Frontal Cortex Activation Measured by Near-Infrared Spectroscopy while Cutting Wood According to Different Teaching Methods

Shunsuke Katsuyama
Tsukuba Municipal Kouki Gakuen Teshirogi Junior High School, Japan
teshi23@tkb.ed.jp
Takashi Usuzaka
Ibaraki University, Japan
takashi.usuzaka.tech@vc.ibaraki.ac.jp
Hiroaki Shoji
Ibaraki University, Japan
hiroaki.shoji.m@vc.ibaraki.ac.jp

Abstract: This study examined hemodynamic brain activity while cutting wood according to different teaching methods. We used near-infrared spectroscopy, which is a brain activity measurement device. Participants were divided into 2 groups. Two types of experiment were carried out in each group. Group 1 cut wood after being given instructions in the first experiment and repeated this in the second experiment. Group 2 cut wood without the instructions in the first experiment and cut it again after instructions had been given in the second experiment. Both cutting results and the concentration changes of oxy-hemoglobin were measured. Comparing the first experiment with the second (a within-groups comparison), the concentration of oxy-hemoglobin in Group 2 increased in the frontal area, including the presupplementary motor area, the right dorsolateral prefrontal cortex, the left dorsolateral prefrontal cortex, and the frontal pole. These results suggest that frontal cortex activation might be due to different teaching methods.

Introduction

Along with advances in the development of apparatuses which can evaluate human brain activities noninvasively, brain studies, which have been mainly conducted on animal experiments, are now widely made an object of study in normal adults and children. In recent years, authors such as Battro et al. (2008) have provided an introduction to the field of neuroeducation, which is concerned with the interactions between mind, brain, and education. Such authors urge that knowledge of neuroscience be made use of in the field of education to deal with modern education problems in a new multidisciplinary field called “Neuroeducation: Educational Neuroscience” (Battro et al., 2008, Mareschal et al., 2014). Indeed, the importance of neuroscientific evidence in evidence-based studies on education has recently been discussed (Tang, 2017). Thus, neuroeducation enables the investigation on education to be based on scientific grounds, and future developments in this field are expected.

Recently, cerebral activity in education has been examined using near-infrared spectroscopy (NIRS), for example, in mathematical tasks (Okamoto, 2009). NIRS is a noninvasive method used to calculate concentration changes in blood oxy-hemoglobin (oxy-Hb), deoxy-hemoglobin (deoxy-Hb), and total hemoglobin (total-Hb). NIRS systems are suited to not only healthy adults, but also infants, children, people with developmental disabilities, and hospitalized patients, as they operate silently and do not require participants to be completely motionless.

Technology education in Japanese junior high schools includes learning how to use tools such as a hammer and saw, whereby the aim is for students to learn basic motor skills. In recent years, several studies have investigated the acquisition of motor skills, including planing skills (Terada et al., 1991). However, to our knowledge, almost no previous studies have adopted neuroimaging techniques to make science-based investigations into education techniques. It is therefore important to review motor skill acquisition and the instruction method in the context of neuroeducation. To this aim, we investigated the neural correlates of two different teaching methods for one key motor skill, cutting wood. Several previous studies have examined the impact of wood cutting instruction, e.g. the cutting precision of wood according to different teaching methods (Murata et al., 1988). However, no study has yet examined how different teaching methods influence cerebral activity when cutting wood. To this aim, we recorded NIRS data during wood cutting as well as processing precision. Implications of different teaching methods based on neuroeducation are discussed.

Methods

Participants: A total of 20 healthy, right-handed female university students (mean age 21.2 years, ranging from 19 to 25 years) participated in the experiment. Prior to the start of the experiment, the procedure was explained, and informed consent for participation was obtained from all participants.

