The Trend in the Frontal Area Activity Shift with Embodied Knowledge Acquisition

Yusuke ASAKA[1], Keiichi WATANUKI[1,2,3] and Lei HOU[3]

[1]Graduate School of Science and Engineering, Saitama University
255 Shimo-okubo, Sakura-ku, Saitama-shi, Saitama 338-8570, Japan
s15dr001@mail.saitama-u.ac.jp
[2]Saitama University Brain Science Institute
[3]Institute of Ambient Mobility Interfaces, Saitama University
{watanuki, hou}@mech.saitama-u.ac.jp

Abstract. This paper discusses the relationship between brain activity and repeatability of actions during the process of embodied knowledge acquisition. Subjects watched a video clip of a working procedure and executed the same series of actions. We conducted the same experiments twice. After the first experiment, we set up three practice trials. In the observation task, the trend in oxy-hemoglobin levels shifted toward a low-level increase in the dorsolateral prefrontal area and a low-level decrease in the frontal lobe with improvement in performing the skill. In the execution task, the trend in oxy-hemoglobin shifted toward an increase in the dorsolateral prefrontal area and toward a decrease in the frontal pole with improvement in performing the skill. These results suggest that activities in the frontal area shift during the process of embodied knowledge acquisition.

Keywords: Body Intelligence, Brain Activity, Near-Infrared Spectroscopy, Knowledge Acquisition

1 Introduction

Explicit knowledge can be expressed as text, figures, tables, etc. On the other hand, knowledge that is not easily expressed is called tacit knowledge [1, 2]. In this study, we define tacit knowledge to include embodied knowledge, which is a set of skills based on experiences and intuitive sense as seen in performing an art, sport, craft, or other skilled task. Embodied knowledge cannot be easily communicated and shared because of the difficulty in evincive expression. For this reason, both the learner's and instructor's efforts are important for acquisition of embodied knowledge.

In core manufacturing industries, embodied knowledge includes skills pertinent to making products, and effective sharing of knowledge is an important issue for developing human resources. Instructors with a lot of embodied knowledge can provide advice to learners regarding the quality of their work and products. However, from a practical standpoint, ensuring that instructors have the time to practice with learners is difficult [3]. In addition, because of the difficulty in evincive expression, the learner's level of embodied knowledge is difficult to evaluate. An example of a method to evaluate the level is a practical exam taken by the learner. Exam monitors need to be experts in the skill, and they evaluate the learner's level based their experiences. Due to the nature of embodied knowledge and the reality regarding the practical work site, learners need to objectively evaluate their own level of embodied knowledge to acquire the knowledge on their own. Acquiring embodied knowledge involves high levels of information manipulation such as internalization of tacit knowledge. Measuring brain activity is an appropriate method for objective evaluation of the level of internalization.

Thus, we used near-infrared spectroscopy (NIRS) to investigate the relationship between brain activity and embodied knowledge during the process of embodied knowledge acquisition. Evaluation of the level of knowledge acquisition with monitoring of brain activity can be an objective indicator of the learner's degree of skill progression. Evaluation of the learner's degree of acquisition enables one to predict improvement with modeling and to present options for more effective methods of learning. Therefore, our final goal is constructing a new learning model and improving learning efficient by the learning model via brain science.

During the process of embodied knowledge acquisition in core manufacturing industries, it is essential to remember the operation procedures of the process machinery. In this paper, we targeted procedural memory and imitation learning and investigated the relationship between brain activity and repeatability of actions.

2 Measurement of frontal area activity by NIRS

2.1 Optical brain imaging system

When neural activity occurs in the brain, blood flow increases in the tissue near the active neurons, and the rate of oxygenated and deoxygenated hemoglobin (oxyHb, deoxyHb) in the blood changes. Near-infrared light (700-900 nm) is harmlessly transmitted through the human body, and hemoglobin characteristically changes following near-infrared absorbance, depending on the oxygen level in the hemoglobin. These properties enable non-invasive measurement of brain activities. Another advantage of NIRS is that it allows subjects to move, unlike other brain function measurement techniques. NIRS has relatively high spatial resolution, and the NIRS device is small and portable. Thus, in this study of the process of learning embodied knowledge, NIRS is a valid measurement technique.

