Analysis of Electromyography and Skin Conductance Response During Rubber Hand Illusion

Takuma Tsuji[1] and Hiroshi Yamakawa[1], Atsushi Yamashita[1], Kaoru Takakusaki[1,2], Takaki Maeda[3], Motoichiro Kato[3], Hiroyuki Oka[4] and Hajime Asama[1]

***Abstract*— Recently, the rubber hand illusion (RHI), which is one of phenomena that the sense of ownership is extended to the objects over the external area, attracts much attention to explain the brain mechanism of self body recognition of human. However, most previous research have only focused on the conditions for the occurrence of the RHI. In this study, we measured the electromyography (EMG) of the arm and the skin conductance response (SCR) of the end of the finger when the strong blow with a hammer would be given to the fake hand in order to examine whether the RHI is in fact occurred to the subject at a certain time during the experiment. As a result, we showed that the measurement of the EMG could satisfy above requirement and it is implied that the measurement of EMG gets closer to the tendency of introspection report than that of SCR.**

I. INTRODUCTION

Recently, as the technology develops, so research about virtual reality or haptic devices attract much attention. In order to generalize these mixed reality systems into our daily life in the future, it is important and necessary to design a better interface to objects. To solve this problem, studies of modelizing human brain or body function from the engineered approach are done widely today. For example, in the series of the study of the Mobiligence[1], which was conducted from 2005 to 2009, modelizing of adaptive behavior ability of creatures was tried by applying the knowledge of neurophysiology and the technology of robotics so as to explain the generating mechanism of that creature's ability. However, the brain mechanism of self body recognition, especially that of human, remains undeveloped although various studies have been done[2].

In the field of body recognition of human, recognition of self body is classified into the sense of ownership (SOO), which Jeannerod wrote in his paper[3]. This is like a kind of feeling that "This hand which I see is mine." and it is reported that the SOO is generated by connecting and processing multi-body information in the brain simultaneously, such as a sense of vision or that of touch[4]. To explain this mechanism of the brain, many research about the rubber hand illusion (RHI), which is one of phenomena that the SOO is extended to the objects over the external area, are conducted in recent years[5].

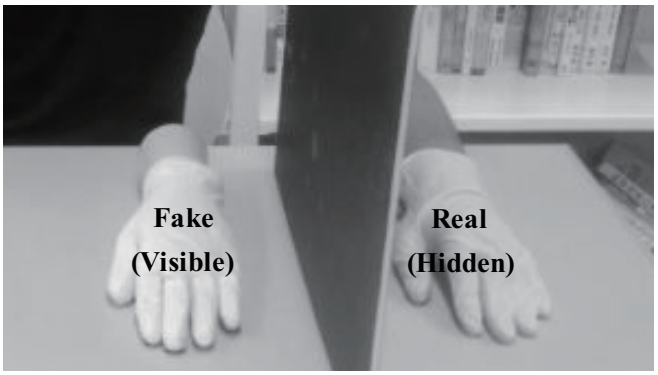

Fig. 1. Experimental condition for the fundamental RHI experiment. There is a wall between two hands. The left hand in the figure is fake, which is visible from the subject, and the right one is real, which is hidden from the subject.

This is an illusion that a tactile stimulus is perceived onto a rubber (fake) hand gradually which is put in front of a subject as Fig. 1. shows, and it is induced by giving temporally and spatially synchronized stimuli to both one's own hand, which is hidden from the subject's sight, and the rubber hand with two paintbrushes for a constant time (about 2-20 minutes)[6]. Since this was published in Nature by Botovinick and Cohen in 1998, a number of additional tests or more detailed experiments have been done by many researchers, and today in many papers it is indicated that the similarities of both hands and the synchronism of stimuli have a great importance for the occurrence of the RHI[7][8][9]. However, most previous research have only focused on the understanding of the conditions for the occurrence of the RHI, and have lacked a perspective of its modelization.

