Stress-induced changes in the functional electromyographic activity of the masticatory muscles

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The present study was undertaken to assess the effect of a non-experimental emotional stress situation on the functional electromyographic (EMG) activity of the masticatory muscles. The material comprised 15 dental students without signs and symptoms of disorders from the temporomandibular system. The activity of the masseter and anterior temporalis muscles was recorded bilaterally by means of surface EMG. The subjective degree of helplessness of the subjects was assessed and related to the EMG activity response, to assess a possible interrelation. The EMG activity during the stress situation was significantly greater than for the non-stress situation. This *shift* in EMG activity was seen for all the muscles and all the functions analyzed. No significant gender differences were found. When the subjective degree of helplessness is taken into consideration, women showed significantly higher ratings than male subjects. The Helplessness Scale ratings correlated significantly with the changes in EMG activity. ☐ *Electromyography; helplessness; masseter muscle; stress; temporalis muscle*

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There is experimental evidence that emotional states such as anxiety, fear, and frustration can elicit increased muscular rest activity (1–7). However, it has been shown that experimental stress is not identical to environmental (non-experimental) stress, even though the physiologic responses are similar (8). To our knowledge little has been ascertained about the effect of emotional stress in a non-experimental situation on the functional activity (chewing and biting) of the masticatory muscles in healthy subjects.

Anxiety and distress are thought to be the result of a cognitive process that begins with the sensation of helplessness (9). The quantification of the degree of helplessness might therefore be useful in understanding the physiologic reactions to emotional stress.

The aim of the present study was to evaluate the electromyographic (EMG) activity response of the masticatory muscles during function to a non-experimental emotional stress situation and to relate this response to the subjective helplessness of the subjects.

Materials and methods

The sample consisted of 15 dental students (5 female and 10 male) attending the sixth semester at the University of Giessen. The age of the subjects ranged from 20 to 27 years (mean age, 23 years). None of the subjects showed any signs or symptoms of dysfunction from the masticatory system as assessed by means of manual functional analysis (10, 11).

Direct and integrated EMG recordings from the masseter and the anterior temporalis muscles were obtained bilaterally with the aid of a Mingograph T 16 (Siemens-Elema, Solna, Sweden) connected to an amplifier (type 15 C 01, Dantec, Skovlunde, Denmark) with a bandpass of 20 Hz to 10 kHz and an analog integrator (type 31 C 17, Dantec). The EMG activity was evaluated by measuring the maximum height (mm) of the integrated signal from the base line, and the absolute value of the integral was calculated by multiplying the height of the signal by a calibration factor (200 μV or 500 μV). Paper speed was 50 mm/sec.

The EMG recordings were performed using bipolar surface electrodes (Tüshaus Tüs 40, Velen, Germany). The skin was cleansed with 70% alcohol to reduce its impedance, and the electrodes were placed in accordance with a standardized scheme (Fig. 1). During the EMG recordings the subjects sat upright in a straight-backed chair without head support. All recordings were carried out by the same operator.

The maximal integrated EMG activity was recorded during the following functions: 1–2) Unilateral chewing of chewing gum: For each muscle the mean value of 10 consecutive chewing cycles for both unilateral left and unilateral right chewing was used for evaluation. 3) Chewing of peanuts: For each muscle the mean value of 10 consecutive chewing cycles in the middle of the chewing sequence was used for evaluation. 4) Maximal biting in intercuspal position: For each muscle the mean value of five consecutive biting cycles was used for evaluation. 5) Maximal biting on cotton rolls: For each muscle, the mean value of five consecutive biting cycles was used for evaluation.

