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Direction-Selective Activation in the Prefrontal Cortex through a Visually Guided Tongue Protrusion Task

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Abstract

Background: Because the rehabilitation of proper of eating and swallowing is important, the motor function of tongue has been highly studied due to its role in these processes. In addition, the previous studies have reported that the plasticity in the primary motor cortex and the primary somatosensory cortex are induced by tongue-task training.

Objective: This pilot study aimed to verify the possibility of neuroplasticity in the prefrontal cortex (PFC) by the visually guided direction-selective tongue-protrusion task (VD task).

Method: Cortical activities were measured by functional near-infrared spectroscopy, while the subjects performed the VD task and other tasks.

Results: The direction-selective activation of the PFC was found in all subjects performed the VD task.

Conclusion: This study suggests that the VD task may contribute to develop a novel rehabilitation method for improving higher brain functions, because the activation have been considered to promote neuroplasticity in the brain.

Keywords: Prefrontal cortex; Brain activity; Functional near-infrared spectroscopy; Tongue

Introduction

The increase of the elderly population has led to a rise in the prevalence of eating and swallowing dysfunction. Dysphagia markedly reduces quality of life of older adults. The coordinated movement of various anatomical parts, such as the lips, mandible, and soft palate, is essential for functional swallowing, with the movement of the tongue being particularly important. Consequently, tongue exercise is often performed as a rehabilitation tool in patients with dysphagia [1]. In addition, studies using tongue exercise in humans or primates have suggested that tongue exercise induces neuroplastic changes in the brain [2-5]. However, these previous studies used relatively simple tasks, such as elevation and anterior protrusion of the tongue, to investigate the relationship between tongue movement and brain activity in the region associated with motor or sensory function, but not in the prefrontal cortex (PFC), which is involved in higher brain functions.

Brain function can be measured non-invasively using functional magnetic resonance imaging [6-12], positron emission tomography [13-16], or functional near-infrared spectroscopy (fNIRS) [17-21]. fNIRS in particular is a popular neuroimaging modality today because it enables the real-time visualization of changes in hemoglobin concentration, which represents neuroactivation-dependent changes in local cerebral hemodynamics, and because the equipment necessary for fNIRS measurement including the device itself, is relatively inexpensive. In addition, because the measurement is performed in a sitting position and the device is portable, fNIRS can be performed relatively readily even in individuals with disorders, further facilitating its application in the field of rehabilitation [22-25].

In this study, we used fNIRS to investigate the activity of the PFC, which is involved in higher brain function, in subjects undergoing a task to protrude the tongue in the direction indicated by a visual stimulus. Results of the tongue protrusion and control tasks were compared. This pilot study was established to develop a novel rehabilitation method that uses a tongue exercise to improve motor and sensory function, and potentially, higher brain function as well.

Materials and Method

Subjects and experimental set-up

Subjects were healthy 12 female students in their fourth year at Kyushu Dental University (right-handed; mean age: 21.6 ± 0.5 years). Subjects were seated in front of a computer screen with a headband-type probe of fNIRS (OEG-16; Spectratech Inc.) placed on the frontal area. The distance between their eyes and the screen was set at 70 cm. Subjects were instructed to protrude the tongue in the direction indicated by a visual stimulus displayed on the computer screen. Each subject continuously performed the visually guided direction-selective tongue-protrusion task (VD task), visually guided tongue-protrusion task (V task), and control task in this order without removing the probe between tasks. Each task consisted of 8 trials.

This study was approved by the Ethics Committee of Kyushu Dental University. We explained the purpose of the study to subjects before obtaining consent. In addition, measurement was terminated immediately when subjects felt uncomfortable or tired.