Near-infrared spectroscopy measurements: A 66-channel NIRS instrument (ETG-7100 Optical Topography System; Hitachi Medical Co., Japan) was used to measure relative concentration changes in oxy-Hb and deoxy-Hb from 2-3 cm beneath the scalp. The 3 probe holders have 22 channels respectively. The 3 locations of the holders over the frontal lobe (Fpz), the right temporal lobe (T3), and the left temporal lobe (T4), were placed according to the international 10/20 system for electroencephalography (see Figure 1).

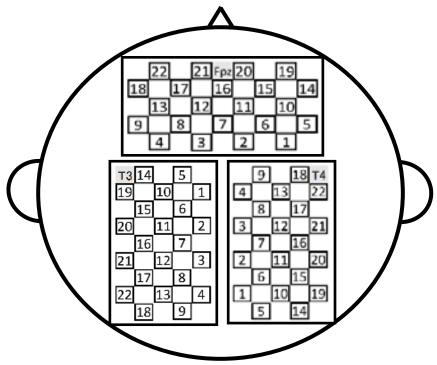


Figure 1. Probe locations over the cerebral cortex.

Experimental material: Experimental material was 12-millimeter thick cedar wood.

Experimental conditions and instruction content: Participants were divided into an 'instructed' group (n = 10) and a 'trial + instructed' group (n = 10). Each group completed two experiments. The instructed group cut wood after being given instructions in the first experiment and repeated this in the second experiment. The trial + instructed group cut wood without having received instructions in the first experiment and cut it again after instructions had been given in the second experiment. A double-bladed saw, which has a crosscut saw on one side and a rip saw on the other, was used in experiments. Participants used the rip saw to rip or cut across the grain of the wood in task 1 and used the crosscut saw to cut across the grain of the wood in task 2 (Figure 2). The rip saw should be used to cut with the grain of the wood, then task 1 was incorrect way, and task2 was correct way. The instructions explained the two aspects of the double-bladed saw, namely, the difference between the crosscut saw and rip saw.

Procedure: Figure 2 shows the experimental protocol and time epoch for analysis. After a standby period of 40 seconds for the baseline of the first epoch, task 1 was performed for 60 seconds. Then, there was another 40-second standby period for the baseline of the second epoch, after which task 2 was performed for 60 seconds. This sequence was repeated 2 times. During standby, they pretended to cut wood without the saw to remove the concentration changes in oxy-Hb and deoxy-Hb caused only by difference in action (cutting movement).

The epoch time used for analysis was 100 seconds, including a 5-second epoch prior to task 1 or task 2 (pre-time), the 60-second epoch during task 1 or task 2, and the 35-second epoch beginning after task 1 or task 2. Baseline correction was done by linear fitting according to the mean value of the 5-second pre-time epoch and that of the 5-second epoch between 30 seconds and 35 seconds after task 1 or task 2 (post-time). The wood was set in the direction to cut across the grain, and cutting wood with the crosscut saw (task 2) was considered correct usage. They needed extra power to rip or cut across the grain of wood with the rip saw on task1, which might have an unnecessary influence for their cerebral blood flow. Therefore, this study focuses on task 2 to analysis. Then, the mean of concentration changes in oxy-Hb between (II) and (IV) in Figure 2 was calculated. Because concentration changes in deoxy-Hb did not show a remarkable change during tasks, it was excluded from the final analysis. Besides, in this study, a result of the frontal lobe, in which a remarkable difference was seen in both groups, was treated.

