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Movement-Related Cortical Potentials Associated with Oral and Facial Functions in Humans

Nakajima Ichiro, Oka Schunichi,
Ohba Hiroiku and Yoshida Masafumi
Nihon University School of Dentistry,
Japan

1. Introduction

It is possible to record the electrical activities of the human brain by placing electrodes on the surface of the scalp. Event-related potentials (ERPs) are the cortical potentials associated with higher brain functions of perception, cognition and movement in humans. They are regarded as manifestations of brain activities that occur in preparation for, or in response to, discrete events (internal or external factors). ERPs can be considered to be one of the useful indicators for understanding information processing of the human brain, as well as other measurement techniques for brain activity, such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG).

Movement-related cortical potentials (MRCPs) and contingent negative variations (CNVs) are classified into ERPs that are related to the preparation, execution, and evaluation of motor responses. There have been many research reports on the diagnosis of patients with neurological motor diseases based on the recording of these potentials. Presently, the recording of these potentials is the most established method in cognitive and behavioral sciences among noninvasive human brain imaging methods.

In recent years, there has been a growing need for the accurate diagnosis and treatment of patients with dysphagia. For the development of research on dysphagia, it is necessary to clarify the nervous system of mastication and swallowing in the maxillofacial regions. However, there have been fewer reports on maxillofacial movements than on other body movements (i.e., hand, finger, and foot movements). To clarify how motor preparation processes of the brain are affected by the features of jaw muscle activities of maxillofacial regions, we have investigated the scalp distribution and waveform components of MRCPs and CNVs in relation to oral and facial functions in humans. We demonstrated that MRCPs and CNVs necessarily occur in humans during oral and facial motor tasks, reflecting the features of cognitive and motor functions of the neural system. In this chapter, therefore, we review the findings of previous studies and discuss the importance of establishing neurological research of oral and facial motor disorders based on these ERPs.

The contents of this chapter are as follows.

1. Mastication and swallowing.
2. Pain research using somatosensory evoked potentials.
3. MRCPs associated with jaw movements in humans.
4. CNVs associated with swallowing in humans.
5. Wavelet transform analysis for ERPs associated with jaw motor function.
6. Frequency changes of jaw muscle activity during reaction to a warning signal.

Furthermore, in this chapter, we discuss their implications in both future research and practice.

2. Mastication and swallowing

Mastication and swallowing are two tightly integrated components of food intake behavior. Jaw muscle activity is a basic parameter related to both chewing and swallowing. Both movements are controlled by complicated neural mechanisms involving the central pattern generator (CPG) in the brainstem as compared with mechanisms for other body movements. It is noteworthy that the motor cortices have an important role in the fine control and coordination of these oral and facial functions.

2.1 Mastication

Mastication is the action of breaking down food, in preparation for deglutition. This action involves a complex highly organized neuromuscular and digestive activities that, in normal individuals, integrate the various components of the masticatory system, such as the teeth and their investing structures, the muscles, the temporomandibular joints, the lips, the cheeks, the palate, the tongue, and the salivary glands. The aim of chewing is to crush, triturate, and mix food with saliva, so that food can be transported by deglutition down the digestive canal. The masticatory muscle is not only an agonist of an actual jaw movement but also a sensory organ involved in sensing the mandible position through stretch receptors (Morimoto et al., 1983). An overview of the neural system of mastication is shown in Fig. 1. Figure 1A shows examples of recordings of jaw muscle EMG activity during mastication. The masseter muscle (jaw-closing muscle) and digastric muscle (jaw- opening muscle) are alternately activated and produce rhythmical jaw movements during mastication. Figure 1 B shows a schema of the neural mechanism of mastication. Mastication is controlled by a rhythmical contraction of bilateral jaw-closing and jaw-opening muscle groups under the control of CPG in the brainstem (Lund & Kolta, 2006). From the results of animal studies, it has been found that the fundamental pattern of mastication—rhythmic opening and closing of the jaws—and the associated repetitive movements of the tongue, cheeks, and lips can be generated by a brainstem CPG in the absence of sensory feedback. On the other hand, oral sensation information from the peripheral sensory receptors (periodontal membrane, oral mucous membrane, and masticatory muscles) is also inputted in the central nervous system to control jaw movements intricately. On the other hand, the activity of most neurons in the masticatory cortex is higher during ingestion than during mastication, suggesting a major role of these neurons in setting the parameters of the first bite. In many species, including the cat, rabbit, and monkey, repetitive electrical stimulation of a certain area in the cerebral cortex induces coordinated rhythmic movement of the jaw and tongue (Nakamura & Katakura, 1995).

Recent studies by fMRI and PET in humans have revealed that several regions of the brain are activated during mastication, including the primary somatosensory cortex (SI),

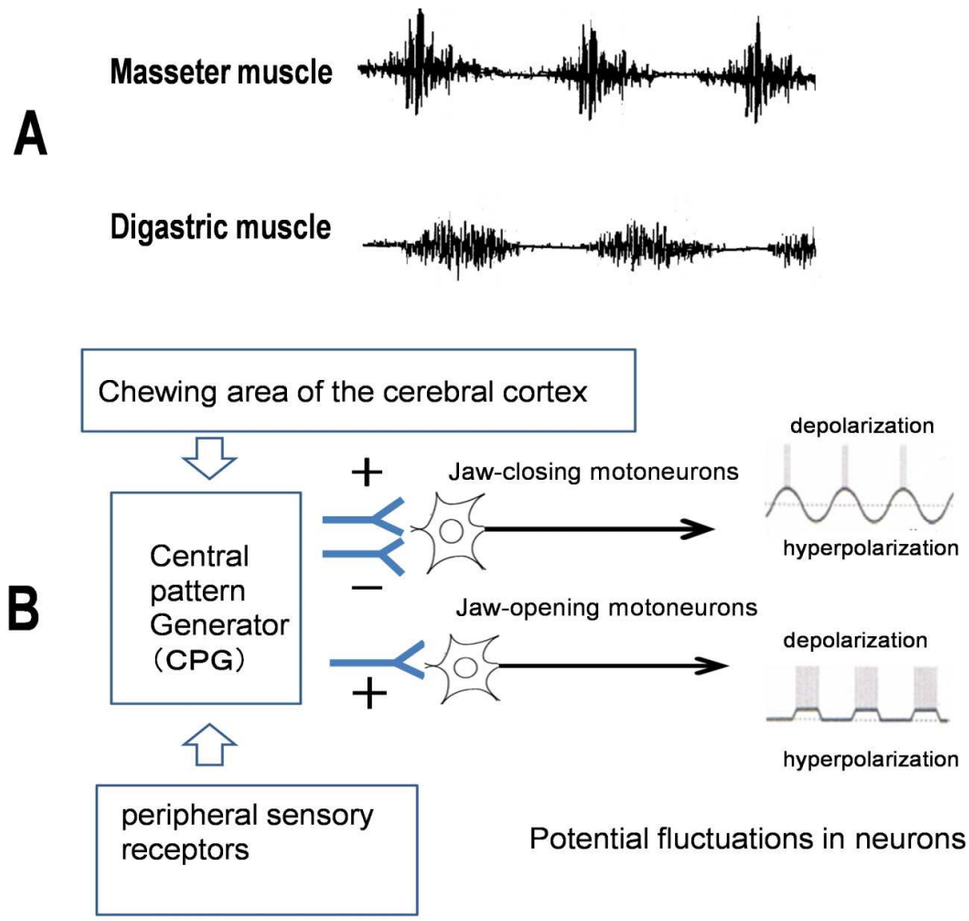


Fig. 1. Neural system of mastication. (Modified from Inoue T, 2008)
A: Masticatory muscle activities during chewing; B: Generation of masticatory rhythm in the brainstem. Efferent/afferent impulses are indicated by arrows.

primary motor cortex (MI), supplementary motor area (SMA), premotor area (PM), prefrontal cortex (PFC), insula, posterior parietal cortex (PPC), thalamus, striatum, and cerebellum (Momose et al., 1997; Onozuka et al., 2002). However, it is still unclarified how CPG in the brainstem is controlled by the cerebral cortex in humans.

