A fundamental study on analysis of brain activity according to the learning level.

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Abstract. Japan in which society is aging need the understanding of skill transfer that has supported the growth of economy in industry. Past studies of the skill transfer was evaluated by external evaluation such as work method and working time. On the other hand, there is little study on internal evaluation such as change in brain activity. The study on relation between work skill and brain activity is paramount to an understanding of skill transfer. This study aims to examine learning relation between work skill and brain activity. Experimental task is juggling. The work skill is measured by subject's arm movement and the number of throwing times is exactly determined by motion capture system. The brain activity is measured by a near infrared spectroscopy (NIRS). The learning level is capable of being quantified by both internal and external evaluation. Subjects practice juggling for net seven days and are measured three times. As a result of the experiment, it is obtained that brain activity is increased then gradually decreased as participants are determined to improve juggling by increasing continuous throwing times and regularly arm movement. Activating the brain may be related to skill learning.

Keywords: skill, learning level, brain activity, near infrared spectroscopy (NIRS), motion capture system

1. INTRODUCTION

Japan in which society is aging need the understanding of skill transfer that has supported the growth of economy in industry. Hence, many companies tackle skill transfer, such as having elderly employees work through re-employment or employment extension, and compilation of skills to hand down in texts and manuals (Ministry of Economy, 2015). Learning skill for workers is required to repeatedly experience acquisition of both knowledge and skills for long time. The skill includes what is called tacit knowledge. Thus elucidation of the skill is particularly difficult. Furthermore, globalization of manufacturing industries recently results in many education issues for foreign workers in an overseas factory. Accordingly, it is significant to facilitate skill transfer (Nakamura, 2002).

Past studies of the skill transfer was evaluated by external evaluation such as work method and working time (Yamamoto and Mori, 2002; Watanuki, 2007; Fukuta et al., 2014). On the other hand, there is little study on internal evaluation such as change in brain activity. It is necessary to focus on brain activity which plays an important part in the function of cognition and decision, as mentioned above, because advanced skills include tacit knowledge. The study on relation between work skill and brain activity is paramount to an understanding of skill transfer.

This study aims to examine learning relation between work skill and brain activity. Experimental task is juggling which is able to be mastered in a short time in general. The work skill is measured by subject's arm movement and the number of throwing times, which is exactly determined by motion capture system. The brain activity is measured by a near infrared spectroscopy (NIRS). The learning level is capable of being quantified by both internal and external evaluation.

2. METHOD

2.1 Motion capture

Operational data is recorded by using a motion capture system (MAC3D; Motion Analysis Corporation). Motion capture system is the general name of apparatus capable of capturing the physical exercise in three dimensions and its software. The joint of the human body or an object is attached a lightweight coating which reflects infrared light painted sphere (marker). There are multiple types of motion capture (for instance optical, mechanical, magnetic, and video type). The optical type is used in this study. Optical type has become a mainstream motion capture because it is comprehensively excellent to take a data exactly, versatility, scalability and lack of burden to subjects. The principle is to calculate the three-dimensional coordinates. Camera captures the position and movement of the object, where is enclosed by plural cameras and the space to be digitized after making space called capture volume. In this experiment eight cameras called Rapter-H are used. Rapter-H has the resolution 640 × 480 pixel, the number of pixels 30 million pixels, and the maximum shooting speed 240 fps. In order to control and analysis motion capture system the core software Cortex is used. Cameras are arranged to detect markers as shown in Figure 1.

To be captured data six markers are attached to subjects. Attached six markers positions are right shoulder, left shoulder, right elbow, left elbow, right wrist, and left wrist. Camera sampling rate is set at sixty frames per second. Both the coordinate position and the elapsed time are obtained for each frame as operation data.