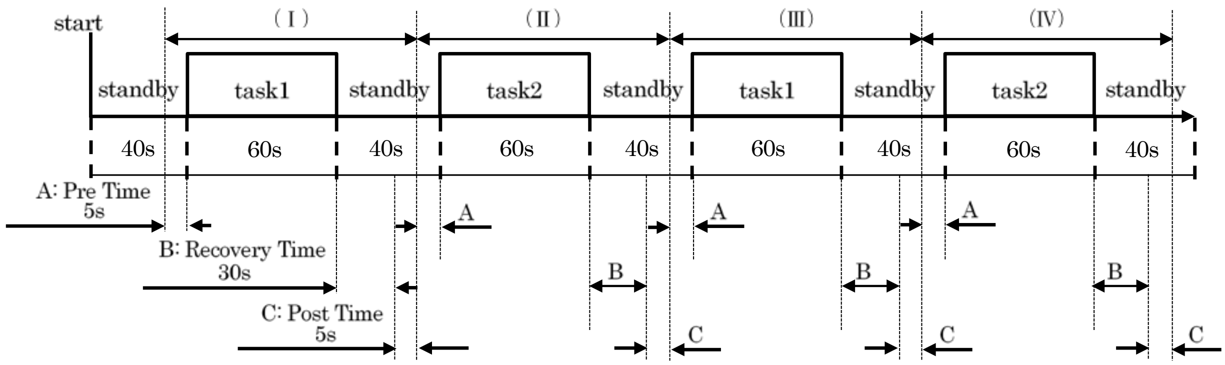


Figure 2. Experimental protocol and time epoch for analysis

Findings

Cutting Results: Figure 3 shows the mean cutting length of the instructed group and the trial + instructed group using a crosscut saw. In the course of one experiment, cutting was performed twice using the crosscut saw ((II) and (IV)). Thus, trial numbers 1 and 2 in Figure 3 refer to the first experimental result, and trial numbers 3 and 4 refer to the second experimental result. As the trial number increased, the cutting length of the instructed group became longer, while the cutting length of the trial + instructed group tended to remain unchanged after the instruction was given, especially on trial 3. For both groups, the cutting length of trial numbers 3 was compared with that of trial numbers 2. As a result, The cutting length of trial numbers 3 of the instructed group was significantly longer than that of trial numbers 2 ($t(9)=4.58$, $p<.01$).

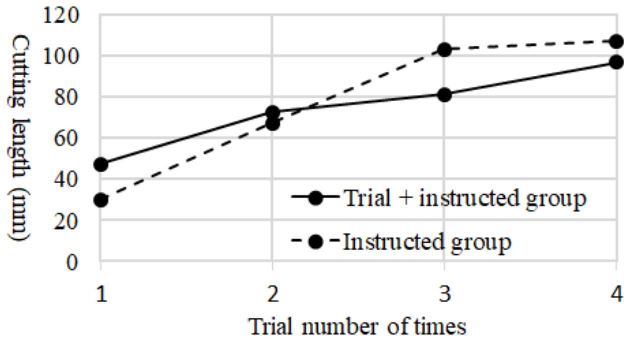


Figure 3. Mean cutting length in both groups

Frontal lobe activation: Within the trial + instructed group, the concentration of oxy-Hb was greater in the second experiment (instructions given) than the first experiment (no instructions given) at about 40 seconds after the task started. Figure 4 shows a subtraction map series of the oxy-Hb concentration changes (i.e., the second experiment minus the first experiment) in both groups at 5 second intervals from 40 to 60 seconds. The 22 channels of the frontal lobe in figure 1 can be divided into the presupplementary motor area (channels 2, 3, 7), the right dorsolateral prefrontal cortex (channels 1, 5, 6, 10, 14, 19), the left dorsolateral prefrontal cortex (channels 4, 8, 9, 13, 18, 22), the frontal pole (channels 11, 12, 15, 16, 17, 20, 21) (Sarkissov et al., 1955). An increase in the concentration of oxy-Hb was observed in the trial + instructed group. On the other hand, a decrease in the concentration of oxy-Hb was observed in the instructed group due to being used to cutting.