In each subject two EMG recording sessions were performed: the first recording (I) was carried out in the afternoon, before the subjects attended a routine lecture (non-stress situation), and the second recording (II) was done under a stress situation identical for all subjects. The stress situation consisted of an important practical

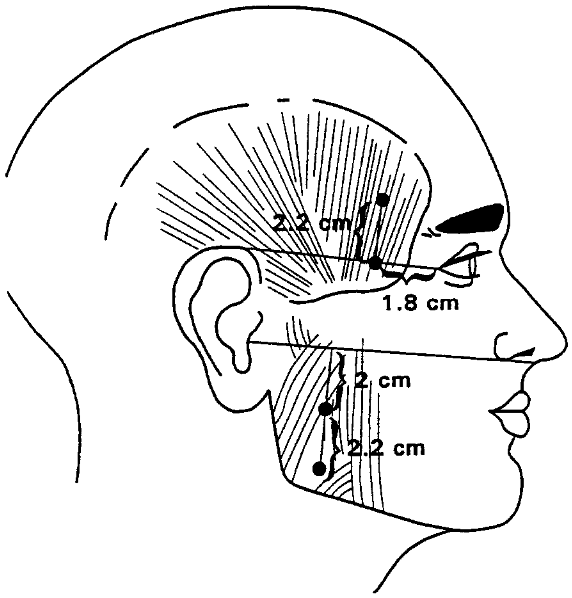

Fig. 1. Diagram showing electrode placement on the anterior temporalis and masseter muscles.

exam: passing the exam was essential for admittance to the next semester. During the exam the subjects were randomly summoned for the EMG recordings. They had to interrupt their activities, while the other students kept on working. In order not to disadvantage the students taking part in the research, the time of the exam was extended by the duration of the recording session.

The subjective degree of helplessness of the subjects was assessed by means of the Helplessness Scale (9, 12), which is a self-report questionnaire (Table 1). It was filled in by each subject at the end of the stress recording session.

Data analysis

EMG recordings. In all subjects the difference in EMG activity (= shift) between the second (II) and first (I) recording sessions was evaluated for each muscle and each function. A negative value represents a higher muscle activity in the first than in the second session.

The EMG muscle shift (Table 2) for each muscle was calculated as the mean of the five different functions. The temporalis shift (mean of the left and right temporalis shifts) and the masseter shift (mean of the left and right masseter shifts) were assessed.

The EMG function shift (Table 2) for each of the five functions was calculated as the mean of the four muscles.

All EMG muscle and function shifts are expressed in microvolts and in percentage.

Helplessness questionnaire. For each of the 20 questions of the Helplessness Scale (HLP), 1 of 5 possible answers could be chosen (Table 1). The different answers were assigned values from 1 (for the answer 'on the contrary') to 5 (for the answer 'exactly'). Missing values were rated 3 (9). The sum of the answer ratings of the 20 items was used to quantify the subjects' degree of helplessness. The average Helplessness Scale rating for 'normal' subjects as assessed by Breitkopf (9) is 41.5. No gender differences have been reported.

Table 1. Helplessness Questionnaire in accordance with Breitkopf (9). Translation from German performed by the present authors

Instructions: Please indicate how you feel in the present situation (exam). Please do not leave out any questions. Answer quickly without thinking too long about each question.	On the Exactly contrary
1. I am completely helpless.	2–1–0–1–2
2. I don't think I will make it.	2–1–0–1–2
3. I am incapable.	2–1–0–1–2
4. I am sad because I can't do anything.	2–1–0–1–2
5. I feel overtaxed.	2–1–0–1–2
6. No matter what I do, nothing is going to change.	2–1–0–1–2
7. I feel very bad.	2–1–0–1–2
8. I can't think clearly.	2–1–0–1–2
9. I can't manage any more.	2–1–0–1–2
10. I am unhappy.	2–1–0–1–2
11. I am completely dependent.	2–1–0–1–2
12. I feel at the mercy of others.	2–1–0–1–2
13. I've got no courage.	2–1–0–1–2
14. Others would presently cope better.	2–1–0–1–2
15. My situation is totally tangled.	2–1–0–1–2
16. My helplessness is unbearable.	2–1–0–1–2
17. I have the sensation that the others are stronger.	2–1–0–1–2
18. Even if I try hard it is of no use.	2–1–0–1–2
19. I don't know what else to do.	2–1–0–1–2
20. Actually I can't take pleasure in anything at the moment.	2–1–0–1–2

Table 2. Method for calculating the electromyographic activity of the muscle and function shifts for each subject. The muscle shift for the left temporalis (A to E) and the function shift during unilateral chewing on the right side (A to Z) are used as examples. I represents the non-stress recording session, and II the emotional stress recording session

