Original Article

Functional Relationships Between the Masseter and Sternocleidomastoid Muscle Activities During Gum Chewing:
The Effect of Experimental Muscle Fatigue

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Abstract: The purpose of this study was to investigate the functional relationship between masseter muscle (MM) and sternocleidomastoid muscle (SCM) activities and between mandibular and head movements during mastication, under experimental muscle fatigue. The sample consisted of 12 adults with individually normal occlusion. The subjects were asked to chew gum at three different times: before maximum clenching, immediately after maximum clenching, and 3 minutes after maximum clenching. At these times, we examined the activity of the MM and SCM as well as the movement of the mandible and head. The activity and movement were simultaneously measured using both electromyography and the motion capture system. The MM activity time after clenching was significantly shorter than that before clenching, whereas the SCM activity time was significantly longer after clenching. There was no significant difference in the changes of three-dimensional distance of the mandibular movement between the respective times. On the other hand, the changes in the three-dimensional distance of head movement after clenching increased when compared with before clenching. Furthermore, the difference in the time of MM and SCM activity onset and of mandibular and head movement onset after clenching was shorter than that before clenching. A functional relationship exists between the MM and SCM activities and between mandibular and head movements during mastication. (*Angle Orthod* 2006;76:452–458.)

Key Words: Masseter muscle; Sternocleidomastoid muscle; Head movement; Masticatory movement; Mandibular movement; Muscle fatigue

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INTRODUCTION

Mastication is done mainly by mandibular movement. A deeper understanding of the mechanism of mastication would be of great value in clinical dentistry. Recent reports suggest that this movement is accompanied not only just by the activation of masticatory muscles but also by a coactivation of the neck muscles,[1] and head movements are synchronized with mandibular movement.[2]

Many reports are found on the functional relationship between the craniofacial region and the head-neck region and the changes in head movement accompanying jaw tapping[3] and mastication.[4] A computer analysis of the static neck muscle activity[5] and electrophysiological experiments using rats have revealed a neural pathway between the trigeminal nerve and the neck muscle groups.[6,7] However, a simultaneous analysis between muscle activity and movement has not yet been reported.

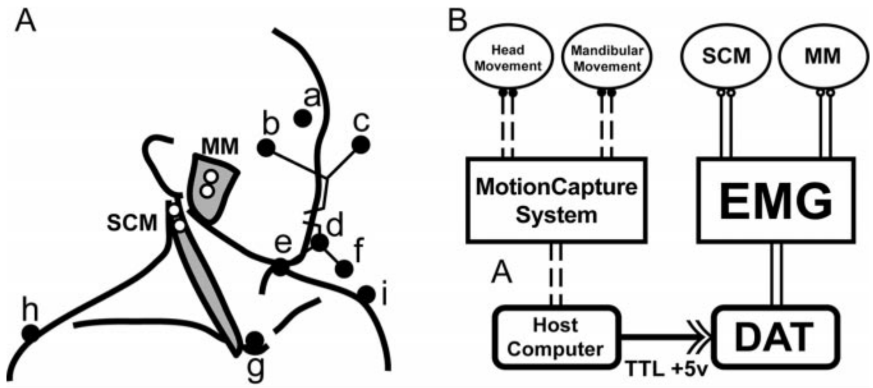

FIGURE 1. (A) Positions of infrared reflective markers and electrodes. The attachments consisted of 1.2 mm Co-Cr alloy wire and self-cured resin. Markers were bonded to the labial surface of incisors through a self-made attachment. a: forehead; b,c: upper incisor; d,e,f: lower incisors; g: sternum; h, i: both shoulder tips; MM: masseter muscle; SCM: sternocleidomastoid muscle. (B) The simultaneous measurements of muscle activity and movement using both the EMG and the motion capture system. EMG indicates electromyography.

In this study, we attempted to examine the functional relationship between the masseter (MM) and sternocleidomastoid (SCM) activities as well as its interaction with mandibular and head movements. A healthy population with normal occlusion undergoes maximum clenching resulting in muscle fatigue. Under this condition, the subjects were asked to chew gum, and the activity of the MM and SCM and the distance of mandibular and head movement were evaluated using both electromyography (EMG) and the motion capture system.