Figure 5 shows the grand average waveforms of oxy-Hb concentration changes in both groups for 100 seconds, including a 5-second epoch prior to task 2 (pre-time), the 60-second epoch during task 2, and the 35-second epoch beginning after task 2. For both groups, the mean values of oxy-Hb between 40 seconds and 60 seconds after the task started in the presupplementary motor area, the right dorsolateral prefrontal cortex, the left dorsolateral prefrontal cortex, and the frontal pole in the first experiment were compared with those in the second experiment. As a result, the trial + instructed group's mean values of oxy-Hb in the presupplementary motor area ($t(9)=3.233$, $p<.01$), the right dorsolateral prefrontal cortex ($t(9)=2.952$, $p<.05$), the left dorsolateral prefrontal cortex ($t(9)=2.860$, $p<.05$), and the frontal pole ($t(9)=2.832$, $p<.05$) in the second experiment were significantly larger than those in the first experiment.

According to neuroimaging studies, the frontal pole subserves the monitoring of outcomes expected from the ongoing course of action (Boorman et al., 2009, Tsujimoto et al., 2010, 2011). The dorsolateral prefrontal cortex and the presupplementary motor area are activated in an initial stage to perform visuomotor sequence learning while making trial and error (Sakai et al. 1998). The increase in oxy-Hb seen after instruction in the trial + instructed group could reflect a strategy of looking back at attempts made during the first, unaided experiment, and feeding back the new instruction contents on this experience.

