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Dysphagia



# Movement-Related Cortical Potentials Associated with Saliva and Water Bolus Swallowing

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**Abstract.** The purpose of this study was to document the movement-related cortical potentials associated with saliva and water bolus swallowing in seven right-handed healthy humans. As the subjects performed a saliva or water bolus swallowing task, electroencephalograms with electrodes at C3, Cz, and C4 and an electromyogram of the mylohyoid muscle complex were recorded. The early slope, referred to as the Bereitschafts potential, before saliva swallowing was significantly steeper than that before water bolus swallowing. Positive potential amplitude during water bolus swallowing was significantly larger than that during saliva swallowing. Negative slope and motor potential were not clearly present during performance of either swallowing task. Those findings imply that the features of movement-related cortical potential associated with pharyngeal swallowing are different from those associated with limb movement, and that both the cortical process associated with sensory information of pharyngeal swallowing and the cortical preparatory process of pharyngeal swallowing depend on the type of swallowing task.

**Key words:** Dysphagia — Swallowing — Movement- related cortical potentials — Mylohyoid muscle — Deglutition — Deglutition disorders.

Although the motor pattern of pharyngeal swallowing is mainly generated within the brain stem [1,2], the cerebral cortex plays an important role in control of swallowing. Indeed, studies using positron emission tomography [3,4] and studies using functional magnetic resonance imaging (fMRI) [5–10] have reported that multiple cortical areas are activated during swallowing. It has been presumed that in volitional swallowing, cortical control is dominant for the initial phase, although swallowing reflex mechanisms arising from the brain stem are dominant for the later phase [11].

Studies using fMRI have reported that different cortical areas are activated between reflexive and volitional swallowing [6,7] and between saliva and water bolus swallowing [8,10]. Those findings indicate that the cortical process differs among swallowing tasks. However, one limitation of those findings is that fMRI can not distinguish among cortical activity before, during, and after swallowing, given that signal changes of fMRI reflect averaged cortical activity throughout all phases of swallowing. Thus, the correspondence between respective phases of swallowing and various degrees of cortical activity has not been elucidated.

Movement-related cortical potentials (MRCPs) are parameters used to investigate cortical activity associated with movement [12]. MRCPs allow us to observe the cortical activity before onset of movement and that during movement separately, through observing potentials such as the Bereitschafts potential or motor potential [12]. If MRCPs associated with swallowing can be recorded, the potentials may allow us to differentiate among the cortical activities of motor preparation, execution, and regulation of swallowing. In the present study, the MRCPs associated with saliva and water bolus swallowing are documented.

## Methods

### *Subjects*

Seven healthy subjects between 19 and 37 years of age participated in this study. All subjects were informed of the purpose and the method of this study, and written consent was obtained before

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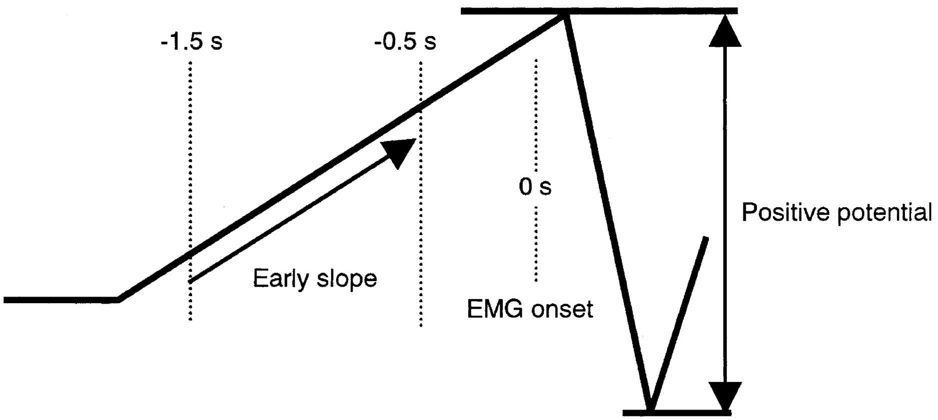


**Fig. 1.** Schematic explanation of analysis of MRCPs waveform.

hand. All subjects were right-handed according to their scores on the Edinburg Handedness Inventory [13], which was administered before the experiment.