Functions		Left temporalis	Left masseter	Right temporalis	Right masseter
Unil. chewing	I	A1	X1	Y1	Z1
(right side)	II	A2	X2	Y2	Z2
Unil. chewing	I	B1			
(left side)	II	B2			
Chewing	I	C1			
of peanuts	II	C2			
Maximal bite	I	D1			
(ICP)	II	D2			
Maximal bite	I	E1			
(rolls)	II	E2			

Muscle shift (left temporalis) =

$$\frac{(A2-A1)+(B2-B1)+(C2-C1)+(D2-D1)+(E2-E1)}{5}$$

Function shift (unilateral chewing on the right side)=

$$\frac{(A2-A1)+(X2-X1)+(Y2-Y1)+(Z2-Z1)}{4}$$

Table 3. Electromyographic (EMG) muscle shifts (difference between the stress and non-stress recording session) during chewing and biting activities in 15 subjects (1–5, female; 6–15, male). The shifts are expressed in microvolts (μV) and in percentage (%). Temporalis: mean of left and right temporalis. Masseter: mean of left and right masseter. The arithmetic mean (mean) and the standard deviation (*s*) is given for the whole subject material and for the subjects with either an increase (mean +) or decrease (mean −) of EMG activity during stress. The *P* values for the comparison of the two recording sessions are shown

	Temporalis		Left temporalis		Right temporalis		Masseter		Left masseter		Right masseter	
Subjects	μV	%	μV	%	μV	%	μV	%	μV	%	μV	%
1	24	49	42	85	6	12	11	18	16	25	6	10
2	55	59	124	128	−15	−10	−10	−12	−13	−10	−7	−13
3	20	32	65	79	−25	−16	68	38	24	16	111	59
4	64	31	−32	−21	159	82	5	4	7	5	2	3
5	26	17	62	37	−11	−4	78	47	90	64	66	30
6	63	39	94	61	31	16	28	20	−6	−3	62	42
7	100	71	148	105	52	34	19	11	−36	−25	74	46
8	64	58	96	94	32	22	36	32	55	46	16	17
9	34	45	67	90	0	0	49	56	36	38	61	73
10	85	49	147	87	22	11	−25	−15	−4	−1	−46	−29
11	37	21	0	0	74	42	−32	−11	−36	−14	−27	−7
12	−1	−1	0	0	−2	−2	12	7	29	21	−5	−7
13	49	23	38	17	59	29	−10	−8	23	12	−43	−27
14	18	12	22	12	14	12	90	50	83	50	96	50
15	29	13	45	20	12	5	68	37	62	35	73	39
Mean	44.2	34.2	61.2	52.9	27.2	15.5	25.6	18.1	22.0	17.2	29.2	19.0
s	27.3	20.5	53.4	46.0	46.0	24.5	38.0	23.8	38.6	25.8	51.0	32.0
P value	<0.01	<0.05	<0.001	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mean +	47.4	36.8	79.2	67.9	46.1	26.5	41.9	28.8	42.5	31.2	56.7	36.9
s	25.2	18.8	42.6	38.1	45.4	22.7	29.9	18.1	28.6	18.7	37.1	22.1
Mean −	−1	−1	−32.0	−21.0	−13.3	−8.0	−19.0	−11.0	−19.0	−10.6	−25.6	−16.6
s	—	—	—	—	9.5	6.3	10.9	3.1	15.9	9.6	19.3	10.7

Method error

In an earlier study (13) the reliability of quantitative electromyography was assessed. The EMG recordings were performed identically to this investigation. The main results of the reliability study can be summarized as follows: electrode relocation had no significant effect on the recorded EMG activity; variation in EMG activity increased with the time interval between recordings; and the percentage shifts (group means) for the different muscles and functions varied between 19% and 28%.

Statistics

Student's *t* tests, Wilcoxon's signed rank tests, and Pearson's correlation tests were used for the statistical analysis.

