Clinical significance
The present study suggests that voluntary ballistic jaw opening is involved in the control of motor programming, and motor programming can be reconstructed through learning. This indicates the possibility of rehabilitating stomatognathic function that leads to the idea of the importance of dental prosthetics.

Abstract
Purpose: Neck pain is one of the main symptoms of temporomandibular disorder. Muscle activity of the sternocleidomastoid muscle during occlusion has been clarified in recent years. We reported that when healthy individuals were instructed to chew rapidly, the activity of the sternocleidomastoid muscle responded to activity of the masseter muscle, however, during voluntary jaw opening, activity of the sternocleidomastoid muscle did not respond, but worked actively due to motor programming. The objective of the present study was to investigate the learning effects of repetitive training, that is, changes in activity mode of the neuromuscular system.

Materials and Methods: The sternocleidomastoid and the anterior belly of digastric muscles in 8 healthy male adults were analyzed. In response to acoustic stimulation, each subject was instructed to open their mouth as quickly and widely as possible a total of 30 times with a break between measurements. EMG-reaction times (RT) of the sternocleidomastoid and anterior belly of digastric muscles were measured, and the length of time from the start of EMG activity of agonist to the start of actual movement was measured.

Results: In all subjects, at first measurement, EMG-RT of the sternocleidomastoid muscle did not precede that of the anterior belly of digastric muscle. With each measurement, the difference in EMG-RT between the sternocleidomastoid and anterior belly of digastric muscles were measured, and the length of time from the start of EMG activity of agonist to the start of actual movement was measured.

Conclusion: Repetitive task movement alters the start times of muscular activities, and from the perspective of EMG kinesiology, motor learning effects were confirmed with maximum ballistic voluntary jaw opening.

Keywords: learning, motor program, sternocleidomastoid muscle, digastric muscle

Introduction
Neck pain is one of the major symptoms of temporomandibular disorder.1 For a long time, the relationship between the sternocleidomastoid muscle (SCM) and the stomatognathic system has been examined. For natural and smooth mandibular movements, postural retention of the head is important,2 and coordinated muscular activities between the SCM and masseter muscles (Mm) have been reported, particularly during occlusal function.3 Studies have reported that these coordinated activities occur in response to the Mm, which is an agonist.4,5 In other words, EMG activity of the SCM follows activity of the Mm. We have also examined relationships between SCM and stomatognathic function and reported that when healthy individuals were instructed to bite as hard as they could or pretend to chew food, activity of the SCM responded to activity of the Mm.6 However, when patients with temporomandibular disorder displaying neck pain were instructed to bite as fast as possible, EMG activity of the SCM preceded that of the Mm as an agonist.7

On the other hand, we have previously examined ballistic (rapid) jaw opening and reported that activity of the SCM, agonist, preceded that of the anterior belly of digastric muscle (Dig) and deduced that this was due to motor programming.8 Motor programming is based on motor learning and is a mode of communication inside the central nervous system involved with posture adjustment and movement.9 Synergistic muscle activities that are necessary for intentional postural movements are also programmed.10
For humans to perform complicated movement behaviors, combinations of various movement patterns are necessary. These complicated movement behaviors are possibly due to learning. Therefore, the purpose of this study was to investigate how the muscle activity of the SCM changed during repetitive maximum voluntary ballistic jaw opening.

Measurement Device and Methods

Subjects
The study group comprised 8 healthy male adult subjects with normal occlusion ranging in age from 20 to 25 years old with no history of respiratory diseases or subjective temporomandibular disorders. After thoroughly explaining the objective of the present study, informed consent to participate was obtained without imposing any preconceived notion about expected outcomes. The present study was also conducted with approval from the ethics review board of Osaka Dental University (Approval number: 050611).

Measurement device and methods
Figure 1 shows a block diagram of this present study. An electromyogram was taken from the right and left Dig and SCM muscles. The electrical potential of each muscle was measured using 4-mm Ag/AgCl surface electrodes with a radio shield wire (EL254S; Monte System, Tokyo, Japan). A bipolar pair with 20 mm inter-electrode distance was placed along the muscle fiber of each muscle utilizing adhesive collars (H760; Nihon Kohden, Tokyo, Japan). Muscle activity signals were subjected to A/D conversion using a Biopac (MP150; Monte System) with a time constant of 0.03 s, sampling frequency of 1 kHz, amplification of ×5000 and high cut frequency of 1 kHz. The stratum corneum at the target site of electrode attachment was exfoliated and cleaned using alcohol to reduce impedance. A reference electrode was also placed on the ear lobe.

Movement of the mandibular incisor point was measured by mandibular kinesiography (MKG-K6I; Myo-tronics, Seattle, USA), and data were subjected to A/D conversion for storage in a computer installed with AcqKnowledge software. Both EMG and mandibular movements were recorded simultaneously.