Then in this paper, we propose a new method which can examine whether the RHI is in fact occurred at a certain time during the experiment and would like to figure out the mechanism of the generation of the SOO extension over the external area. This paper consists of six chapters and is organized as follows: in the second chapter, we share the previous research of this field, especially about the RHI, and explain the purposes and the outline of this study. Then, the third chapter describes the method for the measurement in

[1]T. Tsuji, H. Yamakawa, A. Yamashita, K. Takakusaki and H.Asama are wiith Department of Precision Engineering, School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan tsuji@robot.t.u-tokyo.ac.jp

[2]K. Takakusaki is with Department of Physiology, Devision of Neural Function, Asahikawa Medical University, 2-1 Midorigaoka-Higashi, Asahikawa, Hokkaido 078-8510, Japan

[3]T. Maeda and M. Kato are with Department of Neuropsychatry, School of Medicine, Keio University, 35 Shinanomachi, Shinjuku-ku, Tokyo 160-8582, Japan

[4]H. Oka is with Department of Joint Disease Research, 22nd Century Medical and Reseach Center, Graduate School of Medicine, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

detail. In the next chapter, we share the results of the proposal method. The fifth chapter shows the discussion about the results. We state the conclusions of this study and mention future works in the final chapter.

II. Previous Research About RHI and Approach of This Study

In this chapter, we explain at first the outline of major methods to evaluate the RHI occurrence, which were proposed in the previous research. Then, we clear up the difficulties of these traditional methods and propose the new methods to satisfy the difficulties.

A. Methods to Evaluate RHI Occurrence

The major methods to evaluate the RHI occurrence are introspection report with several questionnaires, measurement of the position drift and measurement of the skin conductance response (SCR). Each outline is shown below.

In introspection report, it is major to answer several questionnaires, such as "It seems as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand touched", with seven-point scale (7: Strongly agree - 1: Strongly disagree) after the experiment.

In measurement of the position drift of the hand, the distance between the positions of own hand that were answered by the subject before and after the experiment, is measured, and it is shown that an own hand is perceived nearer the rubber hand than the true position if the RHI is occurred to the subject[10][11].

In measurement of SCR, the mental sweating, which is caused by the emotion of fear, anxiousness or like that, of a real hand is measured when a stimulus, such as a finger of the rubber hand is reflexed forcibly, is given only to the rubber hand. If the RHI is occurred, the mental sweating occurs to the subject and the value of SCR is elevated significantly because of fear or anxiousness to the stimulus to the fake hand as if the stimulus were in fact given to the real hand[12][13].

Also, it is reported in the study with the measurement of the electroencephalogram (EEG) that the occurrence of the RHI has a strong correlation with gamma wave in the parietal lobe of the cerebral cortex[14][15].

B. Methods Based on Measurement of Electromyography

In the understanding of the brain mechanism of the RHI, it is thinkable that the measurement of the occurrence time of the RHI is very important. Therefore the method which can examine whether the RHI is in fact occurred to the subject at a certain time during the experiment is needed. That is because if we know how long time is taken until the RHI is occurred accurately, we can examine the conditions for the RHI occurrence in shorter time, and it is hoped that we will be able to presume various activities in the brain until the RHI is occurred.

However, in the traditional methods described previously, both introspection report and measurement of the position drift can be conducted only after the experiment, so they do not satisfy the requirement stated above, measure the occurrence time of the RHI. Also, it is possible that these methods tend to be more or less depended on the subjective view of each subject, so there would be large differences in evaluations among subjects. In this point, measurement of SCR can examine whether the RHI is occurred at a certain time during the experiment by changing the timing of giving a stimulus, and is also thought of as a method which does not tend to be depended on the subjective view of a subject. However, it is generally said that the amount of sweating is very different with each person, so it is extremely difficult to define the change of the potential clearly, which is the sign of the occurrence of the RHI.

Then in this study, we focus on the physiological indices which can be measured at a certain time during the experiment like SCR. In particular, we aim at the electromyography (EMG) which is superior in the point of instancy from the stimulus to the reaction. Also, the change of EMG is much clearer than that of SCR, so it is thinkable as the method which can examine the occurrence of the RHI objectively. We share the concept of the new method based on the measurement of EMG as follows.