MATERIALS AND METHODS

Twelve healthy adults (10 men and 2 women, aged 25–28) with normal occlusion and without any subjective or objective problems in stomatognathic function and in the head-neck-arm area were used as subjects. This experiment was performed according to the World Medical Association's Declaration of Helsinki, and all the subjects were given informed consent on the details and aims of this study before any measurements were taken.

The subjects were seated comfortably on a chair without a headrest, within a sealed room (Figure 1A). The electrodes of the EMG were positioned at the right MM and the right SCM. Movements of the mandible and head were monitored by infrared ray reflective markers positioned on the mid forehead, maxillary upper incisors, lower incisors, tip of the shoulders, and the sternum.

Movement of the subjects

Under optical feedback by oscilloscope, the subjects were asked to clench temporarily as hard as they could (maximum clenching) until unable to clench any longer. The subjects were asked to chew gum for 30 seconds on the right side at three different times; before maximum clenching, immediately after maximum clenching, and 3 minutes after clenching. At these times, the activity of the MM and SCM as well as the movement of the mandible and head were examined using both the EMG and the motion capture system.

EMG recording

The subjective muscles were the right MM and the right SCM. Bipolar, Ag-AgCl plate surface electrodes (NE-155, Nihon Kohden Co. Ltd, Tokyo, Japan) were placed 15 mm apart, parallel to the direction of the muscle fibers and perpendicular to the skin surface. The electrodes were placed 1 cm above the mandibular angle for MM, and 1 cm below the mastoids for SCM (Figure 1A). The muscle activity was then amplified (AB-621, Nihon Kohden Co. Ltd), converted using an A/D converter (Power Lab System®, AD Instruments Japan, Tokyo, Japan) down to a sampling time of 1 m/sec, downloaded to a personal computer, and analyzed using an analysis software (Chart4 for Windows®, AD Instruments Japan). The bioelectric amplifier unit was set at high cut frequency of one kHz, and with a time constant of 0.03 seconds.

Measurement of mandibular and head movements

The mandibular and head movements were measured using UM-CAT® (UNMEC Co. Ltd, Tokyo, Japan), a motion capture system consisting of an infrared ray flash unit, two CCD cameras, and personal computer. The minimum analysis capacity of the CCD camera was down to 0.35 mm, with a sampling rate of 120 Hz. In the present setup, a recording volume of $30 \times 60 \times 50$ cm was used.[5] All the measurements were done after calibration with an original apparatus. A total of nine infrared reflective markers were attached to the center of the forehead, upper incisors,