Behavioral paradigm

The temporal sequence of the VD task was as follows: At the beginning of each task, a central fixation point (FP) was displayed at the center of the screen, where subjects were instructed to fix their gaze during the task (Figure 1). Five seconds later, an instruction stimulus (IS) appeared pseudorandomly at one of four sites: above or below or on the left or right side of the FP. Subjects were required to protrude the

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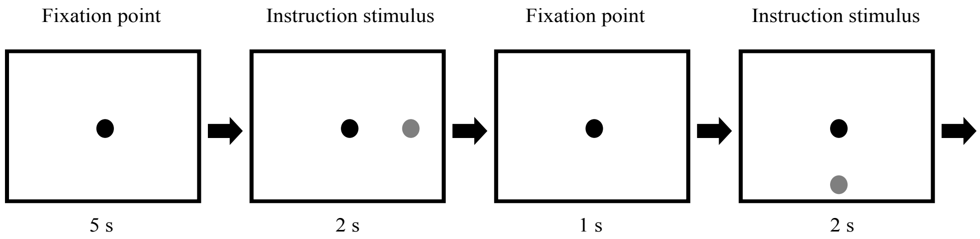

Figure 1: Temporal sequence of the VD task. A central FP (black) appeared at the eye level on the screen. After a FP of 5 s, the IS (blue) was pseudorandomly presented at one of four sites. While the IS was presented for 2 s, subjects were required to protrude the tongue in the direction shown. Then 1 s later, the next trial was initiated. In each task, subjects repeated the trial 8 times. The same sequence of visual stimuli in the VD task was used in the V task and control task.

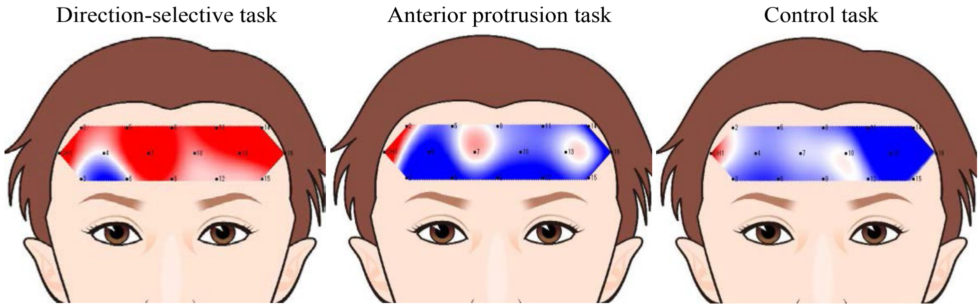

Figure 2: Activity of PFC in the VD task, V task and control task. Panels show brain activity in the same subject after each task in which the IS was displayed on the left side of the FP for 1 s. Functional brain activation and suppression in relation to the background brain activity are shown in red and blue, respectively.

tongue in the direction indicated by the IS and maintain the state until the IS disappeared, 2 s later. The above sequence constituted 1 trial. After each trial, subjects put their tongue back inside the oral cavity and waited for the next IS. In a VD task consisting of 8 trials, IS was displayed twice at each of the 4 sites for a total of 8 tongue protrusions.

The visual stimuli displayed in the V task and control task were identical to those displayed in the VD task. However, in the V task, the IS was displayed only as a visual cue to begin tongue protrusion. In other words, subjects were instructed to fix their gaze on the FP and protrude the tongue anteriorly only, regardless of the direction indicated by the IS. In control tasks, subjects were instructed to fix their gaze on the FP but did not move the tongue upon the appearance of the IS.

Data analysis

During each task, fNIRS was used to measure changes in the concentration of oxygenated hemoglobin (oxy-Hb) in the PFC. Brain Analyzer (B.R. Systems Inc.), the statistical analysis software for OEG-16, was used to compare changes in oxy-Hb during the first 1 s after the appearance of IS on the left side of the FP between the VD, V, and control tasks. The activity of the PFC at the start of recording was defined as the level of background activity to visualize functional activation or suppression in the region.

Results

General

Figure 2 shows brain activity during the three tasks in the same subject. The PFC area in red and blue indicate functional brain activation and suppression, respectively, in relation to the background activity.