It is reported in many previous studies that the subject pulls or stiffens an own hand when the experimenter will hit the fake hand strongly with something like a hammer because the subject cognizes the fake hand as the real hand potently. Then, we try to measure the tone of the muscle which is used when the subject pulls or stiffens a hand when the experimenter will hit the fake hand strongly, from EMG. We enable a detection of the action, such as pull or stiffen an own hand, by measuring the change of EMG in a quantitative way and make a new method to evaluate the occurrence of the RHI.

III. Method for Measurement

In this chapter, we explain the method for the measurement of the physiological indices of this study in detail. In this study, in order to examine whether the proposal method satisfies the previous requirement and to provide a comparison with other methods, we also conduct introspection report and measurement of SCR. Measurement method, flow of the signal processes of EMG and SCR and floe of the experiment are as follows.

A. Measurement Method for EMG and SCR

The measurement region of EMG is the flexor carpi radials. It is a muscle which supports elbow-bending and it is suitable for the measurement because an elbow is bended surely when a subject pulls a hand in the experiment. Also, only the left hand is used in this method because of a report that there is no influence in the difference of a subject's dominant hand[16]. The derivation method of EMG is bipolar derivation and the distance between two electrodes is 20mm. The electrode of the flexor carpi radialis is set on the 10mm lower of an elbow.

Then, the measurement region of SCR is the end of the right finger, which is known as the mental sweating

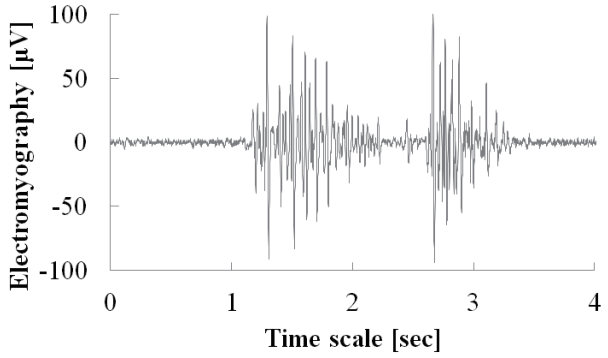

Fig. 2. Example of the result of flexor carpi radials muscle electromyography (EMG). Vertical axis indicates the potential of EMG and horizontal axis indicates the time scale.

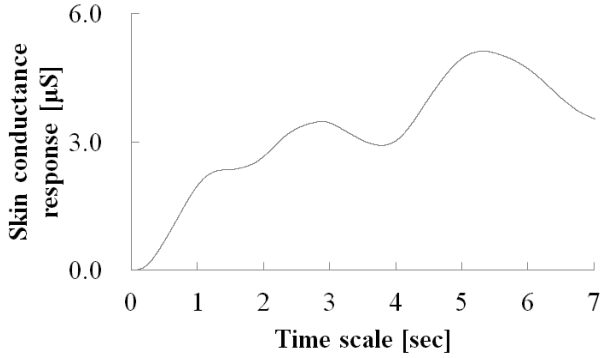

Fig. 3. Example of the result of skin conductance response (SCR). Vertical axis indicates the potential of the skin conductance level and horizontal axis indicates the time scale.

region, because the right hand does not interfere with this experiment. The derivation method of SCR is electrization and two electrodes are set on the each end of the first finger and the middle finger.

B. Signal Processes of EMG and SCR

In the measurement of EMG and SCR, it is natural that the signal processes are done because the noises from home electrical appliance or like that in the experiment room interfere with the important signal which is needed in the analysis. The process of EMG and SCR of this study are as follows.