2.2 Swallowing

Swallowing consists of three phases, the oral, pharyngeal, and esophageal phases. In swallowing, many orofacial muscles are activated during jaw-closing movements. Figure 2 shows an example of EMG recording during the swallowing of water in a human subject. It has been presumed that in volitional swallowing, cortical control is dominant in the oral phase, whereas the swallowing reflex arising from the brainstems is dominant in the later phases.

From the results of animal studies, it has been found that the sequential and rhythmic patterns of swallowing are formed and organized by CPG. CPG can be subdivided into three systems (Andre´, 2001):

- The afferent system corresponding to the central and peripheral inputs to the center

- The efferent system corresponding to the outputs from the center, consisting of various motoneuron pools involved in swallowing
- The organizing system located in the medulla oblongata, corresponding to the interneuronal network that programs the motor pattern

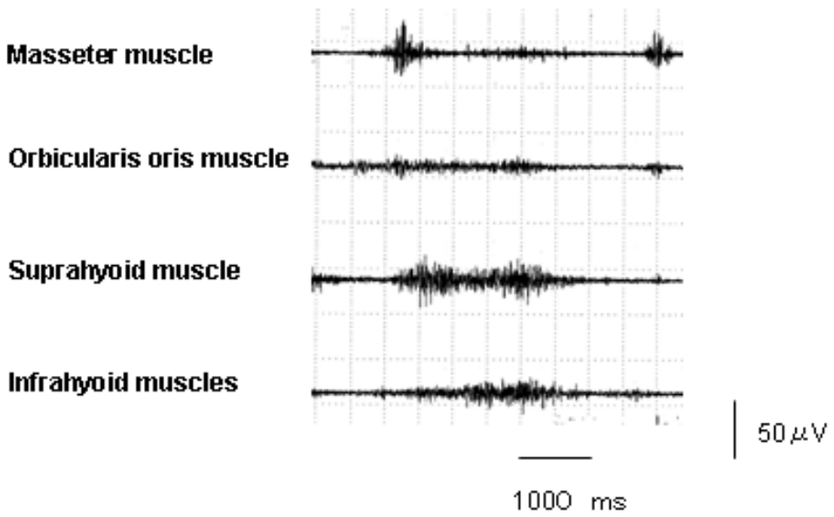


Fig. 2. Example of EMG recording of swallowing.

Recent neuroimaging studies using various techniques, such as PET, f-MRI, and MEG, have revealed that swallowing activates multiple cerebral regions including the face area of the primary sensorimotor cortex, premotor cortex, insular cortex, frontal operculum, anterior cingulate cortex, and other cerebral regions (Dziewas et al., 2003; Hamdy et al., 1999; Hamdy et al., 2000; Kern et al., 2001;Watanabe et al., 2004; Toogood et al., 2005). In particular, f-MRI research revealed that multiple cerebral regions are recruited during swallowing, most notably the anterior cingulate cortex, pericentral cortex, insula, and premotor cortex, with different degrees of symmetry between hemispheres. These findings are consistent with those of previous PET activation studies of swallowing, that showed a similar recruitment pattern, thereby demonstrating strong and relatively direct connections from the regions of the motor and premotor cortices to the muscles of the pharynx and esophagus.
However, the limitations of these techniques are as follows. f-MRI cannot distinguish among cortical activities before, during, and after swallowing, given that changes in f-MRI signal intensity signal reflect the average cortical activity throughout all phases of swallowing. Although MEG is often considered a complementary technique with a higher temporal resolution, it also has some limitations because magnetic fields generated deep within brain tissues decay rapidly over distance and are less likely to be detected at the surface than electrical fields. Thus, the correspondence between the phases of swallowing and various cortical activities has not been elucidated completely.

3. Maxillofacial pain research using somatosensory evoked potentials (SEPs)

Pain, an intimately personal phenomenon, is difficult to assess. There are many studies of oral pain sensation in humans. In this section, we introduce some studies of SEPs in oral sensation and pain sensation.

3.1 Overview of SEPs

Evoked potentials are electrical signals generated by the nervous system in response to sensory stimuli. Auditory, visual, and somatosensory stimuli are used commonly in clinical evoked potential studies. SEPs consist of a series of waves that reflect the sequential activation of neural structures along the somatosensory pathways. Although SEPs can be elicited by mechanical stimulation, clinical studies use electrical stimulation of peripheral nerves, which induces larger and more robust responses.

3.2 Pain research using SEPs

To measure pain, it is important that subjective and objective methods should be performed simultaneously. Pain-related evoked potentials are commonly used in studies in which pain-related brain activities in humans are objectively evaluated. N150 and P250 are the two major components constantly recorded in pain-related evoked potentials. Using this late evoked potential, we have conducted a few studies as follows.

Commercially prepared local anesthetic solutions usually contain a vasoconstrictor agent in dental treatment. First, therefore, we evaluated the effects of different types and concentrations of the vasoconstrictors on local anesthesia. Twelve young healthy volunteers from 18 to 24 years old participated in this study. To estimate subjective pain intensity, the visual analogue scale (VAS) was used. To estimate objective pain intensity, the late component of SEPs recorded from the vertex was analyzed. On the basis of Oono's method (Oono et al., 2008), a monopolar electrode was fixed to the surface of the upper central incisors and single electrical square pulses were administrated at 1 Hz. In this study, stimuli inducing bearable pain sensation (VAS = 5 -7) were administered. After baseline VAS score and SEP were determined, one of the local anesthetics was injected, and then postinjection VAS score and SEP were determined 22 times. The local anesthetics tested in this study were as follows: 2% lidocaine with 1/80,000 adrenaline (EL-8), 2% lidocaine with 1/200,000 adrenaline (EL-20), 2% lidocaine with 1/300,000 adrenaline (EL-30), 2% lidocaine (L), and 3% propitocaine with 0.03 IU felypressin (FP). Each local anesthetic (0.5 ml) was injected into the gingiva.

Five minutes after the injection of each local anesthetic, all the subjects felt numbness throughout their mouth. There were no distinguishable SEP components and their mean VAS score markedly decreased to zero. After the injection of a local anesthetic, the time of the reappearance of SEPs agreed with the time of increase in VAS score from zero. The following shows the duration of the effect of each local anesthetic as determined from VAS score and SEPs. EL-20 showed the same duration of its anesthetic effect as EL-8, but EL-30, and FP showed shorter durations than EL-20. These findings suggest that SEP assessment serves as a useful method for the study of dental analgesic and anesthetic agents in humans.

Second, we examined SEPs in subjects inhaling graded concentrations of nitrous oxide (N_2O) in oxygen (O_2) (Oka et al., 2007). In dental practice, a nitrous oxide inhalation sedation technique is usually used for the patients, to reduce their pain and anxiety. In this study, we used various mixture concentrations of N_2O in O_2 (0%, 10%, 30% and 50%), and measured and analyzed SEP and VAS scores in responses to painful electrical fingertip stimulation using the standard method first introduced by Bromm and Chen at high and low intensities in 15 volunteers (Bromm & Chen, 1995). Mixed effect model statistical analyses revealed that SEP and VAS score decreased significantly with increasing mixture concentration (Fig. 3)

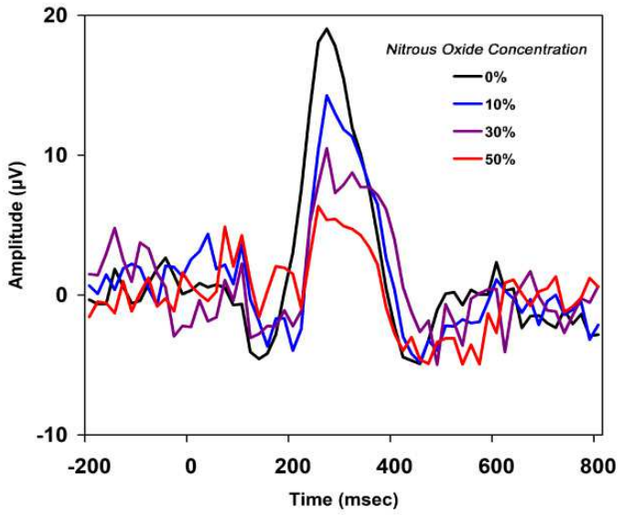


Fig. 3. Relationship between SEP amplitude and N_2O concentration.