2.2 Measurement of the frontal area and removal of artifact due to biofunction

The dorsolateral prefrontal area is closely related to working memory, as it establishes long-term memory [4]. The ability to later remember a verbal experience is predicted by the amplitude of activation in the left prefrontal and temporal cortices during that experience [5]. In a previous experiment we conducted, in which the subject remembered a set of simple body actions by imitation learning followed by execution, the oxyHb level increased in the dorsolateral prefrontal area and decreased in the frontal pole [6]. Thus, we measured activities in the frontal lobe and analyzed the same areas including the right prefrontal area (Channel 20), frontal pole (Channel 23), and left prefrontal area (Channel 26) (Fig. 1).

In NIRS, optical fibers are placed on the scalp of the subject based on the international 10-20 system. Because of the fibers and scalp contacts, the measurements are affected by the subject's body motion, metabolism, and breathing. Thus, assuming that such artifacts are similar in all brain regions, we employed global average references [7]. In this article, the effectiveness of the global average references was verified using NIRS for static tasks such as listening to music, reading text, solving puzzles, or other static tasks. However, global average references were applied assuming that artifacts are similar in all brain regions, and this hypothesis can be applied to such experiments involving body motion. For each trial, results were standardized to the measurement result at rest before the task (Pre-Rest) with Eq. (1).

$$\Delta \mathrm{oxy}(t)_{Z-SCORE} := \frac{\Delta oxy(t)_{raw} - \mu^{\Delta \mathrm{oxy}}_{pre-rest}}{\sigma^{\Delta oxy}_{pre-rest}} \quad (1)$$

Where Δoxy(t) denotes the measured value of oxyHb at time t on each channel, $\mu^{\Delta \mathrm{oxy}}_{pre-rest}$ is the average oxyHb change in the Pre-Rest time, and $\sigma^{\Delta oxy}_{pre-rest}$ is the standard deviation for the Pre-Rest time. Then, the standardized measurement result was averaged for each of the 32 channels in time. Finally, this result was subtracted from the standardized measurement result at each point with Eq. (2).

$$\Delta oxy(t)_{GR} := \Delta oxy(t)_{Z-SCORE} - \frac{\sum_{l=1}^{n} \Delta oxy_l(t)_{Z-SCORE}}{n} \quad (2)$$

Where n denotes the total number of channels. In this experiment, n is defined as 32 channels, the total number of channels.

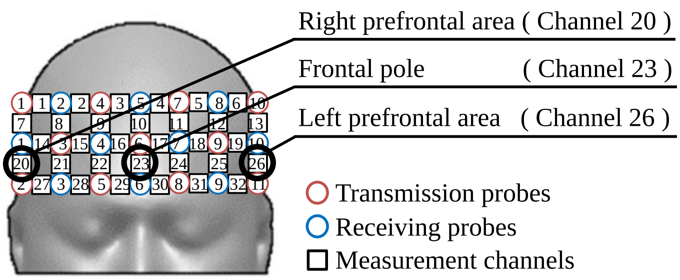

Fig. 1. Region of NIRS measurement

3 Measurement of brain activation during the learning of work procedures

3.1 Imitation learning to form procedural memory simulating skills in industries

Simulating skill acquisition in core manufacturing industries involves acquiring embodied knowledge, which leads to procedural memory of a skill. Subjects remember and execute a set of procedures by imitation learning. The purpose of this experiment was to measure the trends in changes in brain activities with development of a skill by imitation learning.

The subjects were seated at a desk so that they could see a display in front of them (Fig. 2). One experiment was composed of three trials. The portion of the trial during which the subject carried out the experimental task lasted 180 seconds, and the rest time before and after the task lasted 30 seconds. This trial was executed three times by each subject. Instructions for the task were shown on the display for 5 seconds after the task started, and the instructions ended 5 seconds before the task ended. During the rest time, the subject was told to rest without thinking. In the first trial, the subject rested throughout the trial (the rest trial). In the second trial, the subject observed and remembered a set of procedures shown in the display, which was a video clip of assembly work (the observation trial). The assembly work lasted 157 seconds, and then the clip of the finished product lasted 13 seconds. The parts for assembly were placed on the desk after the trial. In the third trial, the subject executed the procedures that he remembered in the observation trial (the execution trial). The end of the task was indicated on the display, and the subject signaled with a buzzer only in the execution trial. Before the experiment, the experimental structure and instructions to remember the procedures as distinct from the finished product were explained to the subject. To carefully handle the assembly parts, subjects assumed a bent forward posture. The subjects were instructed to maintain the bent forward posture, because changes in position cause artifacts. The subjects were five healthy men in their early twenties (A, B, C, D, E) who provided consent for participation in the experiment. The experiment ran for 2 days (Table 1), and the subject practiced the tasks without undergoing NIRS to improve the skill. The subject performed the observation task and the execution task after measurement on the first day, and then performed these tasks two times in a row before measurement on the second day.