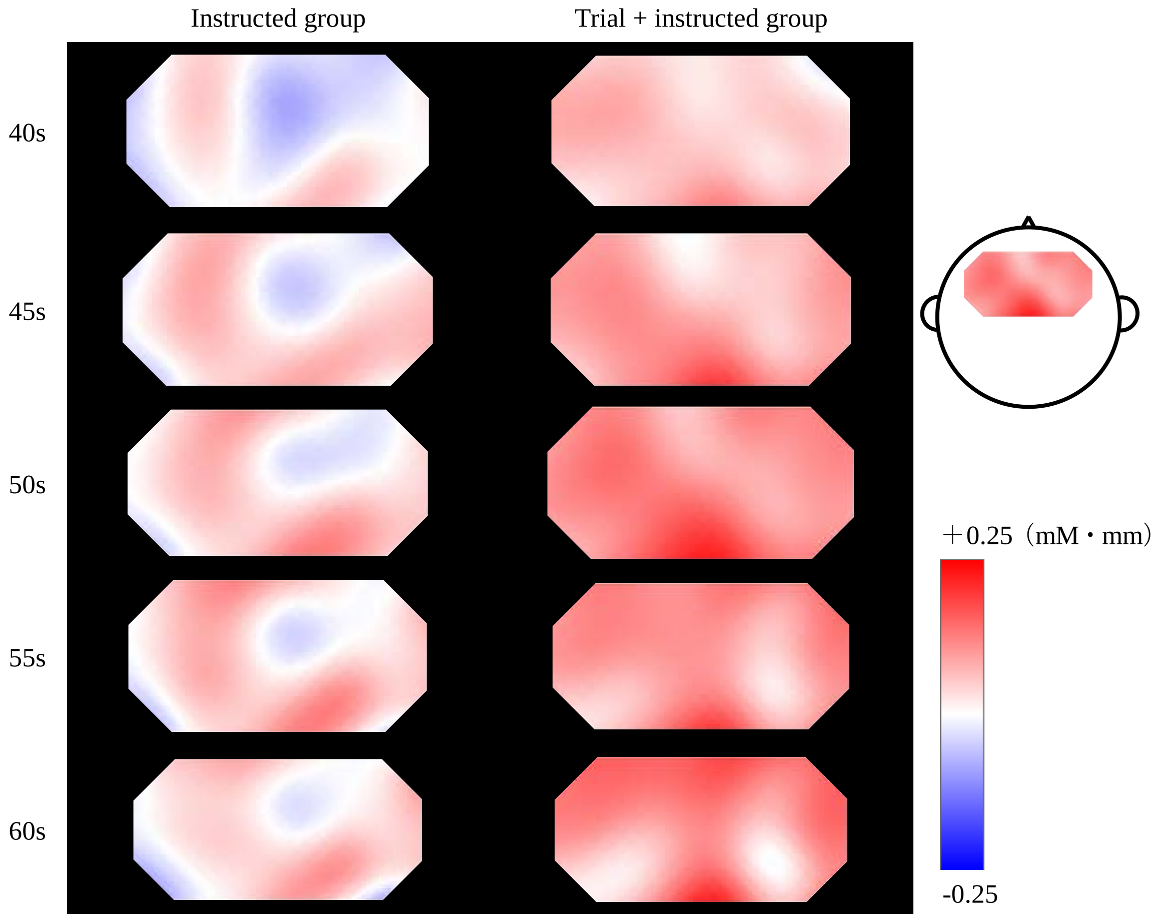
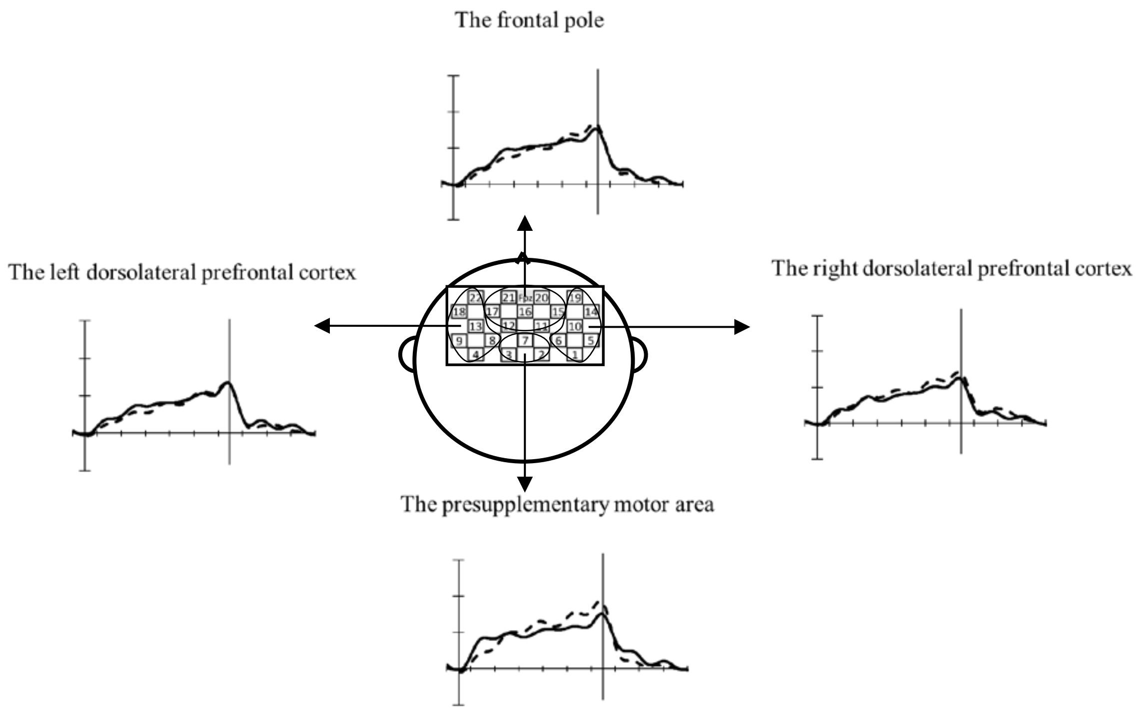


