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HIGH-DENSITY EMG REVEALS NOVEL EVIDENCE OF ALTERED MASSETER MUSCLE ACTIVITY DURING SYMMETRICAL AND ASYMMETRICAL BILATERAL JAW CLENCHING TASKS IN PEOPLE WITH CHRONIC NON-SPECIFIC NECK PAIN

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ABSTRACT

Objectives: To characterize the distribution of masseter muscle activity and force control during bilateral jaw clenching tasks in people with chronic non-specific neck pain, without an associated temporomandibular disorder.

Methods: Twelve volunteers with non-specific neck pain and 12 age and gender matched healthy subjects participated. Submaximal symmetrical and asymmetrical bilateral jaw clenching were performed with and without visual feedback of force. Force performance was assessed with indices of accuracy (mean distance, offset error) and precision (standard deviation, coefficient of variation of force). High-density, two-dimensional, surface electromyography (EMG) was recorded in order to fully characterize bilateral masseter muscle activity. The EMG root mean square was computed for each location of the electrode grid to form a map of the EMG amplitude distribution and the location of the center of activity was measured.

Results: The patient group showed a different distribution of masseter muscle activity compared to pain-free individuals during both symmetrical and asymmetrical bilateral jaw clenching. The position of the center of activity was positioned more cranial ($p<.0001$; right masseter only) and more anteriorly in the patient group ($p<0.000001$). In addition, the patients with chronic neck pain displayed higher levels of masseter muscle activation compared to the control subjects regardless of the specific task performed ($p<.000001$).

Discussion: People with chronic neck pain display increased activation and altered distribution of masseter muscle activity during a jaw-clenching coordination task. These results provide a greater appreciation of how secondary orofacial pain or temporomandibular disorders may develop in people with neck pain.

Key Words: Masticatory Muscles, Neck Pain, Motor Control, Electromyography, Bite Force

INTRODUCTION

Voluntary and semiautomatic orofacial functions such as jaw opening/closing and mastication are initiated by the primary motor cortex (MI) and are strongly modulated by somatosensory inputs from the orofacial area [1] and likely related regions such as the cervical spine [2]. Orofacial muscle coordination is achieved by the activation of cortical microzones each controlling a specific function and involving different muscles depending on the context [1]. This gives rise to many masticatory/tongue muscle synergies, as studied in animals [3] and synergies between mandible and neck movements as investigated in man [2, 4-6]. The high degree of interconnection between the jaw and cervical spine, together with the plasticity of the central nervous system, is the biological substrate thought to favor a functional recuperation or, conversely, a maladaptation as seen in the frequent association between chronic temporomandibular disorders (TMD) and neck pain [7].

Several studies have shown alterations in the behavior of masticatory muscles in people with TMD [8-12] or following experimentally induced jaw muscle pain [13, 14]. Moreover, activation of the neck flexor and extensor muscles is different when people diagnosed with TMD perform isometric contractions of their neck muscles compared to asymptomatic controls [15-17]. On the contrary, less is known about specific changes in the behavior of the masticatory muscles in people with chronic neck pain, although, it may be expected that altered behavior of masticatory muscles would be identified in people with chronic neck pain, similar to the change in neck muscle behavior in people with TMD. A number of studies have shown a high prevalence of TMD in those with neck pain induced from a whiplash trauma and [18, 19] and that jaw function is altered in people affected by a whiplash injury [4] suggesting that changes in masticatory muscle behavior is likely in people with chronic neck pain. One recent study reported greater masseter muscle activity bilaterally during unilateral jaw clenching at high force levels in people with chronic non-specific neck pain, despite the absence of orofacial pain or TMD [20]. This finding lends support to the hypothesis that people with persistent neck pain show indications of altered motor control of jaw clenching, likely reflecting the close neurophysiological, biomechanical, and functional associations between the cervical and orofacial regions [7, 21, 22]. However, the clinical relevance of associations between pain and motor changes in the cervical and orofacial regions remains controversial.

In this study we performed a comprehensive assessment of masseter muscle behavior and force control during bilateral jaw clenching tasks in people with chronic non-specific neck pain, without an associated TMD. We applied high-density, two-dimensional, surface electromyography (EMG) in order to fully characterize masseter muscle activity. This method provides a topographical representation of EMG amplitude, and can identify relative adaptations in the intensity of activity within regions of a muscle and changes under the influence of pain [23, 24]. It was hypothesized, that people with chronic neck pain would display changes in the activation of their masseter muscles bilaterally during jaw clenching and that the distribution of masseter muscle activity would differ in patients compared to control subjects, as seen for the neck muscles in people reporting neck pain [25].

MATERIAL AND METHODS

Subjects

Twelve volunteers with persistent non-specific neck pain were recruited from the Pain Clinic of the University Hospital in Göttingen, Germany. Patients were considered eligible if they were aged between 18 and 45 years, with a history of neck pain lasting more than 3 months over a continuous period in the past year, and a current pain intensity of ≥ 3/10 on a numerical rating scale (NRS) [26]. Twelve asymptomatic volunteers were included in the age- and gender-matched control group and had no relevant history of neck or shoulder pain or injury that limited their function and/or required treatment from a healthcare professional.