3.2 Repeatability of the remembered procedures

We evaluated the procedures that each subject executed in the trial for repeatability, which indicates the degree of imitation. In general, an expert in the skill determines the skill level. However, in this experiment, we objectively determined the skill level due to limited skills in the procedures for the assembly work. Therefore, the procedures were broken down into 12 numerically ordered steps and scored by an additional method. If the number of the executed procedure was higher than that of the previous procedure, one point was scored. This method allowed a score of up to 11 points. Asymmetrical shapes and colors of the assembly parts were distinguished.
Evaluation of the procedures is shown in Table 2. Each subject scored low, around 0 to 2 points, on the first day that the subject was instructed to perform the assembly work. On the second day, all subjects scored 10 points. This result suggests that all subjects improved their skills during the trials.

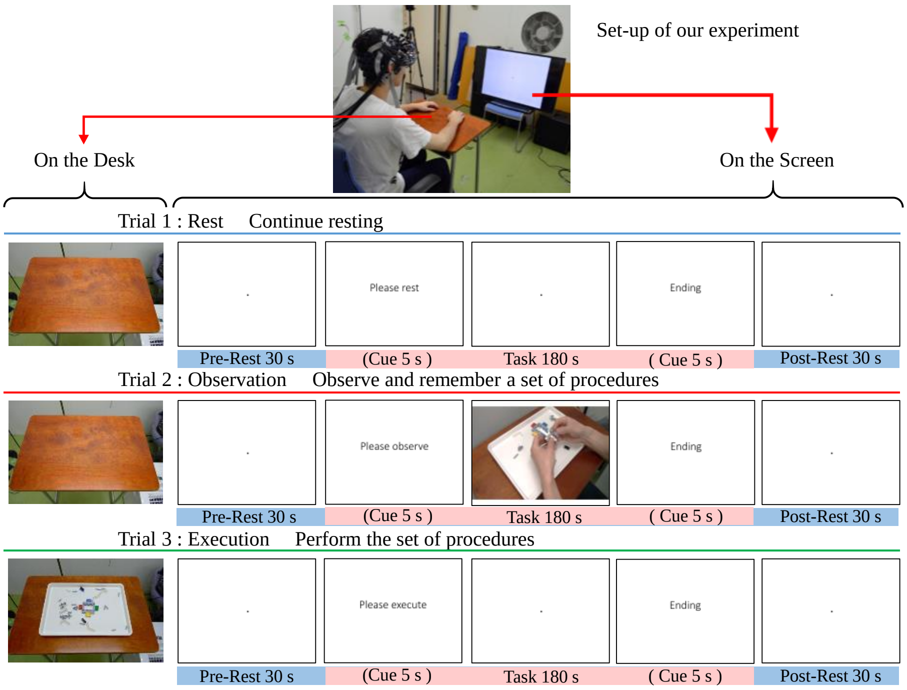

Fig. 2. Experimental design

Table 1. Experimental schedule. The numbers indicate the subject's accumulated performance counts.

	First day		Second day		
	Measure-ment	After measurement	Before measurement	Before measurement	Measure-ment
Task 1 Rest	1	-	-	-	2
Task 2 Observation	1	2	3	4	5
Task 3 Execution	1	2	3	4	5

Table 2. Results of the execution procedure

Subjects		The execution procedures (The numbers indicate the number of procedures)												Total
A	First day	1	4	2	-	-	-	-	-	-	-	-	-	1
	Second day	1	2	3	4	5	6	7	9	10	11	12	-	10
B	First day	2	1	-	-	-	-	-	-	-	-	-	-	0
	Second day	1	2	3	4	5	6	7	9	10	11	12	-	10
C	First day	1	4	2	-	-	-	-	-	-	-	-	-	1
	Second day	1	2	3	4	6	7	8	9	10	11	5	12	10
D	First day	1	2	4	-	-	-	-	-	-	-	-	-	2
	Second day	1	2	3	4	5	6	7	8	9	10	11	-	10
E	First day	2	-	-	-	-	-	-	-	-	-	-	-	0
	Second day	1	2	3	4	5	6	7	8	10	9	11	12	10

3.3 The Relationship between Brain Activity and Repeatability of Actions during the Process of Embodied Knowledge Acquisition

The result of oxyHb in the rest trial was compared with that in the observation trial (Fig. 3). The oxyHb in the rest trial was stable at low levels on both days. The oxyHb in the observation trial increased in Channels 20 and 26 and decreased in Channel 23. These tendencies stabilized at a low level, and the confidence interval of the oxyHb narrowed on the second day. The outcomes indicate that the frontal area activities during formation of procedural memory by imitation learning tended to stabilize at a low level due to practice. One explanation for this may be that practice resulted in a reduced amount of information to remember from the video clip and that frontal area activities shifted to a similar tendency as in the rest trial.