Clinical observations suggest that the perceived intensity of a painful event increases as the unpredictability of its occurrence increases. Therefore, third, we examined the effect of varying stimulus predictability on SEP and pain report (PR) and fear report (FR) scores in 25 healthy volunteers experiencing repeated noxious fingertip shocks (Oka et al., 2010). Each volunteer was exposed to high and low stimulus intensities administered in four stimulus patterns defined by the stimulus sequence (SEQ) and interstimulus interval (ISI) as follows: A) serial stimulus intensity SEQ with a fixed ISI; B) serial stimulus intensity SEQ with varying ISI; C) random stimulus intensity SEQ with fixed ISI; and D) random stimulus intensity SEQ with varying ISI. Results revealed that a lower stimulus predictability led to higher PR and FR scores, and a greater SEP amplitude. These results would conform with the hypothesis that a low stimulus predictability is associated with high PR and FR scores, and a larger SEP amplitude.

The amplitudes of N150 and P250 components are considered to reflect the intensity of perceived pain (Kakigi et al., 2000), and reflect the activities of operculoinsular and cingular cortices, respectively (Iannetti, et al., 1990; Tarkka & Treede, 1993). Numerous investigators have used SEP extensively to study both pain and fear. Recent studies have shown that both the N 150 and P250 peaks are related, at least for some types of stimulus, to the orienting response (Dowman, 2004; Dowman et al., 2007). Nociceptive processing intrinsically involves attentional factors (Bushnell et al., 1985). Pain-related SEP may indicate, in part, attention to a threatening stimulus (Yamasaki, et al., 2000). Some investigators have found that N 150 base-to-peak amplitude-amplitude is related to attentional processing (Gratton et al., 1990; Miltner & Weiss, 1998). Others have reported that pain-related P250 is sensitive to attention (Lorenz & Garcia, 2003).

These findings indicate that SEP appears to be a useful indicator in studies of the analgesic effect and in psychological studies.

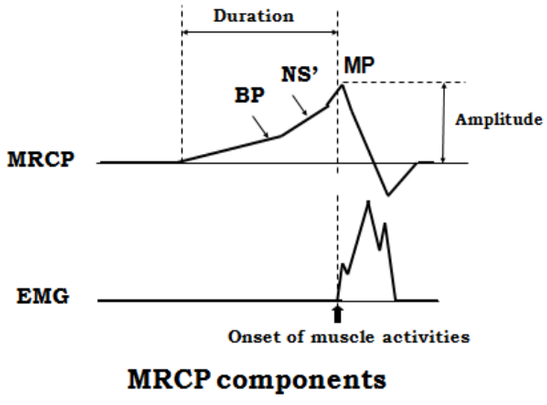
4. MRCPs and CNVs

Recently, noninvasive techniques for human brain mapping during movement have been developed in the fields of clinical neurophysiology. In general, these brain mapping

techniques are mainly classified into two types on the basis of their parameters measured, that is, electrophysiological and hemodynamic responses (Shibasaki, 2008). The former type includes EEG and MEG, and the latter type includes PET and fMRI. The former type has a higher temporal resolution than the latter type. In contrast, the former has a lower spatial resolution than the latter. On the other hand, EEG has been commonly used for many years because of it being a simple analytical technique in addition to its excellent temporal resolution. Thus, various cortical potentials reflecting higher central nervous system functions in humans (cognitive, motor, and sensory functions) can be obtained by averaging EEG data. Today, clinical EEG analysis is well developed for the diagnosis of brain functions in patients with neurological motor diseases. Cortical potentials obtained by EEG that are related to motor responses can be classified into MRCPs and CNVs.

4.1 Overview of MRCPs

MRCP is a slow negative potential in an electroencephalographic recording that occurs about 2 s before voluntary movement production in humans (Kornhuber & Deecke, 1964). MRCP is obtained by averaging EEG data before the onset of voluntary movement. This potential reflects the cortical processes involved in movement planning and movement preparation. In general, MRCP consists of two main components, Bereitschaftspotential and negative slope (Shibasaki et al., 1980; Ikeda et al., 1992). A schema of MRCP waveform is shown in Fig.4. Ikeda et al. (1992) have determined the cortical source of MRCPs by the direct recording of cortical potentials through chronically implanted subdural electrodes in patients with epilepsy as part of presurgical evaluation.



(1) Bereitschaftspotential (BP): BP is a gradually increasing, bilaterally widespread surface negativity with the maximum over the midline vertex region regardless of the site of movement, beginning about 1-1.5 s before the movement onset.

(2)Negative slope (NS'):NS' is a much steeper slope starting about 400 ms before the movement onset, and is characterized by a more localized negativity over the central and vertex regions contralateral to the movement.

(3)Motor potential (MP): MP is well localized to a small area of the contralateral central scalp, corresponding to the movement site, and occurs immediately before the movement onset.

Fig. 4. Schema of MRCP waveform.

From extensive studies, it is the current consensus that BP starts first in the SMA including pre-SMA and SMA itself, and then shortly thereafter in the lateral premotor cortices bilaterally. About 400 ms prior to the movement onset, NS' starts in M1 and the premotor cortex mainly contralaterally. In general, MRCPs recorded from Cz over the human scalp are considered to reflect SMA activity.

MRCPs are also generated from subcortical structures. Sasaki et al. (1981) reported that in monkeys trained to perform spontaneous hand movements, MRCPs recorded before the

initiation of movement disappear following cerebellum resection. Ikeda et al. (1994) reported that in cerebellar infarction patients performing an upper-limb movement task, no MRCP was recorded.

4.2 Features of MRCPs associated with jaw movements

Unilateral limb movements on the unilateral side are controlled mainly from the contralateral hemisphere. Recently, it has been clarified that there are differences in the features of the waveform components of MRCPs between the limb and jaw motor tasks.

Figure 5 shows a typical example of grand averaged waveforms of MRCPs associated with jaw-closing movements in eight subjects. Negative potentials appeared bilaterally and symmetrically approximately 1.5 s before the onset of jaw-closing muscle EMG activity.

The amplitudes of the cortical potentials preceding jaw closing can be classified into two components: BP, the cortical negative potential that initially develops slowly 1.0-1.5 s before the onset of EMG activity; and NS', the gradient of BP that rapidly develops 100-200 ms before the onset of EMG activity. These components are consistent with those of MRCPs associated with limb movements. After the movement onset, it was difficult to identify motor potential, because cortical potentials were mixed with jaw muscle EMGs. It is concluded that the supplementary motor area is necessarily activated preceding the onset of jaw movements as well as limb movements. However, MRCPs associated with jaw biting movements are different from those associated with limb movement, with respect to the NS' component. Previously, we compared the distribution of MRCPs on both sides of the scalp preceding jaw biting movements in 10 healthy subjects (Nakajima et al. 1991).

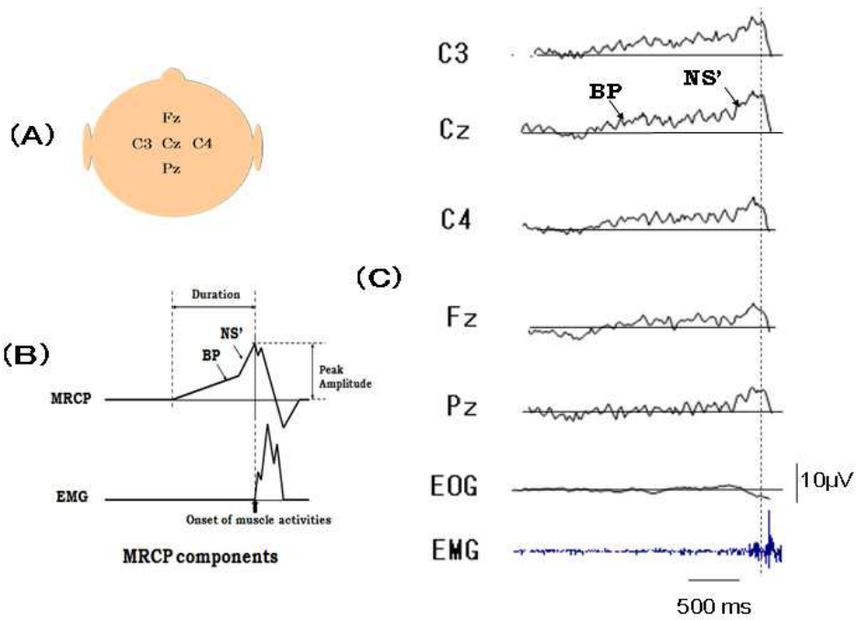


Fig. 5. Grand averaged waveforms of MRCPs associated with jaw-closing motor task in eight subjects. (A): Recording sites of EEGs. (B): MRCP components. (C): MRCP waveforms recorded at five electrodes.