Exclusion criteria for both groups were any ongoing or previous major circulatory, neurological, respiratory disorders, recent or current pregnancies, previous spinal surgery, current treatment for the neck or back pain from health care providers, and participation in neck muscle exercise in the past 12 months. Further, the absence of molar or premolar teeth and the presence of orofacial pain or TMD detected with specific criteria [27] were grounds for exclusion. Regular medication intake (opioids, anticonvulsants, antidepressant or high dosed non-steroidal anti-inflammatory drugs - NSAIDs) was also considered as an exclusion criterion for both groups while NSAIDs as needed were allowed.

Initial screening was accomplished by telephone and eligible persons attended a baseline evaluation appointment where they were screened by a physiotherapist and a medical doctor. Both groups were asked not to take NSAIDs for the day of the experiment.

Ethical approval for the study was granted by the local Ethics Committee (14/11/14) and the procedures were conducted according to the Declaration of Helsinki. Participants provided written informed consent.

Questionnaires

Before starting the experiment, a questionnaire was administered to document subject demographics, history, current pain intensity and duration of pain. Further clinical features of the patient group were documented through the administration of the Neck Disability Index (NDI), which specifically addresses disability related to neck pain (0-50) [28]. Moreover, the patient group completed the Tampa Scale for Kinesiophobia (TSK), which assesses fear-avoidance beliefs and behavior on a scale ranging from 17 to 64 where the highest score indicates high degree of kinesiophobia [29]; the State-Trait Anxiety Inventory (STAI), a forty-item questionnaire that has been shown to be a reliable and sensitive measure of anxiety [30]; and the Short Form 36 (SF-36) which measures the general health status of a person [31]. Patients rated their current neck pain intensity at the beginning of the measurement session on an 11 point Numerical Rating Scale (NRS) where 0 represents absence of pain and 10 the worst imaginable pain.

Procedure

The participants sat upright with their back supported, their arms resting on their lap, hips and knees in 90° of flexion and their feet flat on the floor, in front of a PC monitor positioned 100 cm away, at eye level. Subjects wore a light-weight helmet which housed two laser pointers. They were asked to assume their natural neutral head position at which point the position of the projected laser beams were marked on the wall in front of the subject to ensure a comparable head and neck posture throughout the experiment.

Force sensors (see details below) were housed in a customized 7-mm thick soft envelope and were positioned over the first mandibular molar bilaterally. Their bilateral bite force was displayed in real time on the PC monitor as a red-segment of 20 cm length with the left and right extremities being the bite force delivered, on the left and right sides respectively. Participants were firstly familiarized with the sensors during a training session which consisted of brief submaximal bilateral jaw clenching contractions and a random presentation of targets corresponding to those used in the experiment. Training continued until the subject confirmed their full comprehension and usage of the visual feedback system (~ 5 min).

The protocol then commenced with the execution of two maximal voluntary contractions (MVC) of bilateral jaw clenching during which subjects were verbally encouraged to reach their maximal clenching force over a span of 5 seconds, with 1 minute rest provided between repetitions. The highest force values recorded for each side during the two maximal clenching contractions were retained as the MVC values.

Subjects then performed a series of submaximal bilateral jaw clenching contractions (10, 30, 50, and 70% MVC). Targets were presented in a random order as either symmetrical (e.g. 10% right and 10% left) and asymmetrical tasks (e.g. 10% right and 70% left) for a total of 16 conditions (4 symmetrical and 12 asymmetrical). The reference target was displayed as a line connecting the %MVC values for each side with an interval of ± 5% MVC error (Figure 1A). For example, the reference target requiring 30% MVC on the left side and 70% MVC on the right side is represented as a dotted line passing through the values 30 and 70% of the left and right MVC respectively outlined by two thick lines delimiting the +/- 5% MVC of error tolerated (Figure 1B). When the subject could accurately replicate the force target, the force feedback became green (Figure 1C,D).

Subjects performed the contractions with and without visual feedback of force, thus a total of 32 submaximal contractions were performed. For the condition with visual feedback, each target was displayed for 10 s during which the subjects were required to match the reference target as accurately as possible. In the condition without visual feedback, the feedback on force disappeared after 3 s while the reference target remained on the monitor. The condition without feedback was always performed immediately after the condition with feedback for each force target however the 16 force conditions were presented in a random order following a software generated sequence.

Electromyography was acquired from the masseter muscles bilaterally throughout the tasks (see below).

Force

Bite force was recorded using 2 flexible piezoresistive force transducers (Flexiforce A201; Tekscan, US) with a maximum load of 784.5 N, positioned between the first molar teeth. The force signal was amplified (2-channel Force Amplifier, OT Bioelettronica, Torino, Italy), sampled at 15Hz and converted to digital form by a 16-bit analog-to-digital converter. The reliability of the force acquisition system and of the indices adopted to measure the bite force precision (see below) have been previously demonstrated [32, 33].