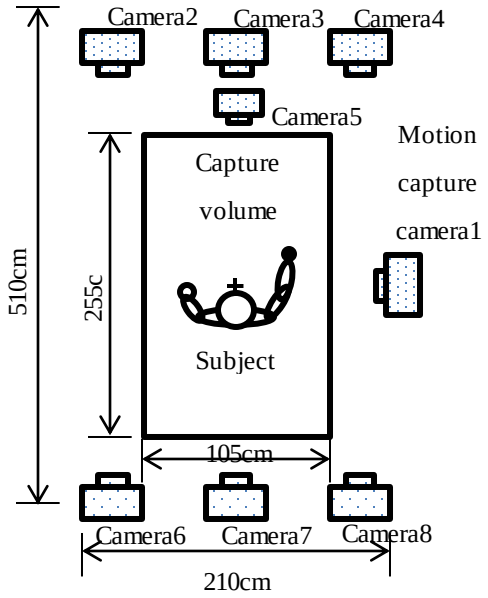

Figure 1: Arranged cameras layout.

2.2 NIRS

To measure change in the concentration of oxygenated hemoglobin (Oxy-Hb) in the brain, especially prefrontal area, a near infrared spectroscopy (NIRS; Spectratech Corporation.) is used. NIRS is the apparatus for measuring the hemoglobin change of each portion in the not too deep portion of a living body, which uses the light absorption characteristics of the hemoglobin in the living body changed by the state of bonding between hemoglobin and oxygen. NIRS measures the change in the concentration of hemoglobin in the brain by the near infrared light from above the scalp is irradiated into the brain, collecting light that caused the absorption and scattering in the brain in an optical fiber using an optical fiber. Concentration of Oxy-Hb to carry oxygen rises because the portion observed active neural activity requires a number of oxygen (Fukuda, 2009). Hemoglobin consumed oxygen is called deoxygenated hemoglobin (Deoxy-Hb). The light absorption of the wavelength is different between Oxy-Hb and Deoxy-Hb, therefore the change in both the hemoglobin concentration is measured by that difference.

NIRS signal is not hemoglobin concentration itself, but the product of the optical path length and the hemoglobin concentration. Thus the unit of concentration is reasonable to express no unit or arbitrary units (au) (Sakatani, 2012). Common in studies using NIRS, it is often used concentration change of Oxy-Hb as an indicator of neural activity. NIRS signal is appropriate to interpret the activation reaction of the cerebral cortex as increasing or decreasing trend of Oxy-Hb concentration (Fukuda, 2009).

To measure the change of Oxy-Hb concentration, NIRS is mounted on subjects as the central portion of NIRS matches the center of the forehead. Therefore the head circumference and the width of the forehead are measured in advance. Of the sixteen channels, the data from the channel ten is used because of the most suitable data except for when subjects move their head or when the channel signal is weak. Original NIRS signal needs to be processed because it is easily affected by the brain blood flow changes and mechanical noise caused by the movement of the head. In order to remove the effects of cerebral blood flow changes and mechanical noise, the original NIRS signal has been processed to take a moving average of eleven points (Miyajima, 2014).

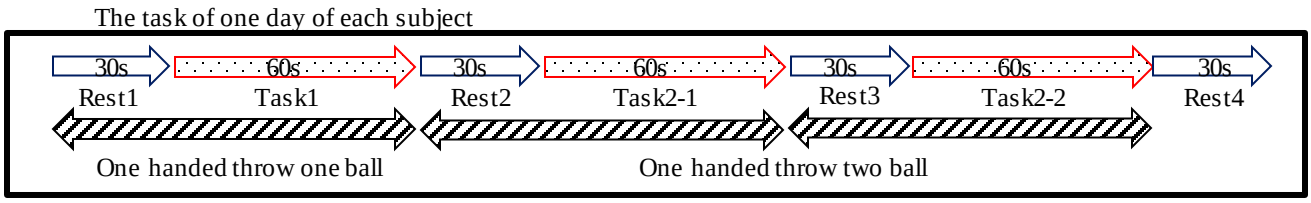

Figure 2: Experiment procedure.