In this study, a subject made a biting movement as instructed, with a 0.5-cm thick gauze pad held between the upper and lower molars on the right or left side, permitting ample biting

motion. Figure 6 shows examples of the three traces of MRCPs from five regions of the scalp obtained on different days with a 1-week interval in the same subject.

BPs were recorded from the midline-central, central, and temporal areas of the scalp in accordance with the international 10–20 system, preceding self-paced biting on one side. The cortical negative potentials began 1.0-1.5 s before the EMG activity onset of the masseter muscle. All of these negative potentials could be considered to be BPs, and the additional NS' appeared 70-80 ms before the EMG activity onset of the masseter muscle. BPs were detected from all the recorded regions of the scalp, whereas NS's were observed only from the bilateral temporal areas. In contrast, NS's were more frequently detected on the side contralateral to the wrist movement in this subject. This is consistent with previous reports. There was a difference in the localization of the MRCP components between unilateral biting and wrist movements.

In this study, the amplitudes of BPs and NSs were largest in the temporal areas that were ipsilateral to the side of biting movement in all subjects.

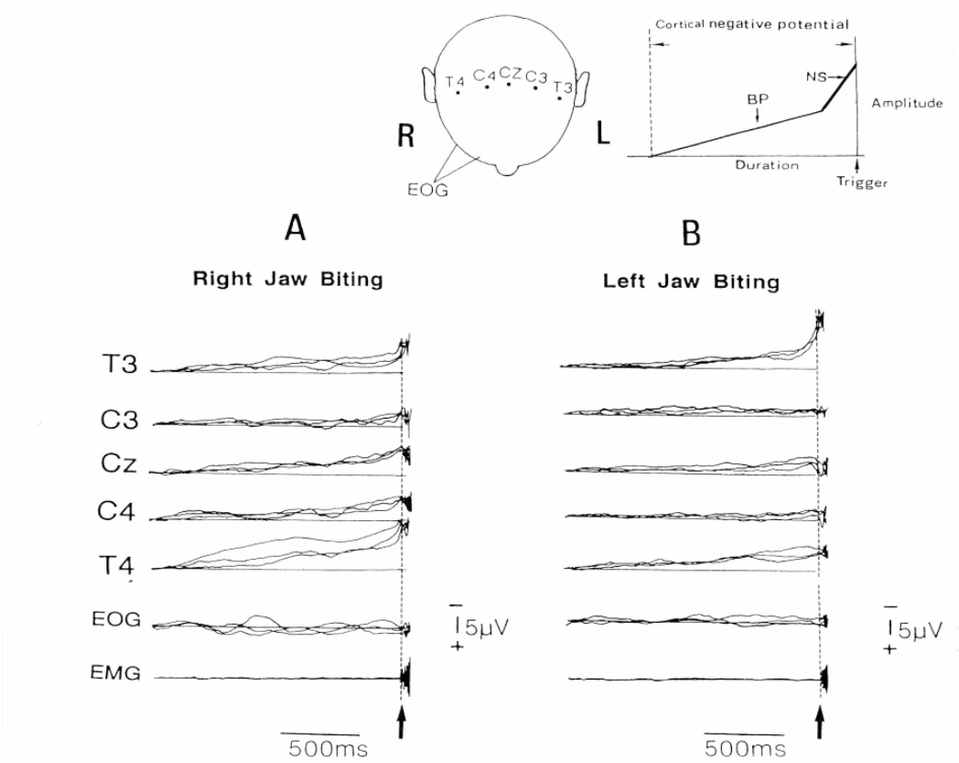


Fig. 6. Examples of cortical potentials preceding unilateral biting on either the right or left side. (From Nakajima et al. 1991)

This difference in localization indicated that impulses from the biting area of the human cerebral cortex descending to the masseter muscle on the ipsilateral side are more powerful than those on the side contralateral to the biting.

Yoshida et al. (2000) compared the MRCPs accompanying various mandibular movements to study the motor control mechanism underlying these movements. The cortical maps of BP/NS' (BP and NS' combined), immediately prior to mouth opening and closing, showed a symmetrical distribution, whereas those for the lateral movements tended to predominate

over the hemisphere ipsilateral to the direction of the movement. They found that BP/NS' amplitudes at the onset of movement differed significantly or tended to differ between mouth opening, mouth closing, and lateral movements. There is a significant difference in the relationship between MRCP components and the agonist muscle activities during the jaw and limb movements.

The above-mentioned findings indicate that the lateral movements of the mandible may be controlled mainly from the ipsilateral hemisphere. This control might be explained in terms of the complicated coordination of the bilateral muscles in the maxillofacial areas in humans.

However, the amplitude of a component's peak identified at one electrode location can radically change and sometimes even cross the zero baseline and switch polarity as a function of the position of the reference electrode. That is, MRCP amplitudes do not represent absolute values of electrical brain activities because of the position of the reference electrode and the use of a limited montage (Desmedt et al., 1990; Michel et al., 2004). Therefore, it is necessary to validate the results obtained by other research methods.

Figure 7 shows examples of averaged fMR images of the human cortex during the jaw-biting motor task on the right side (habitual biting side) in six subjects.

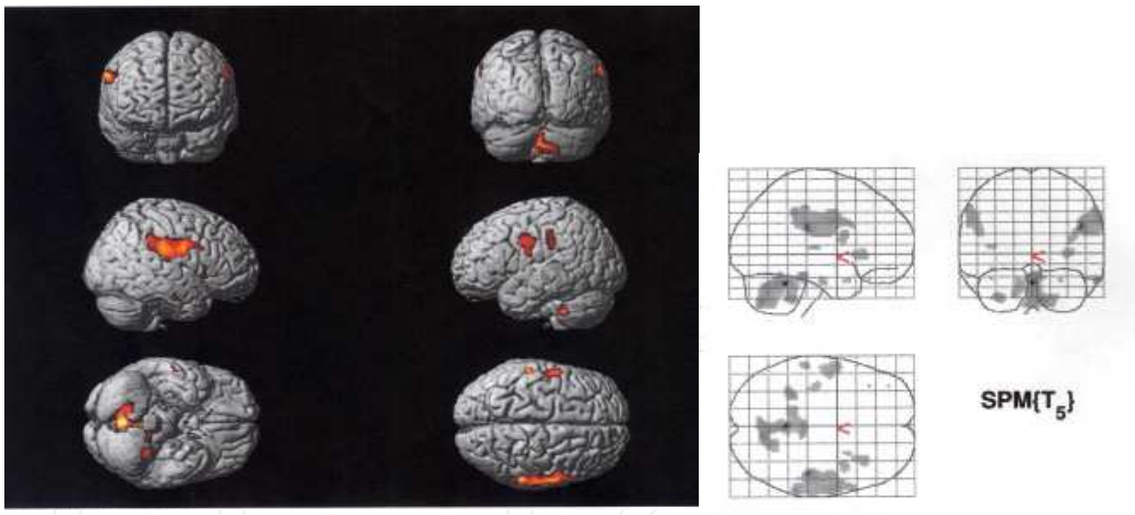


Fig. 7. fMRI recording during unilateral jaw-biting motor task in six subjects.