In order to analyze the force in a bi-dimensional space, the right and left target force levels and the force output delivered on the right and left sensors were considered as points, one still (the target) and one moving (the force output), on a Cartesian plane with the x- and y-coordinates associated with the right and left side respectively. For instance, the reference target requiring 30% MVC on the left side and 70% MVC on the right side was considered as having Cartesian coordinates of 30,70.

The mean Distance (MD), Offset Error (OE), Standard Deviation (SD) and Coefficient of Variation (COV) of the force vector were computed from the last 7 seconds of each target presentation in order to exclude the dynamic phase of the contraction (reaching the target). MD was computed as the mean of the Euclidean distances between the target and the instantaneous force output to indicate the global precision of the task. OE represented the distance between the average of the coordinates of the force output (which can be considered as the barycenter of the force delivered during the task) and the targets coordinates. The index SD was computed as the root mean square of the distance between the barycenter of the delivered force and the instantaneous force output. The COV was calculated as the ratio between SD and the barycenter for each single target. The indices are reported as percentages of the MVC. The total time that the subject stayed within the range of +/- 5% the reference target was also registered.

Electromyography

Surface EMG was detected with two semi-disposable adhesive grids of electrodes (OT Bioelettronica, Torino, Italy) placed over the masseter muscle bilaterally (Figure 2A). Each grid consists of 13 rows and 5 columns of electrodes (1-mm diameter, 8-mm inter-electrode distance in both directions) with one electrode absent from the upper right corner. The position corresponding to the missing electrode was used as the origin of the coordinate system to define the electrode location. The subject’s skin was prepared by gentle local abrasion with abrasive paste (Medic-Every, Parma, Italy) and cleaned with water. Each grid was located with the third column aligned with the mandibular angle – cantus straight line [34] (Figure 2B). 30 µl of conductive gel was inserted into each cavity of the grid to provide electrode-skin contact.

A reference electrode was placed over the spinous process of the seventh cervical vertebra. The bipolar EMG signals were amplified (USB-EMG2, OT Bioelettronica, Torino, Italy; -3dB bandwidth 10-500 Hz) by a factor of 2000, sampled at 2048 Hz, and converted to digital form by a 12-bit analog-to-digital converter.

59 bipolar EMG signals were obtained from each grid (12 longitudinal bipolar recordings in each column except the far right which had 11 electrode pairs). Root Mean Square (RMS) values were computed from each bipolar recording from adjacent, non-overlapping signal epochs of 1-s duration, as described previously [35]. The RMS values during the submaximal contractions were normalized relative to the maximum RMS detected during the MVC and expressed as a percentage. Signal quality was monitored throughout the experiment, and a *a-posteriori* visual inspection was performed on all of the channels. Channels where the signal quality was considered too low were excluded and replaced (sample by sample) with the average of the adjacent electrodes.

For graphical representation, the 59 RMS values were interpolated by a factor of 8 but only the original values were used for data processing and statistical analysis. To characterize the spatial distribution of muscle activity, the following variables were extracted from the 59 bipolar signals: RMS averaged over the 59 signals and the two coordinates of the centroid of the RMS map (x and y-axis coordinates for the ventral-dorsal and cranial-caudal direction, respectively) [36-38].

The coordinates of the centroid of the RMS map were computed as follows:

$$x_c = \frac{\sum_{i=1}^{5}\sum_{j=1}^{12} rms(i,j)\cdot i}{\sum_{i=1}^{5}\sum_{j=1}^{12} rms(i,j)}$$

$$y_c = \frac{\sum_{i=1}^{5}\sum_{j=1}^{12} rms(i,j)\cdot j}{\sum_{i=1}^{5}\sum_{j=1}^{12} rms(i,j)}$$

where rms(i,j) is the RMS value at column *i* and row *j*, and x_c and y_c are computed in inter-electrode distance units. The two coordinates are reported in mm in the results.

With the aim of characterizing the neural control of jaw clenching during the best overall performance, values of RMS and *x* and *y*-axis coordinates of the centroid were obtained over a 1 s window with the least cumulative error (see below). The actual duration of the trial was determined as the interval in which the force signal exceeded a threshold of three times the standard deviation of its resting value. For the computation of the resting value, the subject was instructed to relax prior to each trial while the signal was continuously recorded.

Statistical analysis

Differences in age, height and weight were evaluated between groups using independent t-tests. Moreover, differences in jaw clenching MVC force were evaluated between groups using independent t-tests.

Three way analysis of variance (ANOVA) were applied to each force variable (MD, OE, SD and COV) with group as the between-subject factor (patients, controls) and condition (visual feedback, no feedback) and task (16 submaximal contractions) as within-subject factors.