The result of oxyHb in the rest trial was compared with that in the execution trial (Fig. 4). The oxyHb in the rest trial was the same as in Fig. 3. The result on the first day showed a similar tendency as the oxyHb in the rest trial. The oxyHb in the execution trial increased in Channels 20 and 26 and decreased in Channel 23. The differences in Channels 23 and 26 on the second day were significant. The outcomes indicate that the trend in frontal area activities during the execution of remembered procedures is amplified due to practice. The subject had more information about the assembly work on the second day, and this increase was related to the function of retrieving the memory, executing the remembered procedures, or both.

Comparing the results on the first day with the second day, repeatability was improved by imitation learning, which may increase skill levels. Limited acquisition of embodied knowledge due to procedural memory produced an increase in the oxyHb level in Channels 20 and 26 and a decrease in Channel 23 in the observation trial during the early stage. The tendencies were mitigated due to a reduction in the amount of information to remember. In the execution trial, oxyHb did not show a trend that depended on the task during the stage. The increase in oxyHb in Channels 20 and 26 and the decrease in Channel 23 were due to an increased amount of information to execute.

We compared the summed total amounts of the adjusted oxyHb levels during the task period in each subject on the first day with the second day to focus on the change in the trend (Fig. 5). The total amounts in the rest trial were low on both days. The amounts in the observation trial showed positive high levels in Channels 20 and 26 and a high negative level in Channel 23, and these shifted to a lower level. The amounts in the execution trial were low in the three channels and shifted to positive high levels in Channels 20 and 26 and a high negative level in Channel 23.

These outcomes suggest that frontal area activities shift during embodied knowledge acquisition, improving assembly work. Assuming these activity shifts are applicable to more high-level skills, we can predict a degree of improvement based on brain activities.