First, we explain the flow of the signal processes of EMG. An example of the result of EMG measurement is shown in Fig. 2. It is a part of the result when the subject pulls a hand, and the line in the figure shows the potential of EMG without any processes. At beginning, in order to decrease the noises stated above, band-pass filter of 10-500Hz and HUM filter, which decreases the power-supply noise are set. Then, after commutating the signal, we define the potential gotten at the time of t as $e_e(t)$ and if the value of $e_e(t)$ satisfies the following formula, we regard this as the change of EMG.

$$e_e(t) > \alpha \cdot \sum_{t=0}^{t_{blow}} e_e(t)/t_{blow} \tag{1}$$

In the formula, t_{blow} indicates the potential when the strong blow is given to the fake hand. Meanwhile, this formula shows that if the potential of EMG at the time of the strong blow is α times as high as the average potential before the time of blow, that is defined as the change of EMG.

Next, we explain the flow of the signal processes of SCR. An example of the result of SCR measurement is shown in Fig. 3. It is a part of the result and the line in the figure shows the potential of SCR without any processes. At beginning, the low-pass filter of 20Hz is set and we define the potential gotten at the time of t as $e_s(t)$. The value of SCR often changes easily because of temperature of the experiment room and others, so the amount of increase in the potential of SCR is compared and it is defined as the following formula.

$$\Delta e_s(t) = \max e_s(t) - \sum_{t=t_{blow}-\beta}^{t_{blow}} e_s(t)/t_{blow} \tag{2}$$

However, as the potential of SCR changes for a few seconds gradually around the time of the strong blow, so the normative potential of SCR before the blow is defined the average potential of SCR during β seconds before the blow and the potential of SCR after the blow, which is compared with the normative potential, is defined the maximum potential of SCR during 5 seconds after the blow.

C. Outline of Experiment Conditions

Overview of the proposal method is shown in Fig. 4. A subject sits on the chair which is put at the front side of the table and an experimenter stands in the other side. Subject's own hand is set at the left side of the wall on the table and a fake one is set at the right side, and a subject cannot see an own hand directly. The experiments is conducted when the RHI is occurred to the subject after the experimenter gives stimuli to both the real hand and the fake one with two paintbrushes synchronously while a subject concentrates the vision into the fake hand. Also, white noise is given to a subject during the experiment through a headphone to cut off surrounding noises.

D. Flow of Experiment

First of all, the subject confirmed that the fake hand is not an own hand before the experiment. Then EMG and SCR are measured when a subject observes a strong blow only to the rubber hand with a hammer.

Next, after synchronous stimuli are given to both the real hand and the fake hand with two paintbrushes by an experimenter for 10minutes, EMG and SCR are measured when a strong blow is given only to the fake hand with a hammer. Also, the experimenter gives the stimuli at about 1Hz by using a metronome and the stimuli are given to the whole back of the hand.

Finally, after above experiment, the subject answers introspection report composed of nine questionnaires, which

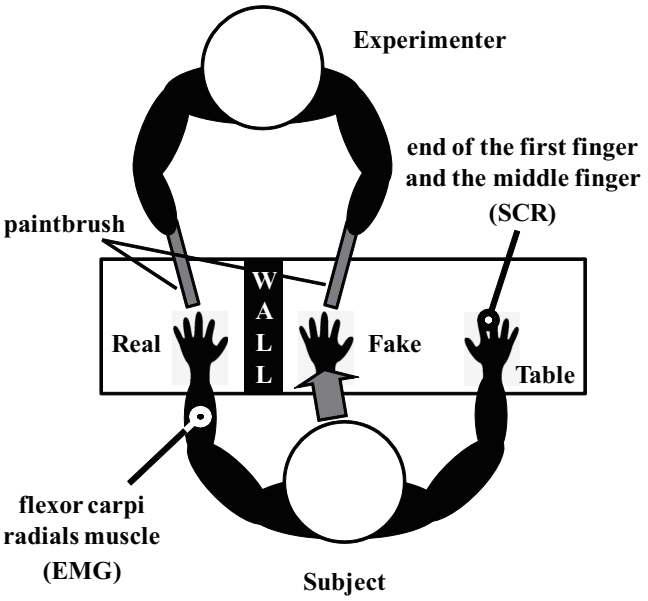

Fig. 4. Overview of the RHI experiment. A subject sits in the front side of the table and an experimenter stands in the other side. Subject's own hand is set at the left side of the wall, and a fake one is set at the right side of the wall, and a subject cannot see an own hand directly because of the wall. The experimenter gives stimuli to both the real hand and the fake one synchronously with two paintbrushes. Also, white marker shows flexor carpi radials muscle.