Results

The EMG muscle shifts are shown in Table 3. When the whole sample is taken into consideration, the mean muscle shifts ranged from 22.0 μV (left masseter) to 61.2 μV (left temporalis), with a mean of 34.9 μV for all the muscles. The percentage shifts ranged from 15.5% (right temporalis) to 52.9% (left temporalis), with a mean of 26.1% for all the muscles. For the whole sample the EMG activity increase in recording session II was significant for all the muscles considered, both in microvolts and in percentage ($P < 0.001$, $P < 0.01$ or $P < 0.05$). However, no significant differences existed between the different muscle shifts.

The average muscle shift was 33.8 μV (28.1%) in the female subgroup and 35.4 μV (25.3%) in the male subgroup. No significant gender differences were found.

The EMG function shifts are shown in Table 4. For the whole sample the functions shifts ranged from 22.5 μV (unilateral chewing on the left side) to 57.3 μV (maximal biting on cotton rolls), with a mean of 35.3 μV for all the functions. The percentage shifts ranged from 19.2% (chewing of peanuts) to 29.4% (unilateral chewing on the right side), with a mean of 24.8% for all the functions. For the whole sample the EMG activity increase in recording session II was significant during all the functions performed, both in microvolts and in percentage ($P < 0.001$ or $P < 0.01$). The function shift (μV) during maximal biting on cotton rolls was significantly greater than during chewing on the left side, chewing of peanuts, and maximal biting in intercuspal position ($P < 0.05$).

The average function shift was 36.6 μV (27.6%) in the female subgroup and 34.7 μV (23.5%) in the male subgroup. No significant gender differences were found.

Even though the EMG activity increase in recording session II was significant for all the muscles and all the

Table 4. Electromyographic (EMG) function shifts (difference between the stress and non-stress recording session) during chewing and biting activities in 15 subjects (1–5, female; 6–15, male). The shifts are expressed in microvolts (μV) and in percentage (%). Right = unilateral chewing on the right side; Left = unilateral chewing on the left side; Peanuts = chewing of peanuts; ICP = maximal biting in intercuspal position; Rolls = maximal biting on cotton rolls. The arithmetic mean (mean) and the standard deviation (*s*) are given for the whole subject material and for the subjects with either an increase (mean+) or decrease (mean−) of EMG activity during stress. The *P* values for the comparison of the two recording sessions are shown

	Chewing						Maximal biting			
	Right		Left		Peanuts		ICP		Rolls	
Subjects	μV	%	μV	%	μV	%	μV	%	μV	%
1	26	40	32	69	8	15	9	12	12	18
2	31	45	24	32	13	17	40	23	10	8
3	30	20	22	22	44	31	55	31	72	47
4	21	19	14	15	58	28	61	41	75	34
5	21	19	17	18	16	8	120	30	85	48
6	40	26	15	8	16	10	23	13	70	35
7	55	43	25	25	51	46	78	38	88	43
8	39	46	32	50	23	27	71	52	80	39
9	25	39	21	32	23	36	41	37	79	45
10	35	18	−8	−4	40	17	23	11	103	34
11	129	61	23	21	−5	−3	−55	−13	−77	−19
12	18	19	36	36	12	11	−50	−45	12	10
13	3	2	19	12	27	16	10	4	38	18
14	19	16	32	31	20	17	63	34	133	42
15	33	28	34	44	18	12	78	26	80	27
Mean	35.0	29.4	22.5	27.4	24.2	19.2	37.8	19.6	57.3	28.6
s	28.6	15.5	11.0	18.0	17.1	12.3	47.0	24.3	51.0	18.6
P value	<0.001	<0.01	<0.001	<0.01	<0.001	<0.01	<0.01	<0.05	<0.001	<0.01
Mean +	35.0	29.4	24.7	29.6	26.4	20.8	51.7	27.1	66.9	32.0
s	28.6	15.6	7.3	16.4	15.6	11.1	31.8	14.0	36.3	13.6
Mean −	—	—	−8	−4	−5	−3	−52.5	−29.0	−77	−19
s	—	—	—	—	—	—	3.5	22.6	—	—

functions considered, some subjects showed a decrease in EMG activity during stress (Tables 3 and 4).

The Helplessness Scale ratings (HLP) are shown in Table 5. Female subjects had significantly ($P < 0.05$) higher scores than male subjects.