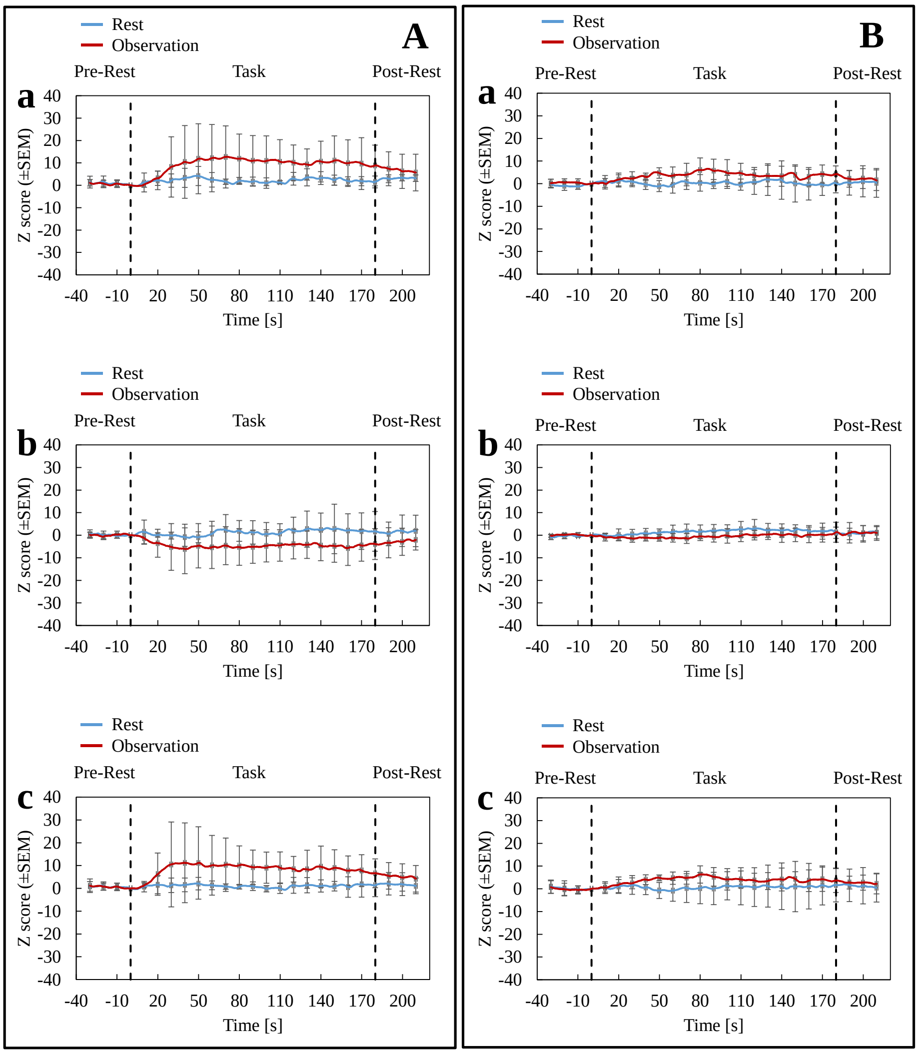

Fig. 3. Comparison of mean oxyHb variation in the observation trial with the rest trial ($P < 0.05$). (A) First day. (B) Second day. (a) The right dorsolateral prefrontal area (Channel 20). (b) The frontal pole (Channel 23). (c) The left dorsolateral prefrontal area (Channel 26).

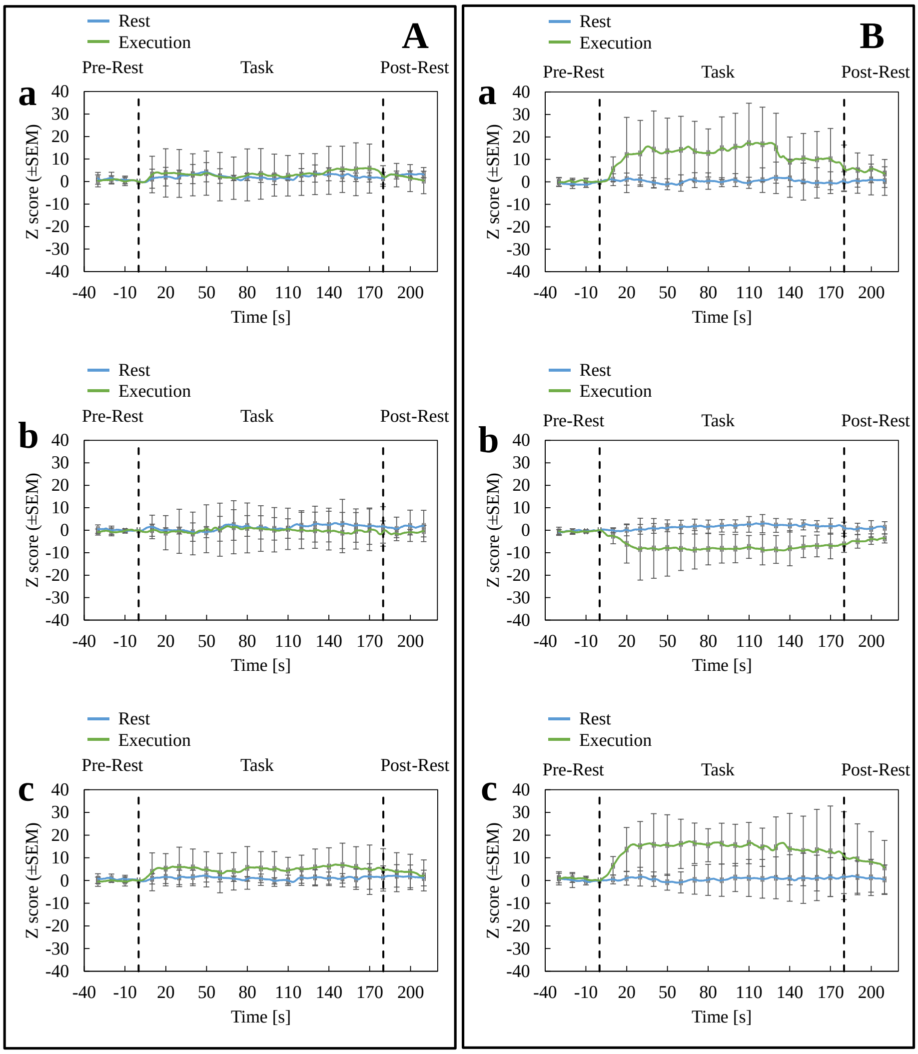

Fig. 4. Comparison of mean oxyHb variation in the execution trial with the rest trial (P < 0.05). (A) First day. (B) Second day. (a) The right dorsolateral prefrontal area (Channel 20). (b) The frontal pole (Channel 23). (c) The left dorsolateral prefrontal area (Channel 26).

