain characteristics of single muscle fibre action potentials. *Electroencephalogr Clin Neurophysiol* 1975; **39**: 371–376.
6. Gerdle B, Wretling ML, Henriksson-Larsen K. Do the fibre-type proportion and the angular velocity influence the mean power frequency of the electromyogram? *Acta Physiol Scand* 1988; **134**: 341–346.
7. Kupa EJ, Roy SH, Kandarian SC, De Luca CJ. Effects of muscle fiber type and size on EMG median frequency and conduction velocity. *J Appl Physiol* 1995; **79**: 23–32.
8. Mao J, Stein RB, Osborn JW. The size and distribution of fiber types in jaw muscles: a review. *J Craniomandib Disord Orofac Pain* 1992; **6**: 192–201.
9. Henneman E, Somjen G, Carpenter DO. Functional significance of cell size in spinal motoneurons. *J Neurophysiol* 1965; **28**: 560–580.
10. Eriksson PO, Stålberg E, Antoni L. Flexibility in motor unit firing pattern in the human temporal and masseter muscles related to type of activation and location. *Arch Oral Biol* 1984; **29**: 707–712.
11. McMillan AS, Hannam AG. Task related behavior of motor units in different regions of the human masseter muscle. *Arch Oral Biol* 1992; **37**: 849–857.
12. McMillan AS. Task related behavior of motor units in the human temporalis muscle. *Exp Brain Res* 1993; **94**: 336–342.
13. Van Eijden TMGJ. Jaw muscle activity in relation to the direction and point of application of bite force. *J Dent Res* 1990; **69**: 901–905.
14. Burton P, Gurrin L, Sly P. Extending the simple linear regression model to account for correlated responses: an introduction to generalized estimating equations and multi-level mixed modelling. *Stat Med* 1998; **17**: 1261–1291.
15. Snijders TAB, Bosker RJ. *Multilevel Analysis: an Introduction to Basic and Advanced Multilevel Modelling*. London: Sage Publications, 1999.
16. Turkawki SJJ, Van Eijden TMGJ. EMG power spectrum and motor unit characteristics in the masseter muscle of the rabbit. *J Dent Res* 2000; **79**: 950–956.
17. Polgar J, Jonson MA, Weightman D, Appleton D. Data on fibre size in thirty-six human muscles. An autopsy study. *J Neurol Sci* 1973; **19**: 307–318.
18. Stulen FB, De Luca CJ. Frequency parameters of the myoelectric signal as a measure of muscle conduction velocity. *IEEE Trans Biomed Eng* 1881; **28**: 515–523.
19. Eriksson PO, Thornell LE. Histochemical and morphological muscle fibre characteristics of the human masseter, the medial pterygoid and the temporal muscles. *Arch Oral Biol* 1983; **28**: 781–795.
20. Korfage JAM, Van Eijden TMGJ. Regional differences in fibre type composition in the human temporalis muscle. *J Anat* 1999; **194**: 355–362.
21. Korfage JAM, Van Eijden TMGJ. Myosin isoform composition of the human medial and lateral pterygoid muscles. *J Dent Res* 2000; **79**: 1618–1625.
22. Ringqvist M. Fiber types in human masticatory muscles. Relation to function. *Scand J Dent Res* 1974; **82**: 333–355.
23. Yemm R. The orderly recruitment of motor units of the masseter and temporal muscles during voluntary isometric contraction in man. *J Physiol (Lond)* 1977; **265**: 163–174.
24. Scutter SD, Türker KS. Recruitment stability in masseter motor units during isometric voluntary contractions. *Muscle Nerve* 1998; **21**: 2190–1298.
25. Lindström L, Magnusson R, Petersén I. Muscular fatigue and action potential conduction velocity changes studied with frequency analysis of EMG signals. *Electromyography* 1970; **4**: 341–356.
26. De Luca CJ. Towards understanding the EMG signals. In: Basmajian JV, ed. *Muscle Alive.* Baltimore: The Williams and Wilkins Company, 1979, 53–78.
27. Loeb GE. Motoneurone task groups: coping with kinematic heterogeneity. *J Exp Biol* 1985; **115**: 137–146.
28. Blanksma NG, Van Eijden TMGJ. Electromyographic heterogeneity in the human temporalis and masseter muscles during static biting, open/close excursions, and chewing. *J Dent Res* 1995; **74**: 1318–1327.