MRI (Toshiba VISART-EX 1.5T) was carried out in this study. Functional MR images were obtained using a superconducting MRI scanner at 1.5 tesla. To enhance blood oxygenation level (BOLD) contrast, images were taken in a T2-weighted echo-planar imaging (EPI) sequence. The imaging conditions were as follows: field of view (FOV), 240 mm; repetition time (TR)/echo time (TE), 4000/45 ms; flip angle, 90 deg; and slice thickness, 8.0 mm. The transverse thickness, 8.0 mm. EPI conditions were as follows. The entire brain was dissected into 18 slices (8 mm/slice for the longitudinal axis of the body; slice thickness, 8 mm). The EPI resolution (voxel) was 2.5×2.5×8 mm^3. T1-weighted autopsy images were also taken at the same position and using the same number of slices. The image resolution was 1×1×8 mm^3. The data obtained from all the subjects were analyzed by the t-test using Statistical Parametric Mapping, SPM99. Areas showing activation with a statistical significance of $p<0.01$ were considered to be "activated" and extracted for the standard brain. In this study,

the subjects were instructed to strongly bite on a 3-cm-thick plastic block held between the upper and lower molars on the right side, for 30 s.
As seen in Fig. 7, the sensorimotor areas were strongly activated on the side ipsilateral to the side of biting movement. It is possible to confirm the activation of the sensorimotor area corresponding to the jaw biting movements, on the basis of the changes in cerebral blood flow. This suggests the possibility that unilateral jaw biting movements may activate mainly the motor cortex on the ipsilateral hemisphere. However, because of the limitations of temporal resolution, fMRI cannot distinguish among cortical activities before, during, and after biting, given that changes in f-MRI signal intensity reflect the average cortical activity throughout all phases of unilateral jaw biting. On the basis of the results of these experiments, we studied the projection of the afferent inputs from the receptors of the periodontal ligament in humans, as a factor that activates the human cortex.

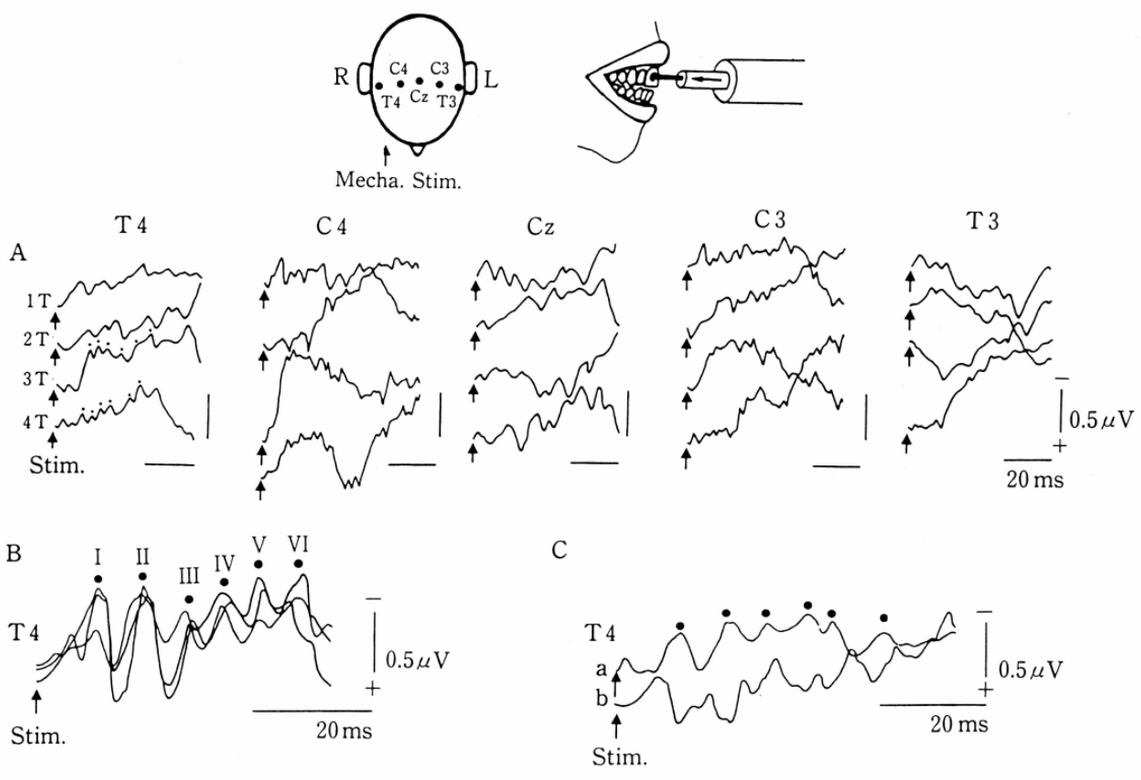
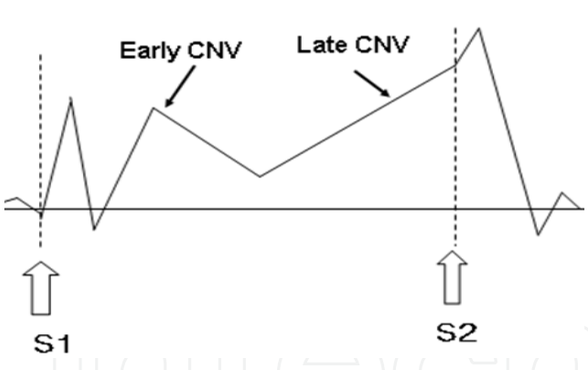


Fig. 8. SEPs and stimulus intensity of right upper first incisor tooth. A: SEPs were recorded from five regions of the human scalp following mechanical stimulation at various intensities: 1T (threshold), 2T, 3T, and 4T. Dots indicate the PM-SEP of T4 with six peaks. T: temporal area. C: central area. Cz: midline-central area. R: right side. L: left side.
B: 3 times superimposed PM-SEPs taken at different times for the same subject. I, II, III, IV, V, and VI indicate six waves of the negative component of PM-SEP. C: SEPs before and after induction of local anesthesia of the periodontal ligament. a) PM-SEP before induction of anesthesia. b) Cortical potentials after induction of anesthesia. Each dot indicates six waves of the negative component of PM-SEP. All of these potentials were averaged 100 times.

Tanaka et al. (1991) conducted topographical analysis of periodontal mechanoreceptor-sensory evoked potential induced by mechanical stimulation of a tooth in eight subjects. Sensory evoked potentials (PM-SEPs) were recorded from various regions of the scalp by the mechanical stimulation of a normal tooth (Fig.8). The mechanical stimulation was applied to the right upper first incisor tooth. PM-SEPs were averaged 100 times following the mechanical stimulation of the tooth that produced six waves of SEP at the ipsilateral temporal area (T4) but did not evoke any potential from the other regions. All the six components were abolished after the induction of local anesthesia of the periodontal ligament. They concluded that the six waves of PM-SEP were evoked by the mechanical stimulation of the tooth, suggesting that the sensory cortex receives afferent impulses from the periodontal mechanoreceptors on the ipsilateral side in humans. These findings suggest the possibility that a sensory area on the unilateral hemisphere is responsible for the jaw movements on the ipsilateral side in humans. It is noteworthy that studies using the combination of ERPs and fMRI show great promise in helping researchers to more comprehensively understand the neural basis of behavior, including motor and sensory functions in the maxillofacial regions.

4.3 Overview of CNV

When a human subject is instructed to make a movement in response to the second of two successive stimuli, a slow cortical negative potential appears on the scalp prior to the movement (Walter et al., 1964). A schema of the CNV waveform is shown in Fig. 9.



(1) Early CNV that is elicited by a warning stimulus that alerts the subject to a forthcoming signal to execute a movement (imperative stimulus).

(2) Late CNV that is associated with the preparation for movement prior to the imperative stimulus.

S1: warning stimulus
S2: imperative stimulus

Fig. 9. Schema of CNV waveform.