Four way analysis of ANOVA were applied to each EMG variable (normalized RMS, *x* and *y*-axis coordinates of the centroid of the RMS map) with group (patients, controls) as the between-subject factor, and side (right, left), condition (visual feedback, no feedback) and task (16 submaximal contractions) as within- subject factors. Since the presence or absence of feedback did not have a significant impact on the EMG variables between groups, the within-subject factor of condition was removed and three-way ANOVAs were applied. In all cases, significant interactions and differences revealed by ANOVA were followed by post-hoc Student-Newman-Keuls (SNK) pair-wise comparisons.

Statistical significance was set at $P<0.05$. Statistical analysis was performed using Statistica 10.0 (StatSoft Inc. USA).

RESULTS

Participant characteristics are reported in Table 1. No differences were found for age, weight, height or MVC (all $p > .05$).

Force

Table 2 reports the force indices recorded for the two groups across all tasks both in the condition with and without visual feedback. The MD differed with the condition (main effect: $F=122.8$, $p < .000001$) and with task (main effect: $F=17.2$, $p < .000001$) but did not differ between groups and no interactions were observed. Not surprisingly, the MD was significantly higher when the tasks were performed without visual feedback. Moreover, the MD was generally higher for the higher load contractions (Figure 3A). The OE also differed with the condition (main effect: $F=142.1$, $p < .000001$) and with task (main effect: $F=15.4$, $p < .000001$) but, in contrast to MD, did differ between groups (main effect: $F=4.1$, $p < .05$)

with the patient group showing larger values of OE compared to controls across all tasks and in both conditions. For both groups, the OE was larger in the condition without visual feedback and increased with increasing contraction intensity (Figure 3B). The SD also differed with the task performed (main effect: $F=6.9$, $p < .000001$) but was the same between conditions and between groups (Figure 3C). Finally, the COV was dependent on condition (main effect: $F=21.0$, $p < .000001$), and task (main effect: $F=1.8$, $p<.05$) but not group. The COV was generally lower in the condition without feedback and reduced with task intensity (Figure 3D).

Average amplitude of masseter muscle activity

Figure 4 presents the normalized RMS values for the right and left masseter muscle for both groups under each condition and all tasks. Normalized RMS values from the masseter muscle were significantly dependent on the interaction between group and side ($F=4.82$, $p < .05$) (Figure 5). Higher right (SNK: $p<.000001$) and left (SNK: $p<.05$) masseter muscle activity was observed for the patients compared to the controls and for both groups, the right masseter muscle was more active than the left (SNK: $p<.00001$). A main effect for task ($F=44.0$, $p < .000001$) showed that, in general, and as expected, higher masseter muscle activity was observed for the tasks performed at higher percentages of MVC (e.g. 70/70, 70/50, 50/70). The post-hoc analysis also showed that comparable tasks (e.g. 10/70 versus 70/10) were associated with comparable levels of masseter muscle activity.

Spatial distribution of masseter muscle activity

The y-coordinate of the centroid of the masseter RMS map was dependent on the interaction between group and side ($F=24.1$, $p < .00001$; Figure 6). More specifically, the results showed that the y-coordinate was larger for the patient group, that is, the center of activity of the masseter muscle was positioned more cranial in this group, but this was only the case for the right masseter muscle (SNK: $p<.0001$). Thus, no side to side difference was evident for the control group (SNK: $p>.05$), but patient group showed larger values of the y-coordinate (more cranial) for the right compared to the left masseter muscle (SNK: $p<.0001$). The position of the y-coordinate changed with the task performed (main effect: $F=1.7$, $p < .05$) and shifted cranially with increasing force, generally following the pattern observed for the normalized RMS.

The x-coordinate of the centroid of the masseter RMS map was also dependent on group (main effect: $F=28.9$, $p<0.000001$) irrespective of side or task (Figure 7). The higher values of the x-coordinate for the patient group, indicates a shift of the center of masseter muscle activity anteriorly.

Representative RMS maps for the right and left masseter muscle from one patient and one control are presented in Figure 8 and illustrate the main difference in the spatial distribution of masseter muscle activity observed between groups.

DISCUSSION

People with chronic, non-specific neck pain showed a different distribution of masseter muscle activity compared to pain-free individuals during submaximal symmetrical and asymmetrical bilateral jaw clenching contractions. More specifically, the center of masseter muscle activity shifted cranially with increasing levels of force intensity for both subject groups but overall, the position of the center of activity was positioned more cranial in the patient group. Moreover, the center of activity was shifted anteriorly for both the right and left masseter muscle in the patient group with respect to the control subjects. Lastly, higher masseter muscle activity was observed for the right masseter muscle versus the left for both groups however, overall the patients with chronic neck pain displayed higher levels of masseter muscle activation compared to the control subjects regardless of the specific task performed. These findings were evident despite relatively similar task performance in terms of force control.