3. EXPERIMENT

Experiments were conducted to examine learning relation between work skill and brain activity in the experimental task, ball-juggling. The work skill is measured by subject's arm movement and the number of throwing times is exactly determined by motion capture system. The brain activity is measured by NIRS. After the end of the experiments, questionnaire is taken to comprehend subjects' impressions of whether subjects acquired skills and knack.

Subjects who are six men and three women of a total of nine in this experiment are healthy college students and graduate students from twenty one years old to twenty five years old. The experiments are conducted when three days out of the period from October 13, 2015 to January 7, 2016, carried out during the period from 11 a.m. to 7 p.m.

3.1 Experimental task

The target of this experiment is to master skill of ball-juggling. The tasks of experiments are kinds of two actions, "one-handed throw one ball", action to throw and grab up one ball by one hand, and "one-handed throw two balls", action to throw and grab up two balls by one hand. "One-handed throw one ball" is called task 1 to get accustomed to experiments. "One-handed throw two ball" is called task 2 and taken place twice as main tasks because NIRS data were assumed to be affected by fatigue and impact due to the change in operation. The all task time is set to sixty seconds. Furthermore, rest time before and after each task is set to thirty seconds in order to measure the activation state of the brain of a resting state for subjects. The gray screen to the PC in front of subjects is set to get staring at the cross in the center. The reason is that during the rest time subjects keep as much as possible a state that does not think of anything. These total five minute experiment in one day is conducted in three times for each subject (Figure 2). It is set to use the dominant hand throughout the entire task. To reduce the impact on the measurement of NIRS due to the fact that the move vigorously head, the third party picks up balls which subjects dropped during the experiments.

3.2 Procedure

Subjects asked to sit on a chair placed on the central portion of the capture volume, the experiment is started. After mounting NIRS to the subject of the forehead, we perform a description of the experimental procedure and carry out in the order of rest 1, task 1, rest 2, task 2-1, rest 3, task 2-2, and rest 4 (Figure 2). After the end of the experiments, we took questionnaires to comprehend subjects' impressions of whether subjects acquired skills or knack. Questions to subjects are the following six:

1. Can you take a rest in the time of rest?
2. Can you acquire more skills than before?
3. Did you get the knack of your own?
4. Did you feel uncomfortable the head module mounting of NIRS?
5. Do you worry about machine sound of motion capture?
6. Do you have any other things?

3.3 Practice

Subjects practice task "One-handed throw two ball" for net seven days before each day of experiments on subjects to learn skill quickly and reliably. Before the second day of the measurement date, the practice of ten minutes is carried out. The breakdown is as follows, two minute practice to throw up balls to be aware of that drop every time in the same position, two minute practice to grab two balls up throwing in each of the time difference, and six minute practice to throw two balls continuously as much as possible. Before the third day of the measurement date, on the basis of the data of the past two days, divided levels into two group (high and low) subjects different practice for each level. Criteria for grouping is whether carried out more than fifteen continuous throwing times up to two days experiments. The reason of different practice for each level is that it is assumed that if a learner is a motor learning, by changing the training method by stage of the learner three stages (cognitive stage, union stage, and automated stage), it is possible to learners efficiently to learn (Tani, 2005). High level group (four subjects) practice

to fit the sound of the metronome sound at the tempo of 129 bpm. The tempo of 129 bpm is set based on the person of the video that appears to be skilled. The practice twice, after ten minutes the experiment immediately before, are performed on the third day experiment. On the other hand, low level group practice the same as before practice twice. After teaching one-on-one (subject themselves to feel and get a knack), it is carried out on the third day experiment.

4. RESULT and DISCUSSION

4.1 Motion capture

The work skill is measured by both the number of continuous throwing times and the variation in trajectory of the subjects' wrist, which is exactly determined by motion capture system. In the three times of the experiment, "continuous throwing times" is the number of times which subjects continued up throwing without dropping the ball most continuously. Figure 3 shows continuous throwing times for each subject. It shows that the continuous throwing times increase in all subjects at the third day compared to the first day. In particular subjects A, B, C, and G, the value of the second day has increased significantly.