Cortical activity in the VD task

In the VD task, ≥ 50% of the PFC was activated in all 12 subjects. The area activated the most was in the right PFC of 9 of the 12 subjects and in the left PFC of the remaining 3 subjects. In the former or latter group of subjects, even though the most activated PFC area was observed on the same side, the activation did not necessarily occur at the same site in the PFC. Although the PFC was activated broadly, a certain area of the PFC was suppressed in 8 subjects. The location of the area showing suppression varied among subjects, showing no particular trend.

Cortical activity in the V task

In the V task, ≥ 50% of the PFC was activated in 5 subjects, whereas in the remaining 7 subjects, the area of suppression was wider than the area of activation. The area activated the most was in the right PFC of 7 of the 12 subjects and in the left PFC of the remaining 5 subjects. In 2 of the 9 subjects whose right PFC was activated the most in the VD task, the V task activated most intensely the left PFC. In the V task, a certain area of the PFC was suppressed in all subjects. In the 8 subjects whose PFC was suppressed in the VD task, the area of suppression was not correlated between the V and VD tasks.

Cortical activity in the control task

In the control task, ≥ 50% of the PFC was activated in 3 subjects. In the remaining 9 subjects, the area of suppression was wider than the area of activation. In 6 subjects, ≥ 80% of the PFC was suppressed, and in 2 of these 6 subjects, no activation at all was observed in the PFC. Except for the 2 subjects showing no activation, in the remaining 10 subjects, the area activated the most was in the right PFC of 5 subjects and the left PFC of the other 5 subjects. As in the VD and V tasks, no particular trend was observed in the activation or suppression in control tasks.

Discussion

This study revealed that the direction-selective activation of the PFC in visually guided tongue protrusion tasks. Conventionally, tongue exercises are known to promote neuroplasticity in the brain [2-5], but previous studies investigated the primary motor and somatosensory cortex involved in motor or sensory functions, respectively. In humans, the PFC plays an important role in integrating sophisticated brain functions, as in the dorsolateral PFC, which is deeply involved in working memory [26]. It is therefore significant that VD tasks induced activation in the PFC. Although, it is currently debatable whether this activation triggers a neuroplastic change in the brain, the present findings suggest that a VD task can be used to develop a novel rehabilitation method for improving higher brain functions.

In this study, the VD task consisted of a visual stimulus that indicated the direction and the onset of exercise and tongue exercise that induced direction selectivity, whereas the V task consisted of a visual stimulus indicating exercise onset and the anterior protrusion of the tongue. While VD tasks activated a wide area of the PFC, V tasks resulted in suppression, rather than activation, in many subjects. These findings suggest that a directional cue for movement and movement with direction selectivity are the factors required for the activation of the PFC and that simple tongue exercises are insufficient. In addition, control tasks with visual stimuli identical to those used in the VD task and V task did not activate the PFC in the majority of the subjects, suggesting that the simple presentation of visual stimuli is not enough to improve higher brain functions. These findings provide important information necessary to develop an effective rehabilitation method in the future.

In summary, this study adequately offered new insight into tongue exercise as a pilot study, but also revealed challenges to be addressed in the future. First, in the V task and control task, the activity of the PFC was suppressed in a broader area during tongue movement than in the relaxation phase at the beginning of recording. This suppression might have been caused by the preceding VD task. The tasks were performed in the order of VD task, V task, and then control task. If this order were to influence brain activation, then the order of tasks should be modified in rehabilitation for promoting neuroplasticity. Therefore, to develop an effective and efficient rehabilitation method, further study is needed to clarify the relationship between brain activity and the order of tasks. In addition, we did not identify the areas of the PFC that were activated or suppressed in this study. In near future, we need to elucidate the association between the task and the anatomical area involved in neuroplasticity.

Conclusion

In this pilot study, the direction-selective activation of the PFC was found in all subjects performed the visually guided tongue protrusion task. The activation has been considered to promote neuroplasticity in the brain. Therefore, our findings indicate that the task using in this study may contribute to develop a novel rehabilitation method for improving higher brain functions.

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