Each subject was instructed to sit in a chair without a headrest with their back straight. The subject was able to look at a monitor to see vertical movements of the jaw. The subject was instructed to open their mouth as wide as possible [maximum voluntary opening (MVO)]. The subject was then instructed to open their mouth as fast and widely as possible in response to a buzzer sound [ballistic voluntary opening (BVO)]. With breaks, this procedure was repeated a total of 30 times. Both during and after the experiment, we ascertained that subjects did not experience subjective muscle fatigue through dialogue. Furthermore, a verbal warning was provided before each buzzer after a variable duration between the two buzzer sounds. Moreover, to avoid effects of the startle reflex, the subject was made accustomed to the buzzer sound prior to the experiment.

During each BVO, EMG-RT of Dig and SCM was measured, and the difference of EMG-RT between the two muscles was measured (DS). Latency between muscle activity onset by the agonist and the beginning of muscle movement was measured [motor time (MT)] (Fig. 2). According to Mizui et al., muscle activity of 20 µV and under was considered as inactivity. The onset of muscle activity was averaged from results for the left and right muscles.

Statistical analysis
Linear regression analysis was performed to ascertain the relationship between each pair among the three parameters of Dig, SCM, and MT. SPSS 12.0J software (SPSS, Tokyo, Japan) was used for statistical analysis, with values of $p < 0.05$ considered significant.

Results

BVO
Figure 3 shows a typical EMG during MVO. In all subjects, during the first BVO, activity of SCM oc-
occurred after that of Dig. Figure 4 shows a typical EMG at every tenth BVO. With the margin of error for the difference in EMG-RT between movement and postural muscles at ≤ 5 ms, activity of SCM preceded that of Dig in 36% of subjects.

EMG-RT of Dig and SCM, and DS

The mean DS for the 8 healthy subjects was plotted with respect to the number of measurements (Fig. 5). With each measurement, the value of DS decreased. In other words, activity of SCM began to precede that of Dig.

The correlation coefficient for the relationship between the mean EMG-RT of Dig and that of SCM was determined for the 8 subjects at every tenth measurement, and high correlation coefficients were achieved, ranging from 0.987 to 0.992 (Fig. 6). Conversely, the relationship between MT and EMG-RT of Dig or SCM exhibited only weak correlations, ranging from −0.040 to 0.290 and from −0.124 to 0.399, respectively (Figs. 7, 8). The regression model, the correlation coefficient (r), and the probability level (p-value) are presented in Table 1.
Motor Learning of Sternocleidomastoid Muscles

Discussion

Movement patterns represent joint movement combinations that form movements, and muscle activity patterns represent the timing for the activity and suppression of related muscles. Instructions are also sent to muscle groups with specific timing and order to elicit the intended movements. In other words, agonist, synergist, and postural muscles dictate the order and timing of movement initiation. Motor learning can also modify movement patterns.11

Furthermore, ballistic movements occur so quickly that modification through peripheral feedback is impossible. Muscle activity elements must therefore be programmed beforehand. Lee reported that when subjects were instructed to raise their arms in a standing position as fast as possible after a signal, activity of the ipsilateral biceps femoris (postural adjustment muscle) preceded that of the deltoid muscle (upper arm movement muscle) and that postural adjustment represented synergistic muscle activity based on motor programming.15

The present study focused on maximum mouth opening as a non-routine action that is not preprogrammed. As a result, the relationship between the start of EMG activity in both the Dig (agonist) and SCM (postural/synergist muscle) changed with time, and eventually the start of EMG activity reversed between SCM and Dig.

In recent years, the mode of head movements during mandibular movements, or in other words, coordinated movements of the head in relation to the mandible, has become clearer.16 In mouth-opening movement associated with tapping, the head moves upward, and as the mouth is opened wider, the amount of head movement becomes greater. Head movements are rhythmical and may be related to postural control.17, 18 Furthermore, one of the factors that regulates maximum mouth opening is the soft tissue in the cervical spine and sub-

Table 1 Model summary of the linear regression analysis.

<table>
<thead>
<tr>
<th>a. Correlation between EMG-RT of Dig and SCM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Regression equation</td>
</tr>
<tr>
<td>Once</td>
<td>Dig = 0.996SCM − 4.78</td>
</tr>
<tr>
<td>10 times</td>
<td>Dig = 1.028SCM − 7.427</td>
</tr>
<tr>
<td>20 times</td>
<td>Dig = 1.088SCM − 6.661</td>
</tr>
<tr>
<td>30 times</td>
<td>Dig = 1.004SCM − 9.005</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b. Correlation between EMG-RT of Dig and MT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Regression equation</td>
</tr>
<tr>
<td>Once</td>
<td>MT = 8.862Dig + 99.419</td>
</tr>
<tr>
<td>10 times</td>
<td>MT = 27.45Dig + 74.502</td>
</tr>
<tr>
<td>20 times</td>
<td>MT = 35.609Dig + 59.242</td>
</tr>
<tr>
<td>30 times</td>
<td>MT = −1.738Dig + 85.125</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>c. Correlation between EMG-RT of SCM and MT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Regression equation</td>
</tr>
<tr>
<td>Once</td>
<td>MT = 23.427SCM + 74.931</td>
</tr>
<tr>
<td>10 times</td>
<td>MT = 39.285SCM + 36.839</td>
</tr>
<tr>
<td>20 times</td>
<td>MT = 35.609SCM + 65.686</td>
</tr>
<tr>
<td>30 times</td>
<td>MT = −5.903SCM + 90.287</td>
</tr>
</tbody>
</table>
mandibular regions, and by leaning the head backward, enough space is created for maximum mouth opening. Therefore, even during first ballistic and maximum mouth opening, some change in head position should occur. Compensatory movement for the looking-up motion is generally enhanced by the action of the SCM. This phenomenon is due to repetitive rapid and continuous mouth opening. This also occurs when head flexors are weak and the SCM is relatively stronger.