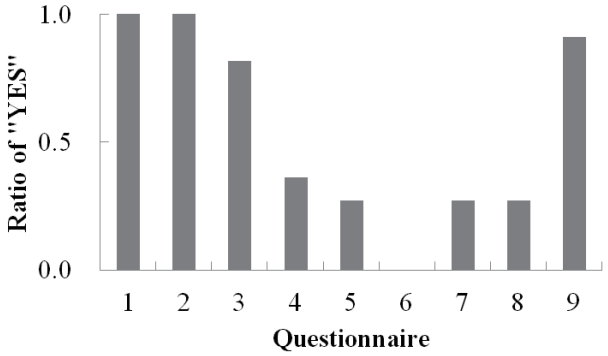

Fig. 5. Result of introspection report of all the subjects. Vertical axis indicates the ratio of subjects who answered yes at each question. Each questionnaire is shown in Table 1.

TABLE I
QUESTIONNAIRES OF INTROSPECTION REPORT

1.	It seems as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand touched.
2.	It seemed as though the touch I felt was caused by the paintbrush touching the rubber hand.
3.	I felt as if the rubber hand were my hand.
4.	It seemed as if my (real) hand were drifting towards the right (toward the rubber hand).
5.	It seemed as if I might have more than one hand or arm.
6.	It seemed as if the touch I was feeling came from somewhere between my own hand and the rubber hand.
7.	I felt as if my (real) hand were turning "rubbery".
8.	It appeared (visually) as if the rubber hand were drifting towards the left (towards my hand).
9.	The rubber hand began to resemble my own (real) hand, in terms of shape, skin tone, freckles or some other visual feature.

was used in Botovinick & Cohen's experiment, with an alternative decision, yes or no. Each questionnaire is shown in Table 1. Also, each questionnaire was written in Japanese when the experiment was conducted because all the subjects of this experiment were Japanese.

IV. RESULT OF EXPERIMENT

Eleven subjects took part in this experiment (median age : 22.5 ; age range : 20-24 ; 7 males ; 4 females) None of them knew the purpose of this experiment previously. Also, this experiment was received the approval of the ethics committee of Faculty of Medicine, The University of Tokyo and informed consent was received from all the subjects. The result of introspection report, EMG and SCR shown below.

A. Introspection Report

The result of all the subjects is shown in Fig. 5. The feature that high rate of subjects answered yes at the question 1, 2, 3 and 9 is similar to Botovinick & Cohen's experiment or others and it indicates that the RHI was occurred to subjects and this experiment would be reasonable. Also, it could be guessed whether the subject perceived the fake hand as an own hand from the question 3, "I felt as if the rubber hand were my hand", and nine subjects answered "Yes".

B. Measurement of EMG

This time, we defined the value of α as $\alpha = 5.0$ from the experiment. The ratio of blows which caused the change of EMG before or after the synchronous stimuli are given is compared. The result of all the subjects is shown in Fig. 6. It is found that there is no changes of EMG before the synchronous stimuli are given and in contrast, over 80% of blows caused the change of EMG after the synchronous stimuli were given. It would be because the subject pulles a hand to avoid the blow if the RHI is occurred to the subject. Therefore, it is implied that the proposal method can examine whether the RHI is occurred at the certain time during the experiment by changing the timing of giving the blow.

Also, in this experiment, PowerLab, Bio Amp (ADInstrument) is used in the measurement of EMG and the sampling rate was 1,000Hz.

C. Measurement of SCR

This time, we defined the value of β as $\beta = 30$ from the experiment. The amount of increase in the potential of SCR before or after the synchronous stimuli are given is compared. The average of the results of all the subjects is shown in the Fig. 7. The unit of the vertical axis is [S] (1S=1mho=$1\Omega^{-1}$), which is defined by The International System of Units (SI), and error bars in the figure show standard error of the mean (SEM).