It is determined distance from the center of motion and the standard deviation using the data of the wrist (x,y,z) for each subject, when the subject has achieved the continuous throwing times. Moreover it is calculated variation in movement of per rotation wrist by dividing the standard deviation by the continuous throwing times. Figure 4 shows variation of wrist of per rotation for each subject. It means that the smaller difference of trajectory shows stable subjects task. Variation in trajectory of wrist of per rotation has decreased as the experiment day passes in all subjects. It may be assumed that the more subjects practice, the smaller variation in trajectory of the subjects' wrist of per rotation is in association with no waste of wrist movement.

Total score are expressed in the two indices that is both the sum of continuous time per day and the sum of variation in movement of per rotation wrist per day. It is defined as the total score of the learning level degree from the average of the two indices defined in the 10-point scale (Table 1). It is classified proficiency level from the total score, as the top four is cllasified into high level, and the lower four is classified into low level (Table 2). The results obtained from the following NIRS data are discussed on the basis of the following grouping of this classification.

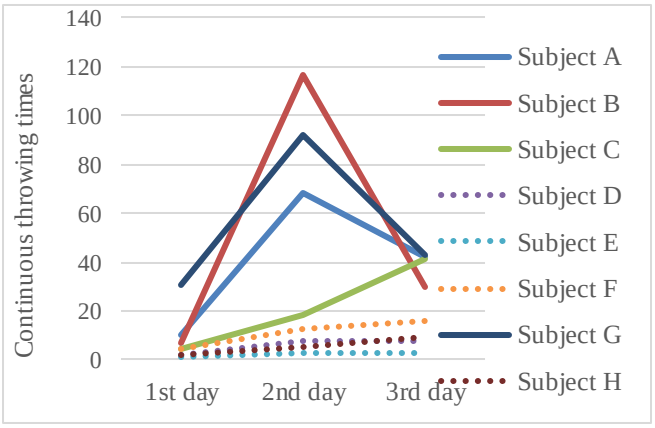

Figure 3: Continuous throwing times.

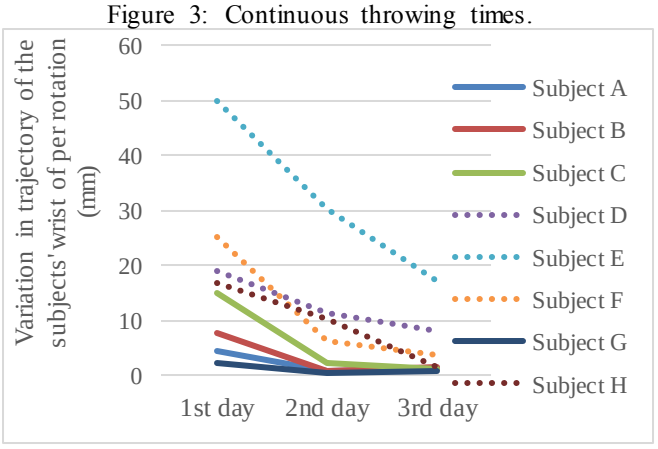

Figure 4: Variation in trajectory of subjects' wrist.

Table 1: 10-point score table about two indices.

Continuous throwing times	Point	Standard deviation (mm)	Point
162 to 179	10	1 to 4	10
144 to 161	9	5 to 8	9
126 to 143	8	9 to 12	8
108 to 125	7	13 to 16	7
90 to 107	6	17 to 20	6
72 to 89	5	21 to 24	5
54 to 71	4	25 to 28	4
36 to 53	3	29 to 32	3
18 to 35	2	33 to 36	2
0 to 17	1	37 to 40	1

Table 2: Skill level classification.