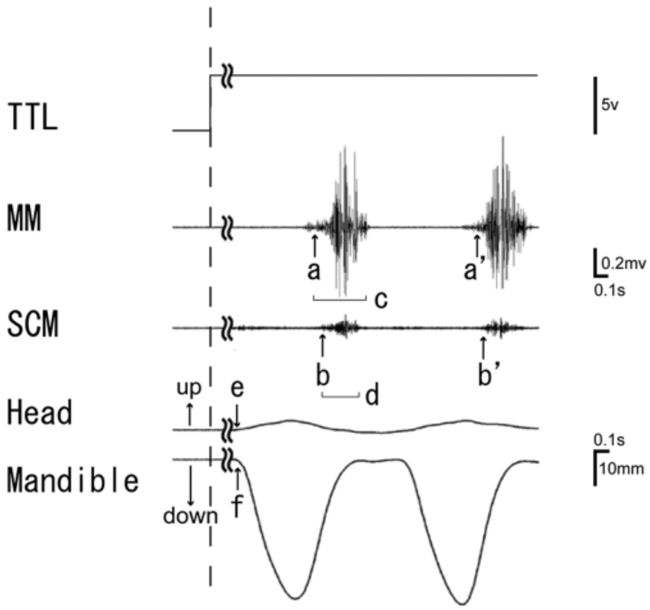

FIGURE 2. An Example of measurement data and the analytic factors. A vertical axis is TTL: TTL (Transistor Transistor Logic) level; MM: right MM activity; SCM: right SCM activity; Head: head movement in relation to the body; Mandible: mandibular movement in relation to the head sequentially from the top. Horizontal axis is time. a: MM activity onset; b: SCM activity onset; c: time of MM activity; d: time of SCM activity; e: start point of head movement; f: start point of mandibular movement; a′-a: MM activity cycle; b′-b: SCM activity cycle; f′-f: mandibular movement cycle; e′-e: head movement cycle; f-e: onset difference between head movement to mandibular movement; b-a: the onset difference between the MM activity and SCM activity; *D*: 3-dimensional distance of mandibular and head movement [$D = \sum_{t=1}^{n} \sqrt{(x_t - x_{t-1})^2 + (y_t - y_{t-1})^2 + (z_t - z_{t-1})^2}$ (*x*: right and left direction; *y*: forward and backward direction; *z*: upward and downward direction)].

lower incisors, bilateral tip of the shoulder, and the sternum (Figure 1A).

The three markers attached to the forehead and the upper incisors were considered as markers for head movement. The three markers of the lower incisors were considered as markers for mandibular movement. The markers attached to both shoulder tips and the sternum were used to adjustfor trunk movement. The numerical data was then downloaded to a personal computer, and the positional axes for head and mandibular movements were obtained. The head, mandibular, and body movement were obtained from the respective center axis. To evaluate the mandibular and head movement by distance, the axis for mandibular movement was the head and the axis for the head was the body.

The simultaneous measurements of the EMG recording and movement distance were obtained by sending data from the motion capture system to the EMG. The motion capture system, attached to a host computer, was connected to the EMG using 30-cm 5C2V cable wire. Therefore, as the motion capture system began measuring, the TTL (Transit Transistor Logic) level of 5V was sent as an electronic signal to the EMG, and a comeasurement was taken onto a computer, incorporating both the EMG recording and movement distance (Figure 1B).

Analysis

The 6th to 15th strokes (10 strokes) of chewing gum before clenching, after clenching, and 3 minutes after clenching were evaluated using the EMG and the motion capture system (Figure 2).

To confirm muscle fatigue from temporary maximum clenching, the power spectrum for MM and SCM was calculated, the frequency was analyzed using Fast Fourier Transformation, and the fraction of power every 25 Hz to the total power was calculated for each frequency. The analytic factors of MM and SCM activities and of mandibular and head movements are as shown in Figure 2.

RESULTS

The changes in the power spectrum for MM and SCM

An example of the power spectrum before clenching, after clenching, and 3 minutes after clenching is shown in Figure 3. In all subjects, between 125 to 150 Hz for MM and 150 to 175 for SCM, the power spectrum for significant decreases in the high-frequency

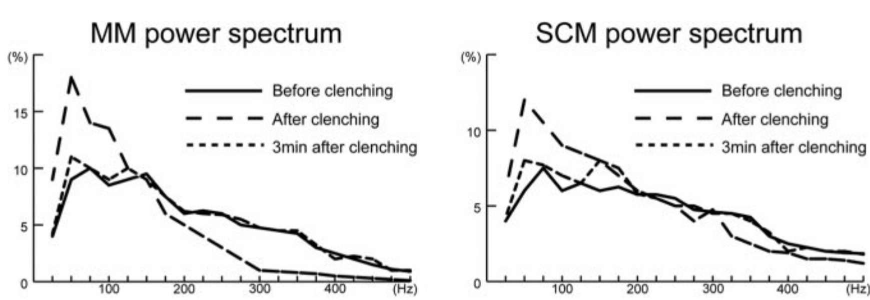

FIGURE 3. An example of the power spectrum for MM and SCM at three different times. MM indicates masseter muscle; SCM, sternocleidomastoid muscle.