## *Recordings*

Electroencephalograms (EEGs) were recorded using Ag–AgCl electrodes placed at C3, Cz, and C4 according to the extended international 10–20 system [14]. Each electrode was referred to the linked ear electrodes. The impedance of the skin under the electrodes was kept at $< 3$ kΩ . EEG signals were amplified with a 2-s time constant and a 100-Hz low-pass filter (Nihon Kohden AB-601G).

Ag–AgCl recording electrodes were attached to the skin over the mylohyoid raphe, 1 cm apart, and used to record the electromyogram (EMG) of the mylohyoid muscle complex. The EMG signals were amplified and band-pass filtered (Nihon Kohden, MEG-2100, band-pass 30 Hz–3 kHz). Amplified EMG signals were converted to digital signals at a sampling rate of 1 kHz using an A/D converter (ADInstruments, PowerLab/800) and stored on the hard drive of a personal computer (Apple, Performa 5220).

## *Procedure*

The subjects took a sitting position, closed their eyes, and performed a total of two volitional swallowing tasks during each of which EEGs and the EMG were recorded. First, self-paced volitional swallowing without a water bolus (saliva swallowing) was performed about 50 times. The interval between swallows was approximately 10 s. Second, self-paced volitional swallowing with a water bolus (water bolus swallowing) was performed. The subjects held a small cup filled with approximately 10 ml of tap water in the right hand and lifted it to deliver the water bolus to the mouth. The subjects were allowed to open their eyes to facilitate delivery. Then they closed their eyes again and rested for approximately 8–10 s before swallowing; thus, movement of the right hand did not interfere with the MRCPs associated with swallowing. After the resting period, the subject swallowed the water bolus. After swallowing, the subject rested for approximately 10 s. This process was repeated about 50 times.

## *Analysis*

After the experiment, recorded data were analyzed offline. First, the mylohyoid EMG was rectified. Next, the onset of the mylohyoid EMG was visually determined and then considered to represent the onset of pharyngeal swallowing, based on the fact that the mylohyoid muscle is considered to be the first muscle to contract in the process of pharyngeal swallowing [1]. Trials that presented mylohyoid EMG activity between 0 and 5 s before the onset of swallowing and those in which the mylohyoid EMG onset was not clear were excluded from the analysis. All successful EEG waveforms between the 1.5 s before the mylohyoid EMG onset and the 1.0 s after that were averaged for each subject. Those averaged waveforms of all subjects were used for statistical analysis, then the EEG waveforms of all subjects were averaged for each swallowing task in order to obtain a grand average waveform.

Figure 1 is a schematic explanation of the analysis of the MRCPs waveform. The average slope of the potential between the 1.5 s before EMG onset and the 0.5 s before EMG onset, referred to as the Bereitschafts potential, was calculated by linear regression for each subject [15]. Positive potential [16] was defined as the positivity of the EEG during swallowing. The amplitude of the positive potential was estimated as the difference between the voltage at the first turn toward positivity and the voltage at the positive peak of the potential. Two-way repeated-measures analysis of variance (ANOVA) was used to test the difference of the early slope and the positive potential amplitude between EEG recording sites, those between swallowing tasks, and the interaction between those factors.

# Results

Figure 2 illustrates the grand average waveform of MRCPs associated with saliva and water bolus swallowings. As shown in Figure 3, the early slope was clearly present before saliva swallowing and was not clearly present before water bolus swallowing. Two-way repeated-measures ANOVA showed a significant difference in the early slope between the two conditions ($F = 5.674$, $p = 0.035$), without any significant effect of the electrode site ($F = 1.113$, $p = 0.345$). In addition, the positive potential during the water bolus swallowing was larger than that during the saliva swallowing, as shown in Figure 4. Two-way repeated-measures ANOVA showed a significant difference in the early slope between the two conditions ($F = 4.853$, $p = 0.048$), with a significant