Subject	Point (Continuous throwing times)	Point (Standard deviation)	Total score	Ranking	Level
A	10	7	8.5	3	High
B	10	9	9.5	2	High
C	9	4	6.5	4	High
D	7	2	4.5	6	Low
E	4	1	2.5	8	Low
F	8	2	5.0	5	Low
G	10	10	10.0	1	High
H	8	1	4.5	6	Low

4.2 NIRS

The brain activity is measured by NIRS. Figure 5 shows the example (Subject C) of the measured amount of Oxy-Hb concentration change for each subjects (Solid line). The original NIRS signal (Oxy-Hb concentration) has been processed to take a moving average of eleven points.

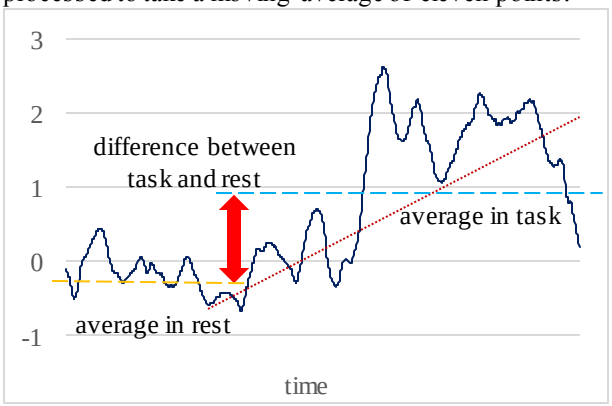

Figure 5: Example of NIRS signal and the gradient.

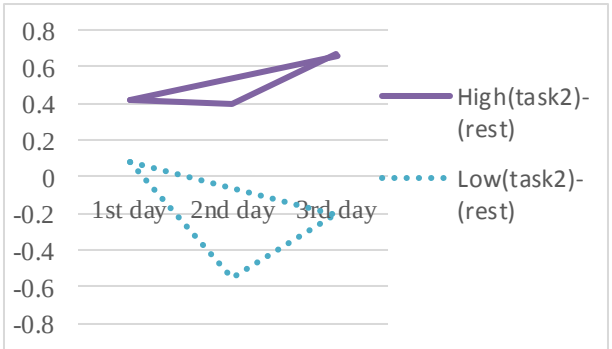

Figure 6: Difference of Oxy-Hb concentration change.

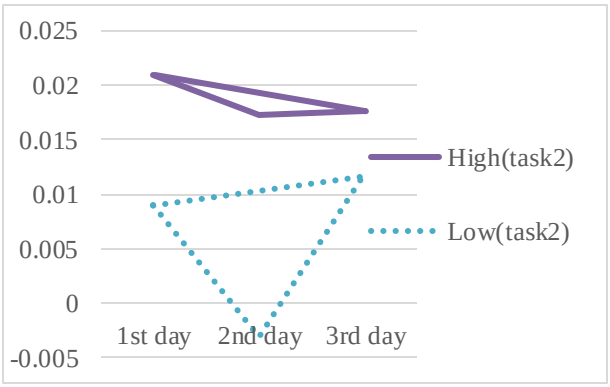

Figure 7: Gradient of linear approximation.

Firstly, for each classified level the average value of Oxy-Hb concentration change "task 2-1, task 2-2, rest 2, and rest 3" is calculated. Figure 6 shows the difference of the average value between task and rest (average of task minus average of rest). The difference means that when this difference is positive, the amount of Oxy-Hb concentration change in the task is larger than in the rest, therefore, the brain is activated. Conversely, when this difference is negative, the amount of Oxy-Hb concentration change in the task is smaller than in the rest, therefore, the brain is deactivated. Figure 6 shows that while in the high group the difference has taken the always positive value, in the low group, except for the first day, the difference has taken the negative value. It is found that while the high group subjects are activated in the task than in the rest, low group subjects are deactivated in the task than in the rest.

Secondly, linear approximation for NIRS data task 2-1 and task 2-2, and the average value of the gradient of the line are calculated (Figure 7). The gradient of the line means that if this gradient changes significantly, it is determined that the brain toward the start and end has been actively. On the other hand, if this gradient change is small, it is determined that the brain toward the start and end has been gradually deactivated.