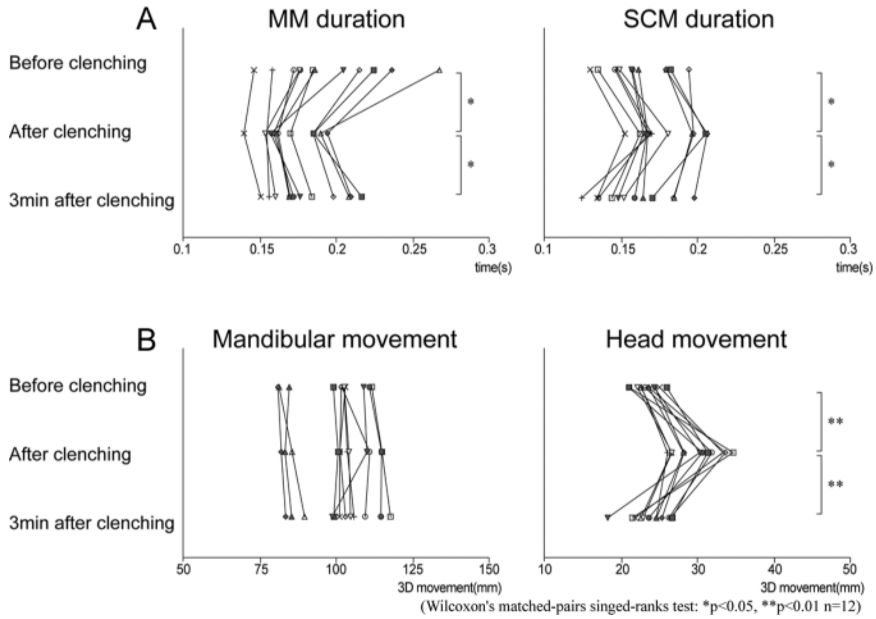

FIGURE 4. (A) The changes in MM and SCM activity over time. (B) The changes in the three-dimensional distance of mandibular and head movement over time at three different times. MM indicates masseter muscle; SCM, sternocleidomastoid muscle.

range and significant increases in the low-frequency range are shown after clenching as compared with before clenching. For 3 minutes after clenching, the frequency distribution was the same as before clenching for both MM and SCM.

The change in MM and SCM activity over time

The time of MM and SCM activity is as shown in Figure 4A. The MM activity time after clenching was 0.168 ± 0.017 seconds (mean ± SD), significantly shorter than before clenching (0.196 ± 0.034 seconds). On the other hand, the SCM activity time after clenching was 0.178 ± 0.018 seconds, significantly longer than before clenching (0.160 ± 0.010 seconds). Similar results for clenching after 3 minutes was seen as before clenching, and the activity time for both MM and SCM were 0.185 ± 0.020 seconds and 0.158 ± 0.022 seconds, respectively.

The change in three-dimensional distance of mandibular and head movement over time

The change in three-dimensional distance of mandibular and head movement over time is as shown in Figure 4B. The three-dimensional distance of mandibular movement before clenching, after clenching, and 3 minutes after clenching were 99.3 ± 10.9 mm, 101 ± 10.7 mm, and 101.3 ± 10.7 mm, respectively. There was no significant difference between the three distances. On the other hand, the three-dimensional distance of head movement after clenching was 30.86 ± 3.24 mm, which was significantly longer than the 23.94 ± 2.49 mm of before clenching. As for 3 minutes after clenching, the distance was similar to before clenching (23.8 ± 2.5 mm).

The change in muscle activity cycle and movement

The cycles of MM activity, SCM activity, mandibular movement, and head movement were as shown in Figure 5. The muscle activity cycles for before clenching, after clenching, and 3 minutes after clenching were 0.89 ± 0.07, 0.90 ± 0.04, and 0.88 ± 0.03 seconds for MM and 0.88 ± 0.06, 0.90 ± 0.04, and 0.88 ± 0.03 seconds for SCM, respectively. No significant difference was seen between MM and SCM in the muscle activity cycles.

Furthermore, no significant difference was seen between mandibular and head movement cycles. The movement cycles were 0.87 ± 0.07, 0.90 ± 0.04, and 0.88 ± 0.03 seconds for mandibular movement and 0.90 ± 0.06, 0.90 ± 0.10, and 0.89 ± 0.11 seconds for head movement at the respective times.