Symmetrical and asymmetrical bilateral jaw clenching

The corticobulbar fibers control the activity of the masticatory muscles via bilateral projections to the brainstem reticular formation and trigeminal motor nuclei in the pons [39]. The projections to the reticular formation arrive on specific premotor nuclei, which act as central pattern generators for chewing movements by controlling bilateral symmetric jaw movements and coactivation of jaw/tongue muscles [40]. Corticobulbar fibers that directly project to the trigeminal motor nuclei are mainly involved during specific voluntary movements [1], such as the bilateral jaw clenching task performed in the current study. The presence of motor evoked potentials in the masseter muscle ipsilateral to transcranial magnetic stimulation sites and the presence of contralateral masseter muscle activity during unilateral biting [41] has been attributed to separate populations of corticobulbar fibers projecting to the ipsilateral and contralateral masseter muscles [42]. Therefore, the cortical engagement during bilateral and asymmetric jaw clenching tasks would imply inhibition of the fibers projecting ipsilaterally and of the contralateral motor cortex during biting tasks where a higher activity of the contralateral masseter is required. Thus, the tasks investigated in the current study can be viewed as relatively complex tasks requiring fine control and coordination between the bilateral masseter muscles. When comparing the force indices recorded during performance of the bilateral jaw clenching task with previous work investigating the same force indices but during unilateral jaw clenching [20], the difficulty of the task is apparent. For instance, values of both MD and OE are considerably higher in the current study for both groups. For example, at 10% of MVC, the control group showed a MD of 1.7 ± 1.4 % and 2.8 ± 1.6 % for the unilateral and bilateral task respectively. At 50% of MVC, the patient group had an OE of -4.1 ± 5.7 % and -8.8 ± 14.1 % for the unilateral and bilateral task respectively.

Force accuracy

In general the patient group and control subjects displayed relatively similar task performance in terms of force control. The only difference observed between groups was for OE, which is a measure of force accuracy as it represents how much the average delivered force exceeds or is below the reference force. Thus, OE characterizes the degree of over- or undershooting of the motor performance and is an indication of the subject's ability to coordinate the force delivered bilaterally to reach the target position. Although subjects in both groups tended to undershoot the target force, the patients with neck pain displayed larger values of OE indicating a larger degree of undershooting, indicating that the patient group had greater difficulty in performing the task.

Not surprisingly, the removal of the visual feedback on force led to a reduction in the amount of force delivered with respect to the target and therefore reduced motor performance in both groups. This phenomenon has been previously described and attributed to the limited temporal capacity that a subject has to retain precise visuomotor information in the short term memory [43]. Interestingly, there was no additional major difference between groups in the condition without visual feedback, which relies on adequate proprioceptive acuity. Previous studies have revealed the presence of sensorimotor disturbances in people with neck pain such as greater error during head relocation tasks [44]. However, these studies have tested proprioceptive acuity in movement tasks and not force as was done in the current study.

Amplitude of masseter muscle activity

In general, for both groups, higher masseter muscle activity was observed for the right masseter muscle versus the left even if the tasks were balanced overall in terms of the load applied to the right and left side. Higher masseter muscle activity was observed for the patient group compared to the control group for both the left and right side, albeit, even greater differences were observed between groups for the right masseter muscle. The existence of a side dominance during chewing has been a debatable topic however, it seems that the existence of a preferred side of chewing is not related [45] or is only weakly related [46] to the dominant side of the body. Recently, Zamanlu and colleagues [47] showed that a side preference, namely a right preference, appears more evidently when hard food is chewed. Chewing hard food, which requires voluntary control over precise and strong biting, is an action executed under close cortical control [1], while usual chewing relies on the activity of the central pattern generators within the reticular formation [40]. The voluntary task administered in the present study would be carried out under strict cortical control, making the existence of a side dominance more evident which explains the greater activity for the right masseter muscle, the dominant side for most individuals.

The results of this study confirms altered activation of masticatory muscles in people with neck pain and reinforces previous observations in people with neck pain during unilateral jaw clenching [20]. Animal studies have shown that cervical nociceptive inputs excite trigeminal brainstem nociceptive neurons and evoke an increase in jaw muscle activity [48-50]. If this phenomenon would be applicable to humans, it could explain the general higher masseter activity showed in people with neck pain. This knowledge, together with the current results, supports the possibility of a bidirectional relationship between neck/jaw pain and motor disturbances. Overall these results add to the body of evidence showing disturbances in motor control in people with neck pain with perhaps the most generic finding being elevated muscle activity (both neck and jaw muscles) during isometric [20, 51] and dynamic activities [52].

Distribution of masseter muscle activity

Previous studies investigating masseter muscle activity in people with either TMD or neck pain have typically used classic bipolar EMG. In these applications, electrodes are placed over a small portion of the masseter muscle and thus only limited information on muscle activation can be obtained. In contrast, in this study we applied high-density, two-dimensional surface EMG which provides a measure of the electric potential distribution over a large surface area, practically over the entire masseter muscle. By measuring the centroid or center of activity, it was possible to obtain an indication of the distribution of muscle activity and how it differs between asymptomatic subjects and people with pain. Earlier work has shown that the distribution of muscle activity may differ within the affected muscle either during clinical pain conditions [23] or experimentally induced pain [37]. For instance, the injection of glutamate into the masseter muscle of healthy volunteers changed the distribution of masseter muscle activity making it more uniform in the painful condition. The current study shows, for the first time, a change in the distribution of muscle activity in a muscle remote to the site of pain. Specifically, we observed that masseter activity was distributed more towards the cranial region of the muscle and more anteriorly in people with neck pain. The anterior shift of the center of activity suggests that the anterior portion of the superficial belly of the masseter, which is usually more active in the range of force between 20% and 60% of the MVC [53], was more active in the patient group. Thus, a higher activation of the anterior and superficial compartment of the masseter muscle could explain the cranial displacement of center of activity in the patient group.