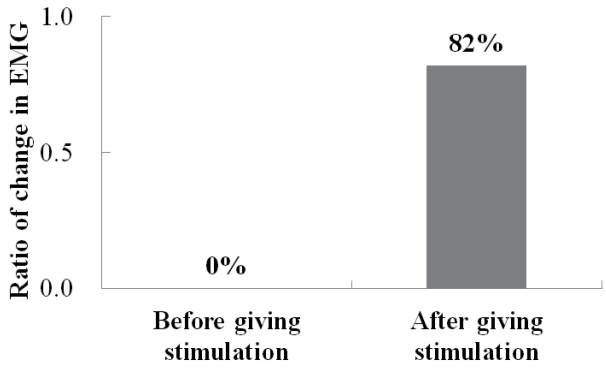

Fig. 6. Result of flexor carpi radials muscle electromypgraphy (EMG) of all the subjects. Vertical axis indicates the ratio of subjects who pulled a hand before or after the experimenter gives synchronized stimuli tp both hands.

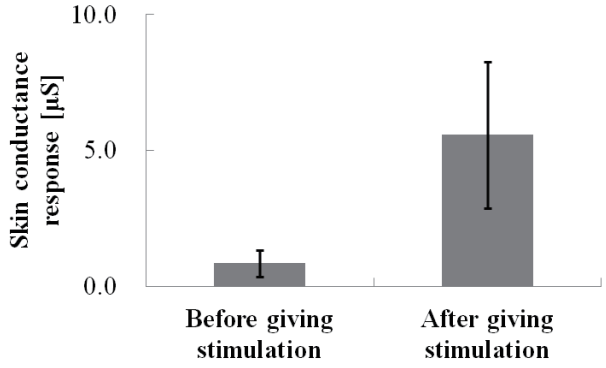

Fig. 7. Result of skin conductance response (SCR) of all the subjects. Vertical axis indicates the amount of increase in SCR when the experimenter hit the fake hand strongly with a hammer. Error bars show standard error of the mean.

$$\Delta e(t) = \max e(t) - \sum_{t=t_{blow}-30}^{t_{blow}} e(t)/t_{blow} \tag{3}$$

The increase in the potential of SCR after the synchronous stimuli are given is 6.6 times as high as before the stimuli are given and it is indicated that the measurement of SCR is reasonable for the method to evaluate the RHI occurrence from this experiment.

Also, in this experiment, PowerLab, Bio Amp (ADInstrument) is used in the measurement of EMG and the sampling rate was 1,000Hz.

V. Disccussion

In this experiment, we attempted to evaluate the RHI occurrence, which is recognition of self body, based on introspection report and measurement of EMG and SCR, and it is indicated that the result from introspection report is depended on subjective view. On the other hand, in the measurement of EMG and SCR, it is thinkable that the result is not depended on subjective view, so it is difficult to know whether the result is same as subject's feeling. For example, it is possible that the subject cognizes the fake hand as an own, but the result from the measurement of EMG or SCR does not reflect that. If the results of each methods are different, it is dubious that one of them is the reasonable method to evaluate the RHI occurrence.

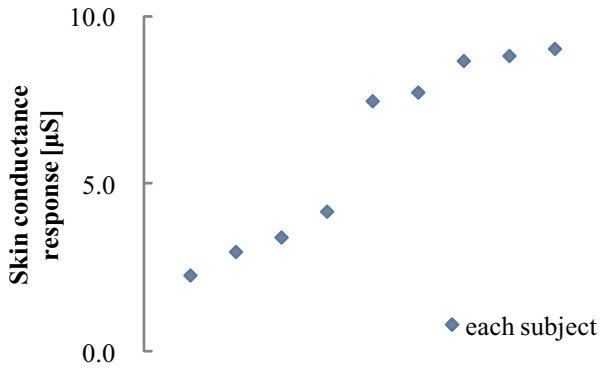

Fig. 8. Increase of the SCR potential of all the subjects who answered yes at the questionnaire No. 3 of the introspection report, "I felt as if the rubber hand were my hand". Vertical axis indicates the amount of increase in SCR.