Time change between MM and SCM activity onset and mandibular and head movement onset

The change in time between MM and SCM activity onset and mandibular and head movement onset is as shown in Figure 6. The difference in the time of MM activity to SCM onset was 0.008 ± 0.014 seconds after clenching and was significantly shorter than before clenching (0.023 ± 0.015 seconds). On the other

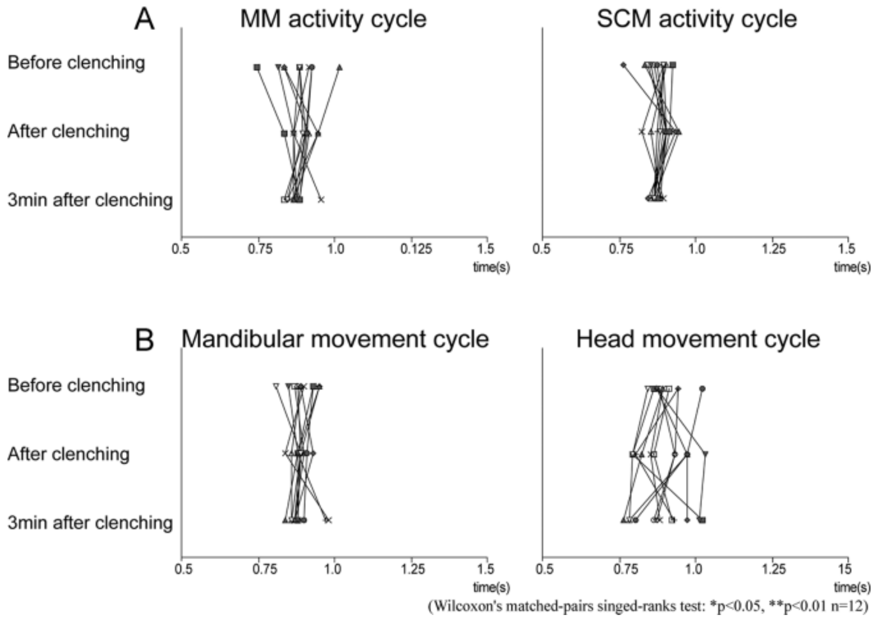

FIGURE 5. (A) The changes in the cycle of MM and SCM activity. (B) The changes in the cycle of mandibular and head movement at three different times. MM indicates masseter muscle; SCM, sternocleidomastoid muscle.

hand, the onset time difference for 3 minutes later was 0.021 ± 0.014 seconds, similar to before clenching.

The difference in time of mandibular movement to head movement onset was −0.054 ± 0.041 seconds after clenching and was significantly shorter than before clenching (−0.012 ± 0.031 seconds). The onset time difference for 3 minutes later was −0.020 ± 0.039 seconds, similar to time before clenching.

DISCUSSION

Temporary maximum clenching

Past experiments induced muscle fatigue by maintaining 80% clenching until it is too painful or too uncomfortable to do so,[8] or by performing maximum clenching until the subject cannot maintain clenching any longer.[9] In this experiment, we considered clenching to have the maximum occlusal force. We believe that in any experiment, the key is whether muscle fatigue is caused by temporary maximum clenching.

Many previous experiments using EMG revealed that when maximum clenching is sustained consciously, a decrease in occlusal force is seen,[10] accompanied by a decrease in muscle activity, conduction velocity,[11] and power spectrum.[12] In our experiment, there was a transitional change to the low-frequency area of MM- and SCM activity power spectrum after clenching compared with before clenching (Figure 3). Therefore, for both MM and SCM, it is evident that we caused muscle fatigue by temporary maximum clenching. Because the power spectrum for both 3 minutes after clenching and before clenching had a similar distribution pattern, the muscles recovered 3 minutes later. This result is concordant to previous results showing recovery at 3[13] and 5[9] minutes after clenching.