For the whole sample a significant correlation ($r = -0.54^*$) was found between the right temporalis shift and the HLP ratings. When the gender subgroups were evaluated, significant correlations could be demonstrated between the left masseter shift and the total HLP score in male subjects ($r = 0.74^*$) and between the shifts during the chewing of peanuts and the total HLP score in female subjects ($r = -0.94^*$).

Significant high correlations were found between the average muscle shifts in women and the score for item 3 ($r = 0.89^*$). For the average function shifts significant moderate to high correlations were detectable for item 3 ($r = 0.97^{**}$) and 13 ($r = 0.90^*$) in female subjects and for item 14 ($r = 0.67^*$) and item 17 ($r = 0.69^*$) in male subjects. Several other items showed moderate to high correlations, even though they did not reach significance.

Discussion

For the whole sample the EMG activity shift under emotional stress was significant for all the muscles considered and all the functions performed. This suggests that emotional stress not only influences the rest activity of the masticatory muscles, as reported by several authors (1, 4, 6, 7), but also has an effect on the functional muscle activity.

Table 5. Helplessness Scale ratings of 15 subjects (1–5, female; 6–15, male). The arithmetic mean (mean) and the standard deviation (*s*) are given for the whole subject material and the gender subgroups

Subjects	Sample	Women	Men
1	68	68	—
2	75	75	—
3	48	48	—
4	26	26	—
5	58	58	—
6	26	—	26
7	35	—	35
8	55	—	55
9	31	—	31
10	28	—	28
11	22	—	22
12	36	—	36
13	45	—	45
14	43	—	43
15	54	—	54
Mean	43.3	55.0	37.5
s	16.2	19.2	11.4

As Hosman & Naeije (14) showed, the EMG activity of a muscle is directly proportional to the exerted force up to a level of 80% of maximal muscle force. The small forces associated with shifts in EMG rest activity between relaxed and stressful conditions (6) raise questions about their clinical significance. However, the functional EMG activity shifts in the present study, exceeding 100 µV for several individuals, seem more likely to be of clinical importance.

The present study compared the EMG activity of two separate recording sessions. As a consequence, there is a greater possibility for method errors (13) to influence the results. Therefore, it would have been desirable to perform duplicate recordings at each session to assess the within-subject variance. Owing to the experimental design (second recording during an exam) this was not possible. Furthermore, the activity of the adjacent mimic muscles could have affected the EMG signal of the masseter and temporalis. However, almost all positive percentage shifts exceeded the method error (13). This implies that the present EMG shifts were most likely induced by emotional stress.

When looking more closely at the muscle shifts, we found that in most subjects the EMG activity increased during emotional stress, whereas in a few it decreased. This interindividual variance could be due to differences in response specificity of the subjects (15, 16), meaning that in the subjects with a decrease in EMG activity of a certain masticatory muscle this muscle is not a stress response area for this particular individual.

The temporalis muscles seemed more affected by emotional stress than the masseter muscles. This is in contrast with the findings of Katz et al. (6), who found that in subjects without craniomandibular disorder the rest activity of the temporalis decreased during repeated experimental stress trials as a result of habituation. The differences between the findings of Katz and ours could possibly be due to differences in physiologic response to experimental and non-experimental stress.

The difference in EMG activity shift between the masseter and temporalis muscles or between the left and right side might alter mandibular position during functional jaw movements. Furthermore, if the muscle shift is asymmetric, as it was the case in most subjects, the alteration of mandibular position might cause overloading in either the left or the right TMJ.

There were several moderate to high correlations between HLP ratings and the muscle or function shifts. Furthermore, some questionnaire items seemed to match the subjects' state of emotion more accurately than others. Female subjects not only had higher HLP ratings than men but also showed on the average higher correlation values, which might be due to either the fact that women are more susceptible to emotional stress than man or that women show their emotional state whereas men tend to hide their feelings in answering the questionnaire. Another possible explanation could be that the response specificity (15, 16) of men and women differs in that the masticatory muscles are a more predominant stress response area in women.

Conclusions

Emotional stress was shown to increase masticatory muscle EMG activity during function. Changes in the EMG activity seemed to be related to the degree of helplessness.

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