The observation that the distribution of muscle activity is different in people with neck pain indicates the potential for a change in load distribution on the temporomandibular joint complex during clenching. This finding may be associated with a forward head posture typically found in people with neck pain, and thus protrusion of the jaw which may increase the activity of the anterior region of the masseter muscle. However, this consideration is based only on biomechanical considerations since we did not perform a postural analysis on the patients included in the study. Considering the high correlation between neck pain and

TMD [54, 55], the findings of the current study may shed some light on the potential development of secondary orofacial pain in people with chronic neck pain due to altered masticatory muscle control.

Methodological considerations

The MVC was taken during a symmetrical bilateral jaw clenching and, although the subjects were instructed to bite evenly, this may have affected their ability to perform a true maximum contraction on each side (e.g. if they had a strong side dominance). However, all subjects from both groups performed their MVCs in the same manner thus this is unlikely to explain the group differences observed in the study. Moreover, the targets with a high degree of asymmetry (e.g. 10/70) may not resemble common physiological activity of the jaw. However, differences between groups were observed regardless of the load of the task.

Conclusion

People with chronic neck pain display increased activation and altered distribution of masseter muscle activity during a jaw-clenching coordination task. Although the clinical relevance of this behavior has still to be demonstrated, these findings may provide preliminary insight into how secondary orofacial pain is developed in people with neck pain.

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TABLES

Table 1. Baseline characteristics of the people with neck pain and asymptomatic people included in the study. Values are presented as mean ± SD.

Characteristic	**Control (n = 12)**	**Neck Pain (n = 12)**
Age (years)	27.2 ± 6.5	28.2 ± 6.2
Sex (% female)	75	75
Weight (Kg)	63.4 ± 11.9	64.8 ± 7.7
Height (cm)	169.3 ± 7.2	174 ± 11.6
MVC (N)	327.3 ± 132.9	301.8 ± 145.0
Duration of pain (months)		60.8 ± 63.7
Current Pain Intensity (NRS)		5.1 ± 1.6
Neck Disability Index (%)		21.9 ± 7.5
SF-36		
Physical		47.4 ± 5.5
Mental		47.8 ± 10.8
TSK		30 ± 5
STAI		47 ± 6

Table 2. Force indices (Mean Distance, MD; Offset Error, OE; Standard Deviation, SD; Coefficient of variation of force, COV) measured during submaximal jaw clenching tasks. Values are presented as mean ± SD.

Targets	**Force Variable**	**Visual Feedback**		**No Feedback**	
		Control	Neck Pain	Control	Neck Pain
Overall	MD (%)	10.2 ± 10.9	10.8 ± 13.6	18.5 ± 13.0	20.6 ± 15.4
	OE (%)	8.3 ± 10.3	9.1 ± 13.5	17.1 ± 12.8	19.6 ± 15.3
	SD (%)	4.8 ± 4.5	4.5 ± 6.7	5.4 ± 4.2	5.1 ± 3.5
	COV	0.8 ± 0.4	0.8 ± 0.4	0.7 ± 0.2	0.7 ± 0.4
10% - 10%	MD (%)	2.8 ± 1.6	2.2 ± 1.6	4.7 ± 2.0	6.9 ± 8.1
	OE (%)	2.2 ± 1.4	1.6 ± 1.2	4.4 ± 2.1	6.4 ± 8.0
	SD (%)	1.9 ± 3.4	1.1 ± 1.0	1.1 ± 0.3	3.4 ± 5.6
	COV	1.1 ± 1.2	0.7 ± 0.1	0.7 ± 0.2	1.1 ± 1.2
30% - 10%	MD (%)	5.5 ± 4.3	4.0 ± 1.9	8.5 ± 4.0	7.8 ± 4.6
	OE (%)	4.6 ± 4.1	3.1 ± 1.9	7.4 ± 4.2	6.9 ± 4.4
	SD (%)	1.9 ± 1.0	1.8 ± 1.0	2.8 ± 1.8	3.5 ± 4.3
	COV	0.8 ± 0.2	0.7 ± 0.2	0.7 ± 0.1	0.8 ± 0.2
50% - 10%	MD (%)	11.9 ± 9.4	8.3 ± 8.1	13.5 ± 8.6	16.2 ± 9.6
	OE (%)	9.9 ± 9.0	6.6 ± 8.1	12.5 ± 9.1	15.4 ± 9.9
	SD (%)	4.9 ± 2.7	8.9 ± 20.9	3.4 ± 1.1	4.3 ± 2.1
	COV	0.8 ± 0.4	1.1 ± 1.2	0.6 ± 0.1	0.6 ± 0.2
70% - 10%	MD (%)	16.5 ± 14.5	13.7 ± 14.1	19.0 ± 13.9	17.8 ± 15.0
	OE (%)	14.5 ± 14.1	11.5 ± 14.3	16.5 ± 14.7	16.1 ± 15.2
	SD (%)	5.9 ± 4.4	5.1 ± 3.8	8.3 ± 6.1	4.5 ± 1.6