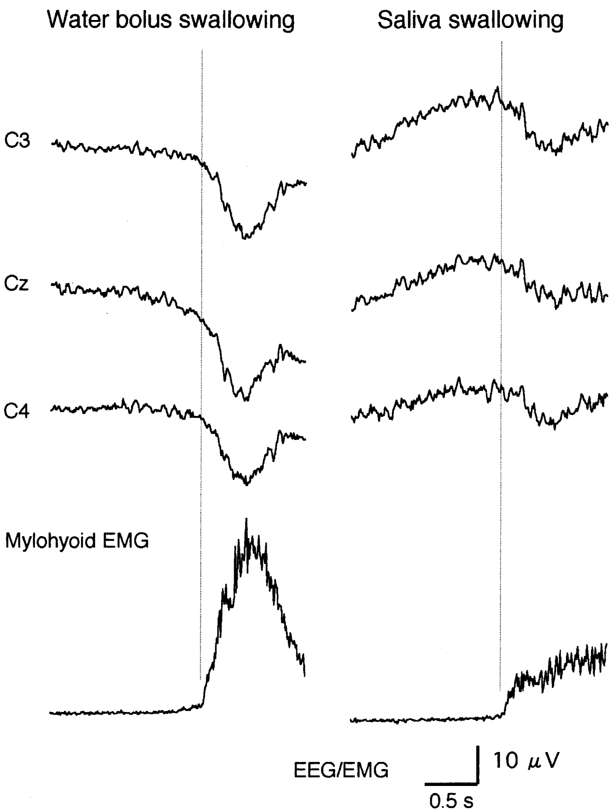


**Fig. 2.** Grand average waveforms of MRCPs associated with swallowing. Dashed lines indicate onset of mylohyoid EMG.

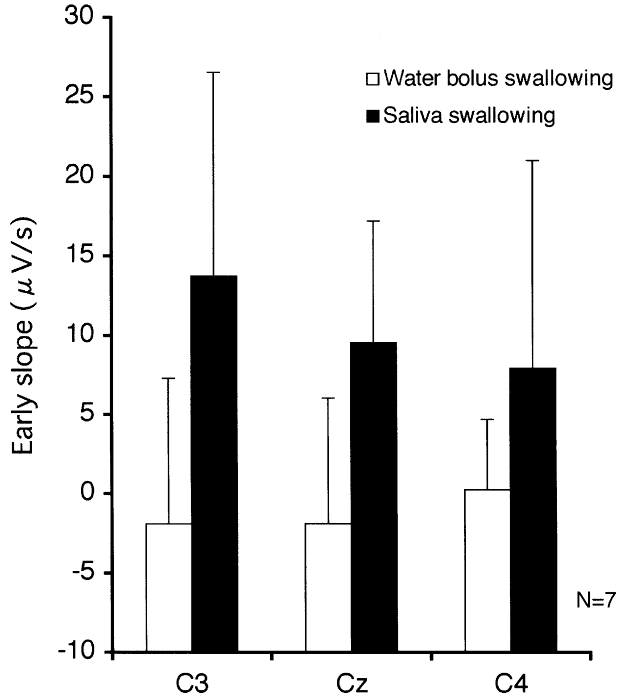


**Fig. 3.** Averaged early slope before swallowing. Error bars indicate standard deviation.

effect of the electrode site ($F = 18.255$, $p = 0.0001$). However, the interaction between the two factors was not significant ($F = 0.590$, $p = 0.5624$). In most of the subjects, neither negative slope (NS′) nor motor potential was clearly observed.

## Discussion

In this study, MRCPs associated with saliva swallowing and those associated with water bolus swallowing were investigated. To the best of my knowledge, this is the first study to document MRCPs associated with swallowing. Some of the features of MRCPs associated with swallowing differed from those associated with movement of a limb. NS′ and motor potential were not clearly present, although the early slope was clearly present before saliva swallowing and the positive potential was present during each type of swallowing task. Those differences should be attributable to the difference between cortical control of the swallowing task and that of limb movement. The primary motor area plays an important role in generation of the motor pattern of limb movement. In contrast, the swallowing motor pattern is mainly generated within the brain stem [2], and cortical representation evoking pharyngeal swallowing is not only located in the primary motor area but in a premotor area [17]. Furthermore, insula is said to play an important role in generating the swallowing motor pattern [18], although this is not so for generating limb movements.

An important finding in this study is that different MRCPs were observed between saliva and water bolus swallowing. The primary difference in features between the two swallowing tasks was the size of bolus to be swallowed. Saliva flow rate is as small as approximately 2 ml/min or less in humans [19]. In the present study, the subjects swallowed approximately 10 ml of water each time they completed a water bolus swallow. Thus, the size of the bolus to be swallowed was very different between the two swallowing tasks. It is well known that different bolus volumes correlate to different latencies of pharyngeal swallowing [20,21], indicating that the threshold of pharyngeal swallowing is associated with the size of the bolus to be swallowed.