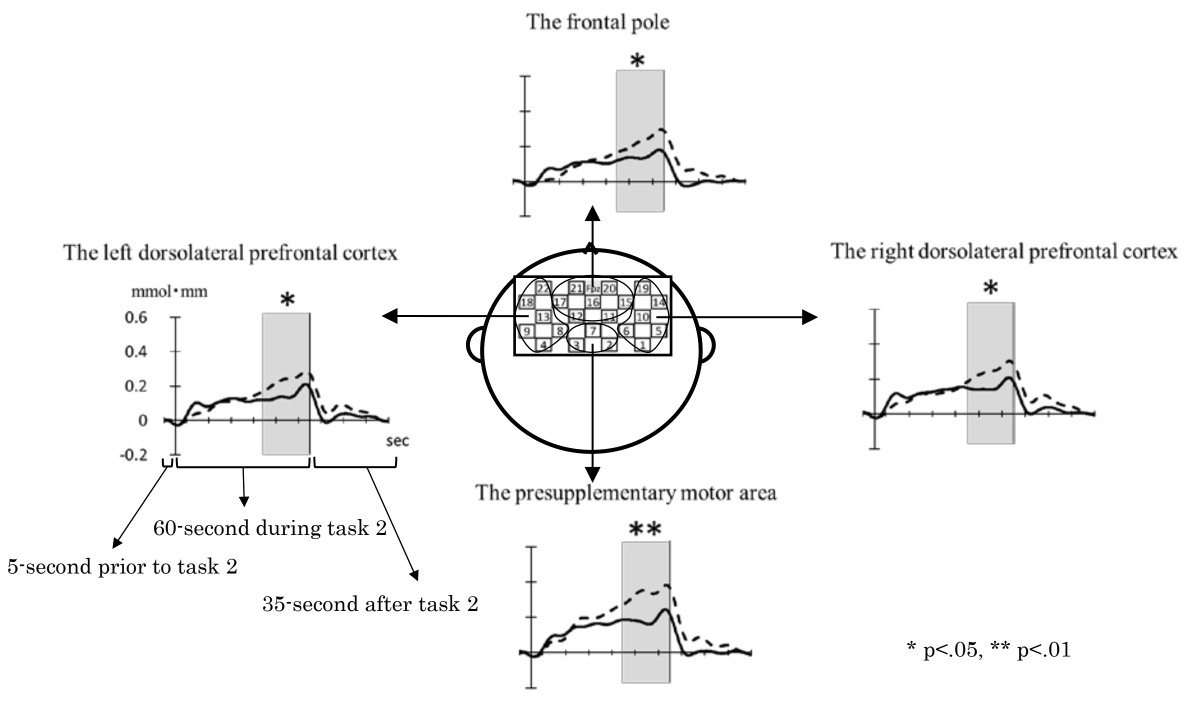
Figure 4. Subtraction map series of hemoglobin concentration in both groups

Conclusions

The instructed group cut wood with prior knowledge of the saw blade and may therefore have only confirmed instruction contents without making new discovery or adjustment during experiments. Therefore, an increase in oxy-Hb concentration wasn't observed across trials. In contrast, the increase in oxy-Hb concentration in the presupplementary motor area, the right dorsolateral prefrontal cortex, the left dorsolateral prefrontal cortex, and the frontal pole in the trial + instructed group, could reflect their strategy of using both feedback of instructions and experience during the first, unaided experiment when cutting wood. In other words, when the instruction content was different from their rule of thumb, in addition to having to rebuild their motor skill style, the trial + instructed group became able to predict a result from their experience in the first experiment and the instruction given before the second experiment.



The grand averaged waveforms of oxy-Hb in the instructed group



The grand averaged waveforms of oxy-Hb in the trial + instructed group

Figure 5. Grand average waveforms of oxy-Hb concentration changes in both groups in the frontal lobe, including the presupplementary motor area, the right dorsolateral prefrontal cortex, the left dorsolateral prefrontal cortex, and the frontal pole. Solid and dashed lines indicate oxy-Hb waveforms respectively for the first experiment result and the second experiment result.

Annotation: This paper is a revision of our conference presentation at the 28th Kanto Branch Conference of The Japan Society of Technology Education. Contents are thoroughly revisited and added where necessary.

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