	COV	0.7 ± 0.1	0.8 ± 0.2	0.9 ± 0.4	0.6 ± 0.2
10% - 30%	MD (%)	5.4 ± 5.7	4.9 ± 2.5	11.1 ± 10.6	11.8 ± 8.2
	OE (%)	4.4 ± 5.3	3.8 ± 2.0	9.6 ± 9.2	11.2 ± 7.9
	SD (%)	2.4 ± 2.1	2.3 ± 1.5	3.4 ± 3.1	3.5 ± 2.1
	COV	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.1	0.8 ± 0.2
30% - 30%	MD (%)	3.8 ± 1.3	3.7 ± 1.9	13.3 ± 6.2	13.2 ± 11.7
	OE (%)	2.8 ± 1.4	2.6 ± 1.9	11.5 ± 6.1	12.7 ± 11.8
	SD (%)	1.7 ± 0.7	2.3 ± 1.5	3.6 ± 2.4	3.7 ± 3.0
	COV	0.7± 1.1	0.8 ± 0.3	0.7 ± 0.1	0.7 ± 0.2
50% - 30%	MD (%)	6.9 ± 3.7	7.0 ± 6.7	13.9 ± 7.3	17.4 ± 9.3
	OE (%)	5.3 ± 2.6	5.3 ± 6.8	13.1 ± 7.7	17.0 ± 9.3
	SD (%)	3.6 ± 3.5	3.1 ± 1.8	4.4 ± 2.3	3.9 ± 1.7
	COV	0.7 ± 0.1	0.7 ± 0.2	0.7 ± 0.2	0.6 ± 0.1
70% - 30%	MD (%)	12.0 ± 14.6	11.1 ± 9.6	21.6 ± 7.3	29.6 ± 16.7
	OE (%)	10.1 ± 15.0	9.6 ± 9.5	19.0 ± 7.9	28.6 ± 17.0
	SD (%)	4.1 ± 3.1	4.0 ± 2.8	7.4 ± 4.6	6.7 ± 3.8
	COV	0.7 ± 0.1	0.6 ± 0.1	0.7 ± 0.2	0.7 ± 0.2
10% - 50%	MD (%)	8.9 ± 5.6	7.2 ± 5.3	12.9 ± 4.6	15.9 ± 9.5
	OE (%)	5.8 ± 4.3	5.4 ± 4.7	11.4 ± 5.1	14.8 ± 9.3
	SD (%)	6.0 ± 4.3	4.2 ± 3.4	5.2 ± 2.4	5.0 ± 2.6
	COV	0.9 ± 0.2	0.9 ± 0.4	0.8 ± 0.3	0.7 ± 0.2
30% - 50%	MD (%)	8.6 ± 7.4	7.6 ± 6.5	24.3 ± 16.7	17.1 ± 8.6
	OE (%)	6.7 ± 6.7	5.8 ± 6.8	22.1 ± 12.6	15.9 ± 8.8
	SD (%)	4.5 ± 3.9	3.6 ± 2.3	6.1 ± 6.6	5.4 ± 2.9
	COV	0.8 ± 0.4	0.7 ± 0.1	0.6 ± 0.1	0.6 ± 0.1