The early slope before saliva swallowing was larger than that before water bolus swallowing. Bereitschafts potential is said to represent cortical activity of motor preparation [22]. It has been hypothesized that the generation sources of the Bereitschafts potential while performing a finger

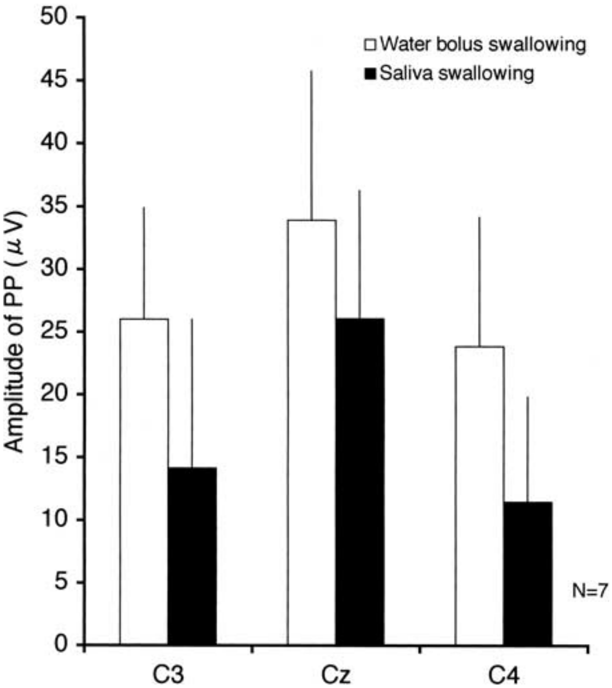


**Fig. 4.** Averaged amplitude of positive potential during swallowing. Error bars indicate standard deviation.

movement task are a supplementary motor area, which is largely associated with motor preparation, and sensorimotor areas [23]. Thus, a possible interpretation of our findings is that the cortical preparatory process differed between the two swallowing tasks. It could be supposed that more intensive cortical activity is required for initiating saliva swallowing than for initiating water bolus swallowing in order to compensate for the fact that the former involves less tactile stimulation of the pharynx and that this higher level of activity caused a higher threshold of initiation of pharyngeal swallowing.

Positive potential amplitude during water bolus swallowing was larger than that during saliva swallowing. Positive potential amplitude is thought to reflect the cortical process associated with sensory information [24]. The large-sized bolus swallowed while performing the water bolus swallowing task should have stimulated the pharynx intensively. Thus, this finding may suggest that different cortical processes mediate afferent feedback from the tactile sensory receptors of the pharynx. If previous interpretations concerning the early slope and the positive potential are accurate, the causes of the different cortical activities between different swallowing tasks reported previously [8] may involve both different cortical preparatory processes before swallowing and different cortical processes associated with the sensory information of swallowing.

Laterality of the MRCPs associated with swallowing was not found in this study. The laterality of cortical activity associated with swallowing remains a controversial issue. A study using fMRI showed symmetrical activity of the pericentral and premotor cortex associated with swallowing [7]. On the other hand, another study reported dominant activity of the right primary sensory/motor cortex associated with swallowing [6]. Furthermore, several studies have reported that the cortical activity associated with swallowing was asymmetrical but that the dominant side was individually different [3,9]. Accordingly, even though laterality was not found in the present study, it is still possible that laterality is present in individuals but that it has been canceled by the pooled averaging of all subjects.

Nonetheless, there is a limitation to this study. The number of recording sites is too small to record the whole cortical activity associated with swallowing. Similar to a previous study [25], in the present study the EEG signals were recorded only from C3, Cz, and C4. As mentioned before, multiple cortical areas are activated during swallowing [3–10]. Thus, further studies using whole-head EEG are needed in order to obtain more detailed information regarding multiple cortical areas.

In summary, MRCPs associated with two swallowing tasks were documented. Early slope and positive potential amplitude differed between the two tasks. Those differences imply that both the cortical process associated with the sensory information of pharyngeal swallowing and the cortical preparatory process of pharyngeal swallowing depend on the type of swallowing to be performed. MRCPs may be useful parameters to investigate cortical control of pharyngeal swallowing, although the features of MRCPs associated with swallowing are somehow different from those associated with limb movement.