This potential has been called CNV and is considered to consist of two main components related to the functions of the brain (Rohrbaugh et al., 1976). The first component is an early wave that is elicited by a warning stimulus that alerts the subject to a forthcoming signal to execute a movement (imperative stimulus). The second component is a late wave that is associated with the preparation for movement prior to the imperative stimulus. There are many experimental reports on the CNVs in relation to body movements (Brunia & Vingerhoets, 1981; Rebert & Lowe, 1984; Nakajima et al., 1994; Ulrich et al., 1998).

Previously, CNVs were believed to be one of the MRCPs for the planning or execution of externally paced movements. Recently, however, late CNVs can be detected during some operation in the domain of mental preparation, that is, expectancy and the anticipation for

the imperative stimulus. Oishi and Mochizuki (1998) demonstrated that the amplitude of CNV significantly correlates with blood flow only within the frontal cortex. In addition, subdural recordings of epilepsy patients revealed that BP and CNV are commonly generated from MI and SMA, but that the late component of CNV is also generated from the prefrontal association cortices (Ikeda et al., 1996). Therefore, at present, CNV is considered to reflect activities of the prefrontal cortex associated with cognitive functions (Fuster, 1984; Bares et al., 2007). Hamano et al. (1997) reported the difference between CNVs and BPs recorded from subdural electrodes implanted in patients with intractable epilepsy.

According to their reports, BPs were recorded from the primary motor area (MI), the primary sensory area (SI), and the supplementary sensorimotor area (SSMA). On the other hand, CNVs showed a patchy distribution in the prefrontal area and SSMA for the early component and in the prefrontal area, MI, SI, temporal area, occipital area and SSMA for the late component. These findings suggest that the CNV recorded from the scalp is the summation of multiple cortical potentials that have different origins and different functions. The cortical distribution of late CNV was different from that of BPs. Moreover, clinical neurophysiological studies have proved the diagnostic importance of CNV and MRCP in subcortical generation mechanisms, although both of them commonly share at least some cortical generators, indicating the clinical criteria that late CNV and MRCP are generated from the basal ganglia and cerebellar efferent system, respectively (Ikeda et al., 1994; Ikeda et al.,1996). There is a functional difference between CNV and MRCP in cognitive processes in the beginning of a movement.

4.4 Features of CNV associated with swallowing

There are many research reports on the cortical potentials associated with volitional swallowing. Huckabee et al. (2003) reported that the MRCP associated with volitional swallowing is characterized by a slower slope rising than that obtained during the finger movement. They also explained that this phenomenon is due to a marked absence of late components 500 ms prior to the movement onset, suggesting the close relationship between SMA and brainstem CPG for oral pharyngeal swallowing in neural tracts. Thus, the characteristic of the MRCP associated with volitional swallowing may be explained in terms of the absence of NS'. Satow et al. (2004) also proved by epicortical recording of MRCPs in the patients with epilepsy that the cerebral cortex does not play a significant role in postmovement processing of swallowing.

Dysphagia is characterized by difficulty in swallowing (Bulat & Orlando, 2005). This symptom is common in neurogenic diseases such as stroke, dementia, Parkinson's disease, multiple sclerosis and muscular dystrophy, and often causes aspiration pneumonia. Recent studies have revealed that rehabilitation training induces reorganization of motor areas in the cortex of the patients with stroke (Allred & Jones, 2008; Raboyeau et al., 2008). This reorganization is believed to be due to the plasticity of the human brain. In this rehabilitation technique, the patient holds his/her breath, swallows, and then releases the air by coughing. During rehabilitation, patients are often instructed to initiate an action such as swallowing in response to a cue from a speech therapist (command swallowing). However, the differences in the cognitive functions of the brain between command swallowing and volitional swallowing remain unclarified. Therefore, we investigated the waveforms of the CNVs in the reaction-time swallowing task, to clarify the difference in

cortical activity between volitional and command swallowing (Nonaka et al., 2009). Previously, we compared the waveforms of CNV associated with the command swallowing task with those of MRCP associated with the volitional swallowing task in healthy adults to elucidate the effects of human swallowing training on brain activities preceding the onset of swallowing.

In this study, the subjects were instructed to swallow their saliva as quickly as possible in response to a sound signal 4 s after the onset of a self-paced breath holding in the command swallowing task or to swallow their saliva while holding their breath for 4 s in the volitional swallowing task.

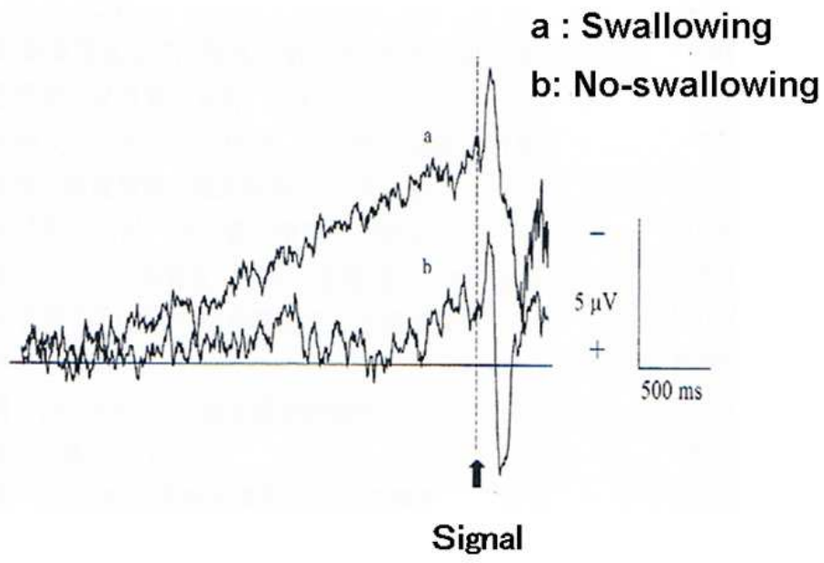


Fig. 10. CNV waveforms obtained during swallowing and no-swallowing task.

Figure 10 shows a comparison between the cortical potentials in the command swallowing task and the no-swallowing (no-motor task) task in the same subject. In the no-swallowing task, a subject was instructed to not swallow his/her saliva in response to the sound signal 4 s after the onset of a self-paced breath holding. The amplitude of CNV was larger in the command swallowing task than in the no-swallowing task. Likewise, the amplitude of CNV tends to increase depending on the intent of swallowing in the subjects. Figure 11 and 12 show a comparison between CNV and MRCP waveforms obtained during both volitional and command swallowing tasks. The amplitudes of CNV recorded at five scalp locations during the command swallowing task were significantly larger than the peak amplitudes of MRCPs during the volitional swallowing task. The findings suggest the possibility that nonsensory/motor regions are activated during the command swallowing task. Considering that the subjects were instructed to not swallow their saliva until the presentation of the signal in this experiment, the generation of CNVs obtained during the command swallowing task in our study may be related to activities of the prefrontal cortex associated with the cognitive functions of attention, memory, and decision. We concluded that CNV is an appropriate index for assessing cognitive functions during the command swallowing.