50% - 50%	MD (%)	7.1 ± 5.0	10.5 ± 14.0	18.7 ± 9.5	21.9 ± 9.7
	OE (%)	4.9 ± 3.8	8.8 ± 14.1	17.0 ± 11.0	20.5 ± 8.4
	SD (%)	5.0 ± 4.5	5.1 ± 3.8	5.2 ± 1.8	6.4 ± 3.5
	COV	0.8 ± 0.3	0.9 ± 0.3	0.6 ± 0.1	0.6 ± 0.1
70% - 50%	MD (%)	11.4 ± 8.6	18.3 ± 17.8	30.2 ± 11.9	33.0 ± 18.8
	OE (%)	9.2 ± 8.0	16.3 ± 18.1	28.7 ± 11.7	31.7 ± 18.8
	SD (%)	5.6 ± 4.0	4.4 ± 2.6	7.2 ± 4.3	6.9 ± 3.1
	COV	0.7 ± 0.2	0.7 ± 0.1	0.6 ± 0.1	0.6 ± 0.1
10% - 70%	MD (%)	14.2 ± 14.3	22.5 ± 18.7	19.2 ± 11.5	27.4 ± 16.6
	OE (%)	11.9 ± 13.0	19.6 ± 18.1	17.9 ± 12.1	25.4 ± 15.8
	SD (%)	5.7 ± 5.0	7.2 ± 4.3	6.3 ± 3.9	7.0 ± 5.2
	COV	0.8 ± 0.2	0.7 ± 0.3	0.7 ± 0.2	0.6 ± 0.1
30% - 70%	MD (%)	12.6 ± 9.9	14.5 ± 15.2	25.0 ± 11.3	28.1 ± 18.4
	OE (%)	9.8 ± 8.7	12.2 ± 15.3	24.4 ± 11.6	27.2 ± 18.6
	SD (%)	7.9 ± 6.0	6.8 ± 7.9	5.9 ± 2.6	5.8 ± 2.9
	COV	0.8 ± 0.4	0.9 ± 0.4	0.6 ± 0.2	0.6 ± 0.2
50% - 70%	MD (%)	13.6 ± 13.5	14.5 ± 17.3	28.2 ± 16.8	33.3 ± 19.0
	OE (%)	11.1 ± 11.7	12.3 ± 18.1	26.5 ± 16.5	32.6 ± 19.1
	SD (%)	6.8 ± 5.9	7.0 ± 9.9	7.3 ± 3.9	6.4 ± 3.3
	COV	0.7 ± 0.1	1.0 ± 1.0	0.6 ± 0.1	0.6 ± 0.2
70% - 70%	MD (%)	22.2 ± 19.2	22.9 ± 25.1	32.6 ± 16.4	31.8 ± 15.9
	OE (%)	20.1 ± 19.7	21.3 ± 25.8	31.2 ± 15.8	31.0 ± 16.1
	SD (%)	9.4 ± 5.6	5.5 ± 4.6	8.5 ± 5.8	5.7 ± 3.1
	COV	0.8 ± 0.3	0.7 ± 0.2	0.6 ± 0.2	0.6 ± 0.1

FIGURE LEGENDS

Figure 1: Graphical representation of the visual feedback. A. The reference target and the feedback are presented. Please note that the dotted black line represents the target with 50% of the Maximal Voluntary Contraction (MVC) on both sides and that the two thick lines are the limits of error tolerance. The black line is the visual feedback and moves according to the force produced on the left and right sensor. Please note that in this case the subject was delivering 30% of the MVC on both sides. B. The reference target is 30% and 70% of the MVC, respectively, on the left and the right side. Please note that the subject is missing the reference force on the right side, therefore the line remain red. C. When the subject matched the reference target, the line representing the produced force became grey. D. A representative example of a reference target asymmetrical to the left, with 50% and 10% of the MVC, respectively, on the left and right side.

Figure 2: Schematic representation of the electrode grid with an indication of the coordinate axes. 59 bipolar EMG signals were obtained from each grid (12 longitudinal bipolar recordings in each column except the far left which had 11 electrode pairs). B. The electrode grid was placed over the superficial bundle of the masseter muscle. The mandibular angle-cantus line (dotted line) was used as a reference for the central column of the grid.

Figure 3: Mean ± SD of the force indices measured during submaximal, bilateral jaw clenching tasks in the condition with (white circles) and without (black circles) visual feedback. Subjects performed submaximal bilateral jaw clenching contractions at 10, 30, 50, and 70% MVC. Targets were presented in a random order as either symmetrical (e.g. 10% right and 10% left) and asymmetrical tasks (e.g. 10% right and 70% left) for a total of 16 conditions (4 symmetrical and 12 asymmetrical). A. mean distance, B. offset error C. standard deviation and D. coefficient of variation of force.

Figure 4: Average normalized root mean square (RMS) values recorded from the right and left masseter muscles measured during submaximal, bilateral jaw clenching tasks during conditions with visual feedback of force. The tasks are illustrated as 10/10, 10/30 which refers to the force on the left side/ right side. The data presented for the left and right masseter are those recorded during the tasks where force is highlighted in **bold.**

Figure 5: Mean ± SD of the normalized root mean square (RMS) values recorded from the right and left masseter muscles for both the control group and patients with neck pain measured during submaximal, bilateral jaw clenching tasks. Data is averaged across tasks.

Figure 6: Mean ± SD of the *y*-coordinate of the root mean square (RMS) map recorded from the right and left masseter muscles for both the control group and patients with neck pain measured during submaximal, bilateral jaw clenching tasks. Data is averaged across tasks.

Figure 7: Mean ± SD of the *x*-coordinate of the root mean square (RMS) map recorded from the right and left masseter muscles for both the control group and patients with neck pain measured during submaximal, bilateral jaw clenching tasks. Data is averaged across tasks.

Figure 8: Representative topographical maps (interpolation by a factor 8) of the EMG RMS values recorded from the left and right masseter for a control subject and a person with neck pain performing bilateral jaw clenching at 70% MVC on the left side and 50% MVC on the right side (70/50). Compared to the control subject, the patient shows higher masseter muscle activity and a shift of activity in the anterior and cranial direction.