In the present study, repeated fast and wide mouth opening resulted in changes in motor learning for moving the head upward. During the process of learning, DS becomes smaller, and as a result of learning, the SCM preceded the agonist. Due to individual learning ability, this phenomenon didn’t occur for all subjects. The results suggest that, at least in rapid mouth opening, activity of the SCM does not appear to respond to activity of the Dig agonist.

RT is latency between the buzzer sound and muscle activity onset by the agonist. MT is latency between muscle activity onset by the agonist and the beginning of muscle movement. It is said that the former reflects the central process of motor appearance, and the latter reflects the peripheral process. In this study, the relationship between RT of Dig and that of SCM showed high correlations (Fig. 7). However, the relationship between MT of Dig and that of SCM exhibited weak correlations (Fig. 8). This means that activity of SCM preceding that of Dig showed a high degree of correlation with the time of the beginning of muscle movement, with no process of Dig muscles to start actual muscle movement. Therefore, activity of the SCM does not appear to respond to activity of the Dig agonist.

One study suggested the existence of a mechanism by which the head and neck muscles work to place the head in a more suitable position during mastication. In the present study, the SCM might be active in stabilizing the head. However, the head is supported by about 25 neck muscles. Further investigation into antagonist and head position are needed.

Humans have learned to walk on two feet and to talk, and while the angle formed by the skull and spine is almost horizontal in most animals, the angle for humans is nearly perpendicular. This has caused morphological changes in the oropharynx. Furthermore, the two forelimbs are no longer required to support the body, and because of these two arms, humans have acquired oral functions that differ from those of other animals. This has enabled humans to push food through the body without excessive use of neck muscles. Origins of the SCM are on the sternum and rib, and insertions are on the occipital bone and mastoid process. This long and large muscle running superoinferiorly has a muscle length of about 20 cm. Contraction of the left or right SCM results in contralateral rotation, and contraction of both left and right sternocleidomastoid muscles results in head flexion. In cervical spine extension and head extension involving the cervical vertebrae, the carotid sheath and various vessels are displaced posteriorly into the SCM. In other words, the muscle functions to protect deeper soft tissues. The change in head position due to mouth opening is thought to at least push forward the pharynx to activate the SCM.

Two types of control are used for executing intended actions and movements. One involves feedback-controlled slow movement with closed-loop control based on the continuous feedback of sensory input from a body part moving towards a target or intermittent feedback due to visual inputs. The other involves forward control based on open-loop control where movements are executed without any change once started. The latter is already programmed into the central nervous system and is automated, and this regulates rapid movements. Repeatedly performing unprogrammed voluntary movements could change the mode of control from feedback to feed-forward. For this reason, the present study selected maximum mouth opening, a non-routine movement.

Learning is a process through which experience changes the nervous system, thus altering behaviors. In terms of electromyography, motor learning is a process wherein exercises construct and modify programs for executing movements within the central nervous system, and involves a series of processes acquiring the abilities to execute skills, rather than the skills themselves. Furthermore, motor learning comprises a series of processes related to experience or training resulting in relatively permanent changes in abilities to acquire skills. In the field of rehabilitation, motor learning can aid the acquisition of permanent movements or re-acquisition of lost movements within a short period. Study of more movements to ascertain the required lengths of time for motor acquisition and long-term motor acquisition will thus be necessary.
In the present study, it was clear that activity of the SCM was not only controlled by reflection, but also motor programming in maximum mouth opening. In the future, we expect that it will be possible to apply motor programming in a clinical setting to TMD.

Conclusions

Eight healthy subjects were asked to open their mouth as fast and wide as possible in response to a sound stimulus for a total of 30 times each, and muscle activity of the Dig and SCM and movement of the mandibular incisor point were simultaneously measured.

In all subjects, activity of the SCM occurred after activity of the Dig (movement muscle) at first measurement.

With each measurement, activity of the SCM tended toward preceding activity of the Dig (movement muscle).

Acknowledgments: The author greatly appreciates Dr Masahiro Tanaka and Dr Takashi Nagasuna, Osaka Dental University, for help, suggestions and valuable advice on this paper. The author also thanks Mr Yoshi nobu Ueda and Mr Syuzi Ueno for subject cooperation with figures.

References
20. Takeuti T. Surface anatomy and compensatory move-