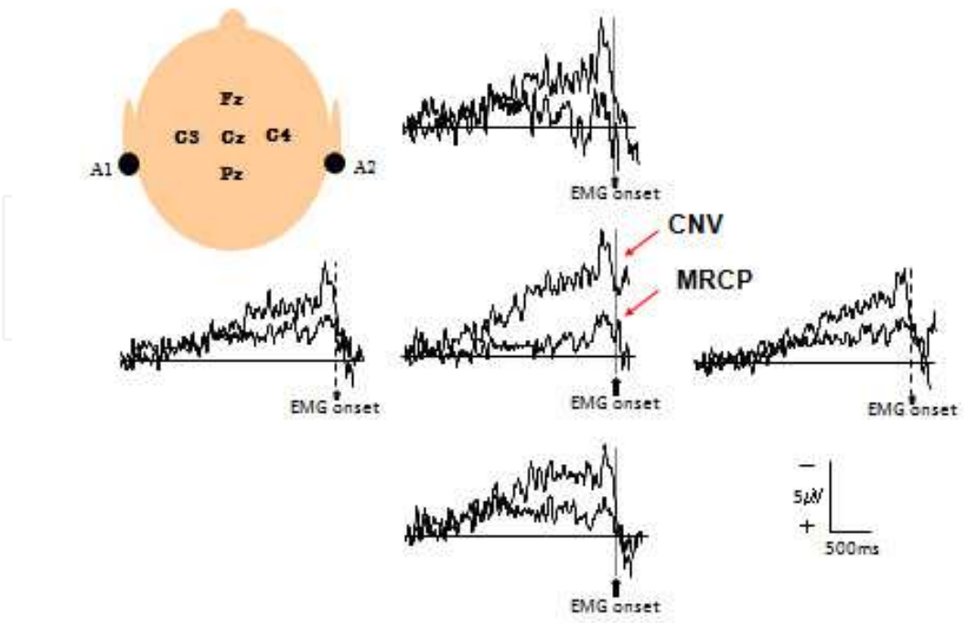


Fig. 11. Comparison between CNV and MRCP waveforms in 10 subjects.
CNV, contingent negative variation; MRCP: Movement-Related Cortical Potentials. (From Nonaka et al., 2009)

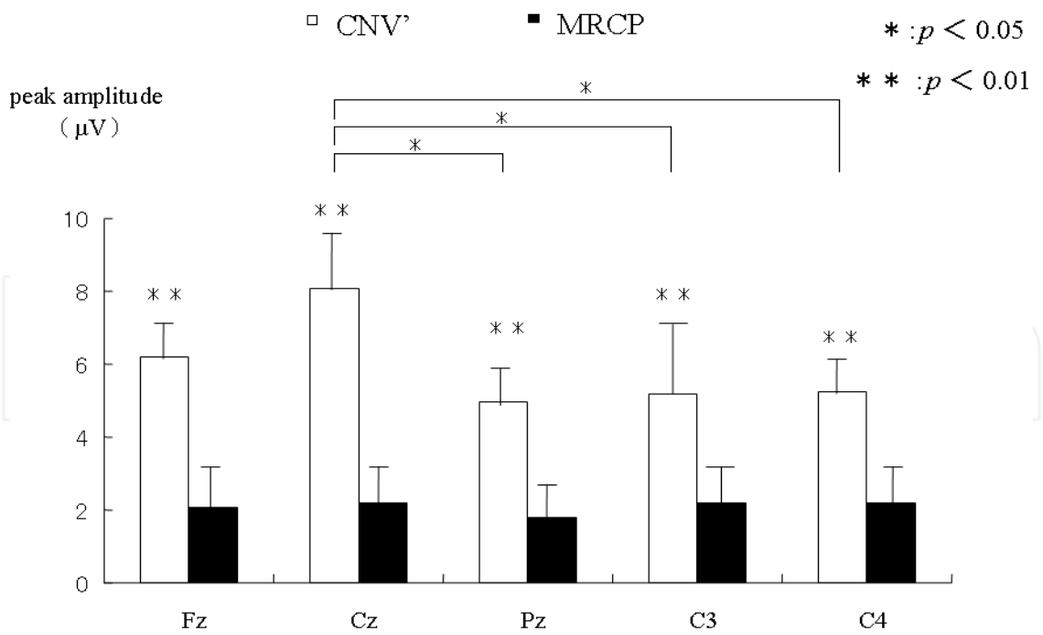


Fig. 12. Mean peak amplitudes of CNV and MRCP at five electrode sites for both swallowing tasks in all subjects. CNVs were significantly larger than MRCPs at five electrode sites and were also significantly smaller at Pz, C3, and C4 than at Cz.
** CNV>MRCP, p<0.01; * CNV smaller than CZ, p<0.05.

5. Wavelet transform analysis for ERPs associated with jaw motor function

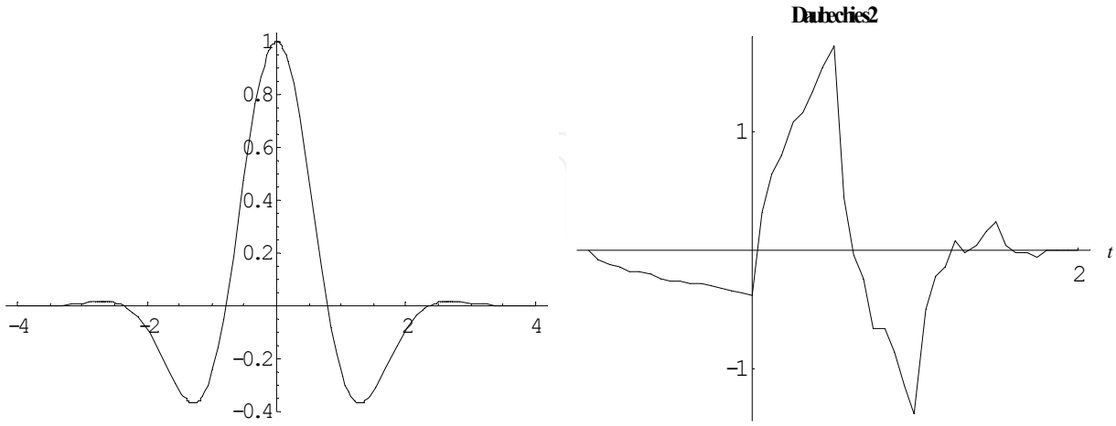
Neuroscience is the integrated region of many academic fields, its development contributes to the advance of various science technologies. In particular, the industrial application of neuroscience is expected not only in the medical field but also in many other fields.

A brain–machine interface (BMI) is a direct communication pathway between the brain and an external device. BMIs are developed at assisting, augmenting or repairing human cognitive or sensory-motor functions. For example, BMI provides a new communication pathway for patients with neurological disorders that left them unable to make make voluntary muscle contraction. A potential BMI application is that patients may control a neuro-prosthetic robot directly from their brain so that they can achieve virtual interaction with their environment.

Recently, EEGs have been the most studied potential non-invasive interface, mainly owing to its fine temporal resolution, ease of use, portability and low set-up cost (Akin, 2002; Graimann, 2004; Wei-Yen & Yung-Nien, 2009).

MRCP and CNV are ERPs that reflect human psychological activities, such as the intention and motivation of movement. If MRCP and CNV components can be directly extracted from original brain waves in real time without averaging their components in original brain waves, such a technique will become a new means of information communication for man-machine interfaces. Similarly to the Fourier transform, the wavelet transform is a technique of signal separation.

As a major difference between them, the Fourier transform represents a target signal with an infinite series of sine waves, whereas the wavelet transform represents a target signal with temporally localized waves (wavelets). In other words, the Fourier transform enables the detection of the degree of similarity of a target signal to sine waves, whereas the wavelet transform enables the detection of that of a target signal to wavelets. Compared with the Fourier transform, the wavelet transform has an inferior frequency resolution but a superior temporal resolution. Figure 13 shows a Mexican hat wavelet and a Daubechies wavelet (N=2).



Mexican hat wavelet Daubechies wavelet(N=2)

Fig. 13. Examples of wavelet.

In this section, we focus on a case in which the components of brain potentials are extracted using the temporal localization properties and frequency range of the wavelet transform as a

means of detecting MRCP and CNV waveforms. In this case, using the wavelet transform, electromyogram components are eliminated from CNV waveforms obtained by measuring the reaction time during a jaw-opening motor task.

Figure 14 (a) shows a waveform obtained simply by averaging brain waves during a jaw-opening movement using S1 as a reference (20 trials). In the figure, CNV is observed in the vertex region (Cz), where the CNV amplitude is maximum.

Although a moderate negative gradient likely to be attributable to CNV is clearly observed between S1 and S2, it is confirmed that noise components caused by the myopotential are mixed in the waveform.

When a discrete wavelet transform is applied to the above waveform obtained by averaging, the waveform can be decomposed into individual wavelets from high- to low-frequency components.

In addition, the original waveform obtained by averaging can be reconstructed by applying the inverse wavelet transform to all the decomposed components. When the amplitudes of particular components are assumed to be zero in this reconstruction, a waveform from which these components are eliminated can be obtained. Using this technique, we reconstructed a signal using particular components alone, compared its waveform with the original waveform obtained by averaging, and eliminated components that are not related to CNV.