Therefore, we discuss about it by examining whether the change of EMG was occurred or the mental sweating was elevated when the strong blow was given, among nine subjects who answered yes at the question 3 of introspection report, "I felt as if the rubber hand were my hand", which is assumed to be shown the objective recognition of self body.

However, as previously stated, it is difficult to define the change of the potential clearly because the amount of sweating is very different with each person. Then we compared the results of all the subjects as shown in Fig. 8, and it was found that the values of the increase of the potential of each subject were polarized. Therefore we defined the elevation of the mental sweating as the increase in the potential of SCR was over $5.0\mu S$.

The ratio of subjects who pulled a hand or elevated SCR among nine subjects who answered "Yes" at the questionnaire 3 is shown in Fig. 9 Then it is found that 78% of subjects pulled a hand and 56% of subjects elevated SCL. Therefore, it is implied that the measurement of EMG gets closer to the same tendency of introspection report, which is assumed to be objective recognition of self body, than that of SCR.

Also, considering the time from the stimulus to the response of the experiment, EMG could be measured almost instantaneously, and on the other hand, it took a few or more seconds to measure SCR, so it is indicated that the method of EMG measurement has an advantage in instancy. In addition, the change of the potential of EMG is obviously and on the other hand, that of SCL is not so because there are differences among individuals.

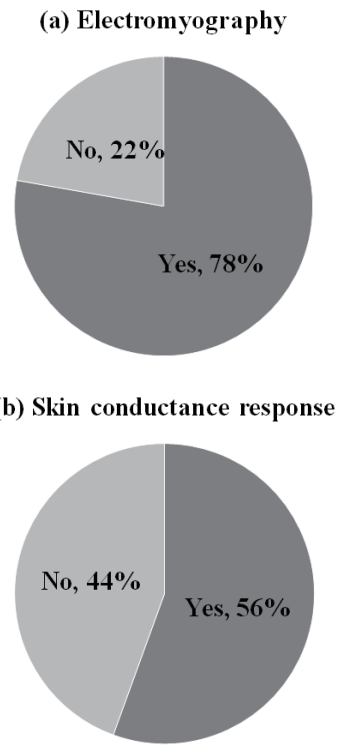

Fig. 9. Ratio of subjects (a) who pulled a hand in carpi radials muscle EMG experiment and (b) who elevated SCL in SCR experiment, among nine subjects who answered yes at the questionnaire No. 3 of the introspection report, "I felt as if the rubber hand were my hand". Dark gray area shows the ratio of subjects who pulled a hand or elevated SCL, and bright gray one shows the ratio of subjects who did not.

VI. Conclusion

In this paper, we proposed the new method which can examine whether the RHI is in fact occurred to the subject at a certain time during the experiment, based on the measurement of EMG when the blow with the hammer is given to the fake hand. This method does not impose any tasks on the subject, so does not tend to be depended on the subjective view. Also, this method is more superior in the point of instancy for the measurement.

In addition, we compared the results from introspection report, the measurement of EMG and that of SCR, and showed that the measurement of EMG gets closer to the same tendency of the result of introspection report than that of SCR.

On the other hand, one of the future works of this study is to explain the difference or the relationship between the RHI and the mirror system. The mirror system is known as the phenomenon that when the man only observes the action of others, the certain activity in the brain is induced as if the man is behaving that action in fact[17]. From this point, it is thinkable that illusion of the RHI is very similar to the mirror system, however, so far the relationship or the difference between the both the RHI and the mirror system has not been clear.

As stated in the first chapter, the study of brain mechanism in the SOO gets much attention from not only the field of engineering but also of medical study, psychology, philosophy and others today, and is suited for wide application. The future work of this study is to modelize the brain mechanism of the RHI continuously and we would like to contribute to the explanation of the human brain mechanism of recognition of self body.

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