## References


1. Doty RW, Bosma JF: An electromyographic analysis of reflex deglutition. *J Neurophysiol 19:*44–60, 1956
2. Jean A: Brainstem control of swallowing: localization and organization of the central pattern generator for swallowing Taylor A (ed.): *Neurophysiology of the Jaws and Teeth.* London: MacMillan, 1990, pp 294–321
3. Hamdy S, Rothwell JC, Brooks DJ, Bailey D, Aziz Q, Thompson DG: Identification of the cerebral loci processing human swallowing with $H_2{}^{15}O$ PET activation. *J Neurophysiol 81:*1917–1926, 1999
4. Zald DH, Pardo JV: The functional neuroanatomy of voluntary swallowing. *Ann Neurol 46:*281–286, 1999
5. Hamdy S, Mikulis DJ, Crawley A, Xue S, Lau H, Henry S, Diamant NE: Cortical activation during human volitional swallowing: An event-related fMRI study. *Am J Physiol 277:*G219–G225, 1999

6. Kern MK, Jaradeh S, Arndorfer RC, Shaker R: Cerebral cortical representation of reflexive and volitional swallowing in humans. *Am J Physiol 280:*G354–G360, 2001
7. Martin RE, Goodyear BG, Gati JS, Menon RS: Cerebral cortical representation of automatic and volitional swallowing in humans. *J Neurophysiol 85:*938–950, 2001
8. Mosier K, Patel R, Liu WC, Kalnin A, Maldjian J, Baredes S: Cortical representation of swallowing in normal adults: Functional implications. *Laryngoscope 109:*1417–1423, 1999
9. Mosier KM, Liu WC, Maldjian JA, Shah R, Modi B: Lateralization of cortical function in swallowing: A functional MR imaging study. *Am J Neuroradiol 20:*1520–1526, 2001
10. Mosier K, Bereznaya I: Parallel cortical networks for volitional control of swallowing in humans. *Exp Brain Res 140:*280–289, 2001
11. Ertekin C, Kiylioglu N, Tarlaci S, Turman AB, Secil Y, Aydogdu I: Voluntary and reflex influences on the initiation of swallowing reflex in man. *Dysphagia 16:*40–47, 2001
12. Kohnhuber HH, Deecke L: Hirnpotentialänderungen bei Willkürbewegungen und passiven Bewegungen des Menschen: Bereitschafts potential und reafferente Potentiale. *Pflügers Arch Physiol 284:*1–17, 1965
13. Oldfield RC: The assessment and analysis of handedness: The Edinburg Inventory. *Neuropsychology 9:*97–113, 1971
14. Jasper HH: Report of the committee on methods of clinical examination in electroencephalography. Appendix: The ten twenty electrode system of the International Federation. *Electroencephalogr Clin Neurophysiol 10:*370–375, 1957
15. Cunnington R, Iansek R, Johnson KA, Bradshaw JL: Movement-related potentials in Parkinson's disease: Motor imagery and movement preparation. *Brain 120:*1339–1353, 1997
16. Fang Y, Siemionow V, Sahgal V, Xiong F, Yue GH: Greater movement-related cortical potential during human eccentric versus concentric muscle contractions. *J Neurophysiol 86:*1764–1772, 2001
17. Hamdy S, Aziz Q, Rothwell JC, Singh KD, Barlow J, Hughes DG, Tallis RC, Thompson DG: The cortical topography of human swallowing musculature in health and disease. *Nat Med 2:*1217–1224, 1996
18. Daniels SK, Foundas AL: The role of the insular cortex in dysphagia. *Dysphagia 12:*146–156, 1997
19. Bergdahl M: Salivary flow and oral complaints in adult dental patients. *Community Dent Oral Epidemiol 28:*59–66, 2000
20. Miller AJ: *The neuroscientific principles of swallowing and dysphagia*. San Diego: Singular Publishing, 1999
21. Pouderoux P, Logemann JA, Kahrilas PJ: Pharyngeal swallowing elicited by fluid infusion: role of volitional and vallecular containment. *Am J Physiol 270:*G347–G354, 1996
22. Cunnington R, Iansek R, Bradshaw JL: Movement-related potentials associated with movement preparation and motor imagery. *Exp Brain Res 111:*429–436, 1996
23. Neshige R, Luders H, Shibasaki H: Recording of movement-related potentials from scalp and cortex in man. *Brain 111:*719–736, 1988
24. Shibasaki H, Barrett G, Halliday E, Halliday AM: Components of the movement-related cortical potential and their scalp topography. *Electroencephalogn Clin Neurophysiol 49:*213–226, 1980
25. Fang Y, Siemionow V, Sahgal V, Xiong F, Yue GH: Greater movement-related cortical potential during human eccentric versus concentric muscle contractions. *J Neurophysiol 86:*1764–1772, 2001