At first, as a whole tendency, the high group took a higher value than the low group. It is found that high group subjects are more activated than low group in the task. Figure 7 shows that the value from day one through the second day is reduced, then, the value is increased from the second day over the third day.

Next, features for each group are confirmed that in the high group the gradient has taken the always positive value and higher value than low group. Consequently it is found that the brain of subjects in high group toward the start and end has been actively. The reason why the value from the first day through the second day is reduced is inferred that subjects would consider a variety of things in the first day, such as way of rotation of the arm, the experiment itself

unfamiliar, and to do consciously tasks to become well. However in the last day, it is assumed that it is no longer thought for subjects to be unnecessary to concentrate on the task due to skilled operation. Conversely, the gradient in the low group subjects has taken the negative value. Accordingly, it is suggest that it is possible for learners thinking leads to acquire skill. Further, it is assumed that the difference between these high group and the low group is that as learners get skill, the result that subjects can afford to be able to think of other than the task (just throwing balls continuously) cause the brain to be activated. This is based on both the questionnaire after the end of the experiments and recorded video (Table 3).

Table 3 summarizes the answers that the number from 1 to 6 is as shown in Chapter 3 of the experimental procedure. Table 3 shows that "1 and 3" is the case subjects answered "I can" and "2, 4, 5" is the case subjects answered "I feel". Table 3 indicates that unlike low group, the high group subjects could take a rest in the time of rest, got some knacks of their own, and tried the knack. The high group subjects answered I felt that in the task, that is, brain is made to the fact that has been activated. Switching of thinking that is rest when it should rest and activating the brain to try knack may be related to skill learning.

Finally, it seems that there is a stage in the learning level and those skilled consciously perform a task. The result of NIRS in the high group and the low groups suggests the following that as learner got skills while consciously doing tasks and learning the work, the brain is activated while repeatedly increasing and decreasing. However it has been reported preceded by the research that decreasing task-related brain activity over repeated functional MRI scans and sessions (Bradley and Erin, 2009). In this study, the decreasing trend was observed in the high group, comparison of the first day and the second day and comparison of the first day and the last day. Conversely the decreasing trend was not observed in the low group probably because learning degree was small. The results indicate that low group in this experiment is developing, and can be considered a further proficiency is expected. In addition, high group is developing as well as low group because not in the last day but in the second day subjects achieved the most continuously throwing balls.

Table 3: Questionnaire after the end of the experiments.

Subject (Level)	1st day	2nd day	3rd day
A (High)	6(felt uneasy with markers, Looked for trick)	1,3,(was aware of rhythm),4	1,6,(tried trick)
B (High)	1,6,(heard class sounds)	1,3,(was aware of rhythm) 4,6,(heard class sounds)	1,6,(tried trick)
C (High)	1,6,(was about to be off markers)	1,6,(was about to be off markers)	
D (Low)	1,6,(was aware of not moving head)	1	-
E (Low)	6,(not understood how to throw two balls by one hand)	6,(not understood how to do task, got used to experiments)	-
F (Low)	1,	1	1,3,(was aware of throwing position)
G (High)	1,	1,6,(forgot direction of rotation, was about to be off markers)	1
H (Low)	6,(confused and laughed)	6,(forgot procedure of experiment, suddenly started to laugh)	6,(muttering)

5. CONCLUSION

This study aims to examine learning relation between work skill and brain activity by means of motion capture systemand NIRS.

In conclusion, it is obtained that the gradient of the linear approximation for the amount of Oxy-Hb concentration change, that is, brain activity is increased then gradually decreased as participants are determined to improve work skill (juggling) due to increasing continuous throwing times and regularly arm movement. Moreover it is found that the brains of high group (skilled subjects) are more activated than low group in the task. Activating the brain to try knack may be related to skill learning. However the results indicate that high and low group in this experiment is developing, and can be considered a further proficiency is expected.

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