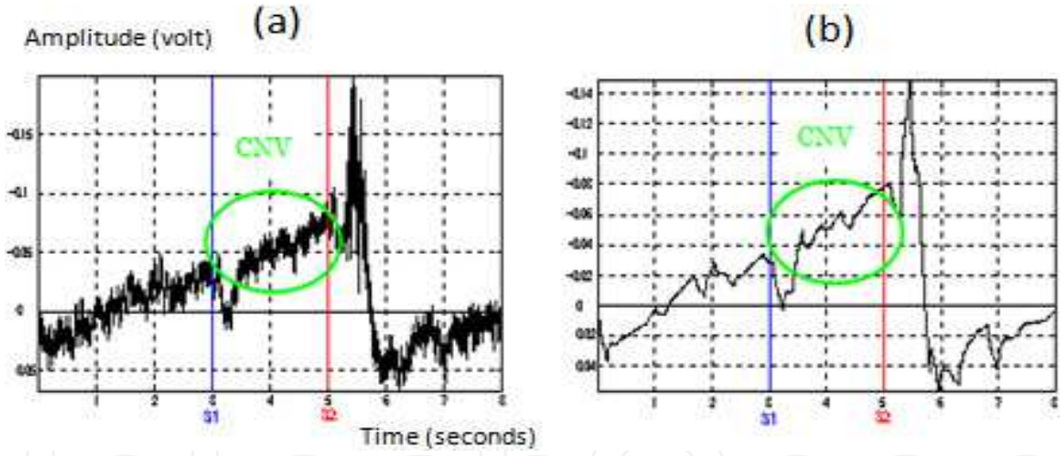


Fig. 14. Wavelet analysis of CNV during jaw-opening movement.
(a) waveform obtained by averaging. (b) waveform obtained after wavelet analysis.

Figure 14 shows a waveform reconstructed after eliminating the first to eighth high-frequency components and using only the ninth and subsequent high-frequency components (sampling frequency = 1.5 kHz). Considering real-time analysis, a fast wavelet transform algorithm developed by Mallat was used for decomposition and reconstruction employing a Daubechies wavelet (N=2). It is confirmed from Fig. 2(b) that noise components were eliminated whereas CNV components were maintained. This finding indicates that CNV is characterized by the ninth and subsequent high-frequency wavelet components. At the same time, we also confirmed a technique of separating artifact components due to, for example, myopotential and eye movements, which disturb the detection of waveforms by machines; such a technique may lead to practical applications of MRCP and CNV to man-machine interfaces.

6. Frequency changes of jaw muscle activity during reaction to a warning signal in the reaction time task

In this chapter, we discuss how MRCPs and CNVs reflect the brain activities corresponding to the onset of oral and facial movements. Actually, they can provide useful information on the control system for these movements. On the other hand, surface electromyography (EMG) is commonly used as a technique for the recording of skeletal muscle activity during a movement. Presently, EMG data are believed to provide information on the muscle contraction only. Recently, however, it has been clarified that the frequency changes of the muscle activity reflect motor preparation in the central nervous system. This changing can be also detected in jaw muscle EMGs.

6.1 Overview of EMG frequency changes preceding rapid movements

Rhythmic slow waves with a periodicity of 20-30 ms in elector spinal muscle EMG appear preceding a rapid voluntary trunk movement in humans (Tanii, 1984; Tanii & Kinugasa, 1986). These waves are is followed often by a silent period. This is similarly observed in the EMG recording in the reaction-time trunk movement task (Tanii at al., 1985). The surface EMG of the elector spinal muscle changes to rhythmic slow waves after a warning signal in this task. The power spectrum of surface EMG frequencies after the warning stimulus shifts to lower in the task, owing to the rhythmic slower waves, in association with motor preparation to perform the movement. The slowing of waves in surface EMG during the preparatory period is believed to reflect the modification of firing rates of individual motor units during the phasic contraction in the movement. On the other hand, motor imagery (MI) is the mental representation of a specific action without any corresponding motor output. Recently, Lebon et al. (2008) demonstrated that the EMG frequency was significantly higher during MI, than under the control condition (during resting). Their findings also suggest that a specific motor program requires recruitment of motor units during motor imagery.

6.2 Frequency changes in jaw muscle EMG during reaction to warning signal

Frequency changes in the masseter muscle EMG were examined in eight healthy subjects during the reaction time in a unilateral jaw-biting paradigm (Nakajima, 1995).

Each subject sat comfortably in an armchair and was presented with a visual warning stimulus (S1) followed 2 s later by a visual imperative stimulus (S2).

He/she was instructed to perform the jaw-biting movement upon the presentation of S2, with a small piece of wood held between the first upper and lower molars on the right side. Subjects were also instructed to make six biting movements, each separated by a 60-s rest period. Bipolar surface EMGs were recorded from the masseter muscle and digastric muscles on the right side as the agonist and antagonist, respectively.

The EMG signals from 1.0 s before S1 to 3.0 s after S1 were digitized. The samples were analyzed by fast Fourier transform (FFT) for each 1-s period. The analysis interval was divided into following three periods:

- The period 0-1 s before presentation of S1 (prestimulus period).
- The period 0-1 s after presentation of S1 (early poststimulus period).
- The period 1-2 s after presentation of S1 (late poststimulus period).

In five subjects, masseter EMG power spectra significantly shifted to lower frequencies in both the early and the late poststimulus period periods than those in the prestimulus period period (Wilcoxon signed rank test, $p<0.05$). In two subjects, the EMG power spectra

significantly shifted to lower frequencies in either the early or the late post-stimulus period than those in the pre-stimulus period ($p<0.05$). In one subject, no change was observed ($p>0.05$).

Masseter muscle EMG power spectra shifts to lower frequencies when biting force increases. This shift is well explained in terms of the recruitment of larger motor units at higher bite force. If this is so, our findings suggest that the slowing of waves in the EMG after the first signal is related to the recruitment of larger motor units. Considering the findings of this other previous study, the frequency changes of jaw muscle activity may indicate a state of readiness in the central nervous system for rapid and strong biting movements after the second stimulus.

In conclusion, these findings suggest the possibility of obtaining useful information on higher brain activities from the data of EMG. In the future, the study using the combination of ERP and EMG recordings will show great promise in helping scientists to more comprehensively understand the neural basis of motor functions in the maxillofacial region.

7. Conclusion

We concluded that MRCPs and CNVs are reliable Indicator the study of which may lead to the understanding of the oral and facial motor functions in humans. These cortical potentials have the advantage of temporal resolution for the detection of cortical activities. They are likely to be a very useful tool for elucidating the mechanism underlying the central processing of motor functions, as compared with PET and fMRI. Therefore, in further studies, we should clarify the significance of these cortical potentials in patients with oral motor dysfunctions.

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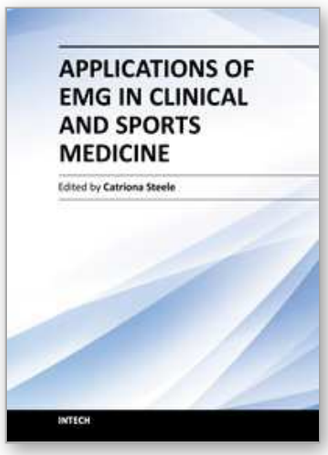

Applications of EMG in Clinical and Sports Medicine

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This second of two volumes on EMG (Electromyography) covers a wide range of clinical applications, as a complement to the methods discussed in volume 1. Topics range from gait and vibration analysis, through posture and falls prevention, to biofeedback in the treatment of neurologic swallowing impairment. The volume includes sections on back care, sports and performance medicine, gynecology/urology and orofacial function. Authors describe the procedures for their experimental studies with detailed and clear illustrations and references to the literature. The limitations of SEMG measures and methods for careful analysis are discussed. This broad compilation of articles discussing the use of EMG in both clinical and research applications demonstrates the utility of the method as a tool in a wide variety of disciplines and clinical fields.

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Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
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InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
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