SCM activity during mastication

The SCM is located in between the trunk and the skull and is responsible for head movement and orientation to the trunk.[14] For smoothness of movement, a preparatory activity is required at the start of the movement, and the location for both voluntary movement and posture control needs to function normally.[15]

In this experiment, there was no significant change in the movement cycle for chewing gum after clenching. On the other hand, SCM was activated before the MM, and the MM activity time was shortened and SCM activity time prolonged. Furthermore, whereas the three-dimensional distance of mandibular movement remained constant, the distance for head movement increased. These results combined, SCM activity was dominant whereas muscle fatigue was seen in both the MM and SCM. Although a smooth and coordinated mandibular movement along with head movement is difficult after muscle fatigue, a control regulation mechanism for stable mandibular movement must take place.

Feed forward regulation explains the results above. This regulation, opposite to feedback regulation, is defined as a corrective regulatory mechanism that prevents outside information to have an effect. In humans,

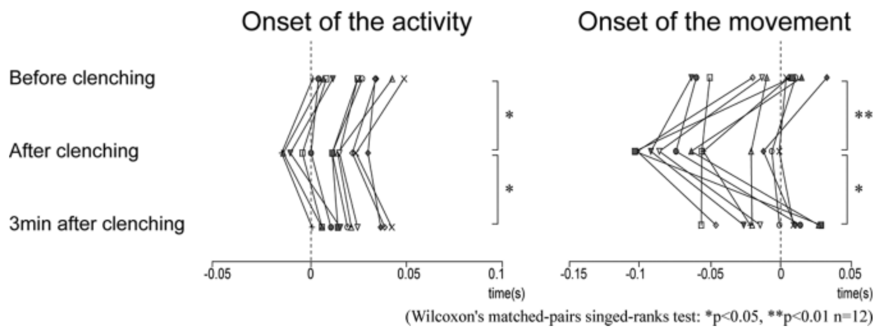

FIGURE 6. The changes of start time difference between MM and SCM activity onset between mandibular and head movement onset at three different times. MM indicates masseter muscle; SCM, sternocleidomastoid muscle.

this regulatory system is believed to play a role in the posture control before voluntary movement and is located in the cerebral cortex, the basal ganglia, and the motor area.[16,17] Therefore, the head movement during muscle fatigue can be considered as supportive for a smooth mandibular movement during mastication.

The regulatory mechanism of SCM during mastication

It is generally understood that mastication is regulated by rhythm, created by a pattern generator from the central nervous system,[18,19] modified through the reflex regulators: periodontal mechanoreceptor and the muscle spindle. In animal experiments, a neural circuit has been found both anatomically[20] and physiologically.[21] A circuit from either the mesencephalic nucleus or the ganglia of the trigeminal nerve to the spinal nerve has been found anatomically. Neurophysically, Zeredo et al[7] reported that splenius muscle activity was induced by inputs from periodontal mechanoreceptors in rats. Neck muscle activation coordinated with mastication has been reported to be induced by the cerebral cortex stimulus in rabbits.[22] These results combined, the change in SCM activity occurred via the mesencephalic nucleus of the trigeminal nerve, and to the nerves that innervate SCM, and the accessory and the neck nerve plexus.

The association of this study to the clinical features of patients

After maximum clenching, muscle fatigue and decreased activity level of MM and SCM was seen in this experiment. Clinically, patients with pathological clenching complain more of head-neck muscle pain[23] and are significantly relieved after wearing sprints.[24] Moreover, there are reports that the SCM activity of temporomandibular disorder (TMD) patients with neck muscle pain with discordant mastication is small and irregular.[25,26] This experiment helps us further understand the pathological effect that these neck muscles have on craniofacial function.

A further study is required, incorporating the patients above, to reveal the functional relationship between the craniofacial region and the head-neck region.

CONCLUSIONS

- After temporary maximum clenching and then chewing gum, the activity of the MM decreased and the SCM increased significantly.
- In this condition, head movement significantly increased while mandibular movement remained constant.
- These results revealed an articulation between masticatory muscles and the head-neck muscles.

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