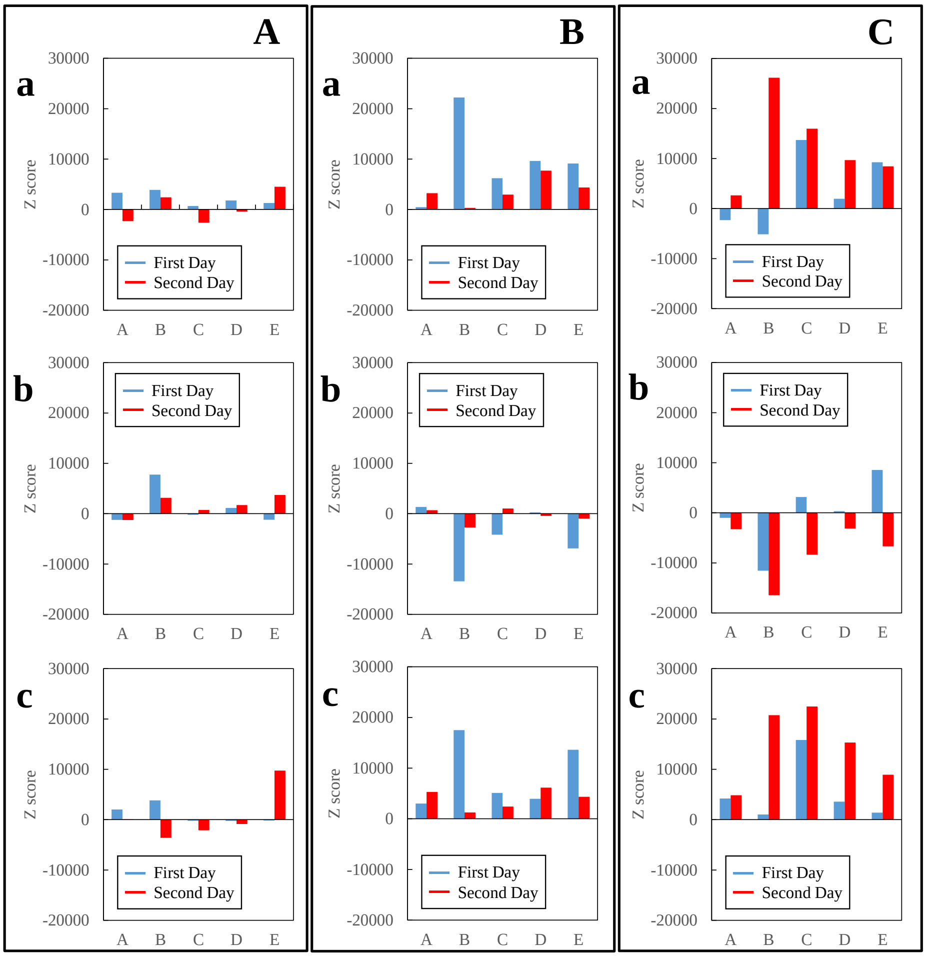

Fig. 5. Comparison of the total oxyHb during the task period on the first day with the second day. (A) The rest trial. (B) The observation trial. (C) The execution trial. (a) The right dorsolateral prefrontal area (Channel 20). (b) The frontal pole (Channel 23). (c) The left dorsolateral prefrontal area (Channel 26).

4 Conclusion

In this paper, by limiting acquisition of procedural memory through imitation learning, we analyzed the relationship between brain activity and repeatability of actions during the process of embodied knowledge acquisition. With low repeatability, the oxyHb level increased in the right and left dorsolateral prefrontal areas and decreased in the frontal pole during the process of observing and remembering the procedures. The level stabilized to a level similar to that in the rest trial during execution of the task. With high repeatability during observing and remembering, the oxyHb level stabilized to a level similar to the level during rest. The oxyHb level increased in the right and left dorsolateral prefrontal areas and decreased in the frontal pole during the process of execution. These outcomes suggest that the frontal area activities shift during embodied knowledge acquisition. In the future, we intend to perform more long-term experiments and reliable analyses by increasing the number of subjects and changing the tasks. Additionally, although analytical methods can be used to reduce the effect of the subject's body motion, an experimental method that separates brain activities elicited by a task from the effect of body motions is needed.

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