A STUDY OF INFORMATION PROCESSING IN THE BRAINS OF PLAYERS DURING PLAYING THE *HYAKUNIN-ISSHU KARUTA* GAME

Shoichi TAKEDA [*a], Yu HASEGAWA[b], Yoshiyuki HIRAI[a], Kazunori KOSUGI[a], Tsutomu TSUKUI[c] and Seiichi YAMAMOTO[d]

[a] *Faculty of Biology-Oriented Science and Technology, Kinki University, Japan*
[b] *Graduate School of Biology-Oriented Science and Technology, Kinki University, Japan*
[c] *All-Japan Karuta Association, Japan*
[d] *Department of Information Systems Design, Doshisha University, Japan*

ABSTRACT

This paper describes an experiment using an optical functional brain imaging (fNIRS) aiming at clarifying information processing in the brains of players during playing the *Hyakunin-Isshu karuta* game (traditional Japanese playing cards). We measure oxidized hemoglobin (oxy-Hb) in the prefrontal cortex, which is responsible for the most important information processing to produce tactics for winning, at 22 measuring points using 8 optical detectors. The experimental results for 4 players show the following. (1) One of the characteristics common to all the players is that a peak of the oxy-Hb is observed in every cycle of one-unit game of taking one card (one poem-reading unit). This cycle corresponds to the cycle of "tense → maximum tense → relax" in the mind of the players. (2) Oxy-Hb values in the front parts of the prefrontal cortex are greater than those in the back parts of the prefrontal cortex and are sustained until the end of the game. This suggests that various high-degree thinking continues all through the game. (3) The results of investigation for one top-grade player about brain activities depending on situations show that there are significant differences in many parts between when the player has taken the *karuta* (card) and when there is no target *karuta*. (4) The major reason for this significant increase in oxy-Hb values when the player has taken the *karuta* may be the production of high-degree tactics in the prefrontal cortex.

Keywords: *Hyakunin-Isshu karuta game, brain, prefrontal cortex, optical functional brain imaging, oxidized hemoglobin*

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[*] **Corresponding author**: 930 Nishi-Mitani, Kinokawa-shi, Wakayama 649-6493, JAPAN, takeda@gakushikai.jp

1. INTRODUCTION

As brain-function-measurement equipment and technology advance, research on the human brain is prevailing not only in the field of medical treatment, but also in many other fields. Such fields include research on exploring how the brain responds to various visual and auditory stimuli and processes information obtained from these stimuli, and, very recently, research on a BMI (Brain-Machine Interface) or a BCI (Brain-Computer Interface), through which the human brain controls an artificial arm or a computer [1].

We have also been working on the brain responses to various visual and auditory stimuli, aiming at exploring *kansei* information, mainly using an EEG. Several such examples are research on extraction of EEG components that relates to impression of color pattern [2], on brain responses to chords of synthetic piano tones [3], on brain responses while beat tracking [4], etc.

The EEG measurements mentioned above have been conducted mostly in situations that the subjects receive visual or auditory stimuli passively without or with slight body movements. In the case that a subject acts with body movements, however, it has been difficult to measure correct EEG due to artifacts such as ECG noises. We had to substitute finger tapping for clapping even in the case of beat-tracking experiment to avoid artifacts. EEG is therefore not a suitable means for measuring brain activities with body movements.

If a measurement of brain responses becomes possible in a situation that human intelligence, *kansei*, exercise, etc. are systematically activated including body movements, we will find a way to clarify the essence of human high-degree spiritual activities such as fine art, sports, etc. Our goal of study is to clarify such essence in terms of *kansei*. As our concrete research themes on *kansei*, we have selected several themes such as brain responses to musical activities, brain responses to emotions or emotional speech, etc.

To arrive at the goal of our research in deeper domains, we have come to use an optical functional brain imaging (henceforth called "fNIRS"), which can produce robust data against artifacts, instead of an EEG. Here, "fNIRS" is an abbreviation of "Near-Infrared Spectroscopy". Among such research, this paper describes experimental results on information processing in the brains of players during playing the *Hyakunin-Isshu karuta* game.

The *Hyakunin-Isshu karuta* game is a traditional Japanese card game, which is a kind of sports, played on Japanese mats called "*tatami*". In this game, cards called "*karuta*" are used on which the poems of the *Hyakunin-Isshu*, a collection of 100 famous ancient Japanese poems of 31 syllables each, called "*tanka*", are written. Two players sit down on *tatami*, facing each other, and play the game. The players select at random each 25 cards from 100 cards, and place the 25 cards on each player's field on *tatami* as they like. Another person called a "reciter" reads aloud a *tanka*-poem written on one of another set of the 100 cards. If there is a card on which the latter phrase (the latter fourteen syllables) of the same poem read by the reciter is written on either of the two players' fields, they have to get this card faster than the counterpart. If one player touches this card faster than the counterpart, he/she gets this card. If all the cards have been cleared on the one player's field, he/she wins. If all the cards on the counterpart's field have been cleared, on the other hand, the counterpart wins.

The *Hyakunin-Isshu karuta* game is a kind of sports whose player must make full use of "spirit, techniques, and physical strength", which will be explained in the following section. In other words, a player cannot win the game without any of sharp vision and auditory sense, capability of recognizing the target-card to take instantaneously, excellent memory, quick body movements, capability of producing high-degree tactics by organizing these excellent capabilities, capability of enduring extremely tense state for a long time, etc. The *Hyakunin-Isshu karuta* game is therefore a good example of human activities that demands high-degree information processing in the brain with body movements.

Works relating to the *Hyakunin-Isshu karuta* game are few. Among such works, Toshima compared the brain activities between the *Hyakunin-Isshu karuta* players and non-*karuta* players using ERP and fNIRS in combination [5]. The task used in this study, however, was not a *Hyakunin-Isshu karuta* game.

We conducted experiments using an fNIRS to examine how the player's brain was working during the game. In this experiment, we obtained data for only one player and its analysis remained only qualitative [6].

We have further continued experiments by adding the number of players to four and conducted quantitative analysis in detail. This paper reports analysis results of this experiment.

2. INFORMATION PROCESSING IN THE BRAIN DURING PLAYING THE *HYAKUNIN-ISSHU KARUTA* GAME

It is said that the most important things are "spirit, techniques, and physical strength" (henceforth, called "STP") to win a *Hyakunin-Isshu karuta* game. Every player first begins with "techniques". When he or she has learned that he/she cannot advance without successive winning, he/she then knows that "physical strength" is necessary. He/She finally knows that "spirit" determines the winning of the game [7].

Figure 1 shows an example of hypothesized information processing in the brain of a *karuta* player during one-unit game of taking one *karuta* (one poem-reading unit) in the case that the player gets a *karuta*. One-unit game begins with the start of reciting the latter phrase of the immediately previous *karuta*. Exactly after one-second pause following the end of the voice of the latter phrase, the reciter begins to recite the former phrase (the former 17 syllables) of the following *karuta* appearing at random. As a rule of reciting Japanese-*tanka*-poems, this pause-length must be constant all through the game, because if the pause duration values disperse, the player will find it difficult to predict the *karuta* to take quickly.

The *karuta* player begins to tense when the reciter begins to recite the latter phrase, and the player's tense is assumed to reach maximum around the moment when the reader begins to recite the following former phrase. Then, based on the auditory cue of the reader's voice, the player recognizes the target *karuta* to take quickly. As soon as the player determines the target *karuta*, his/her hand begins to move toward the target *karuta* and his/her finger touches it, and finally at this moment he is released from the tense.

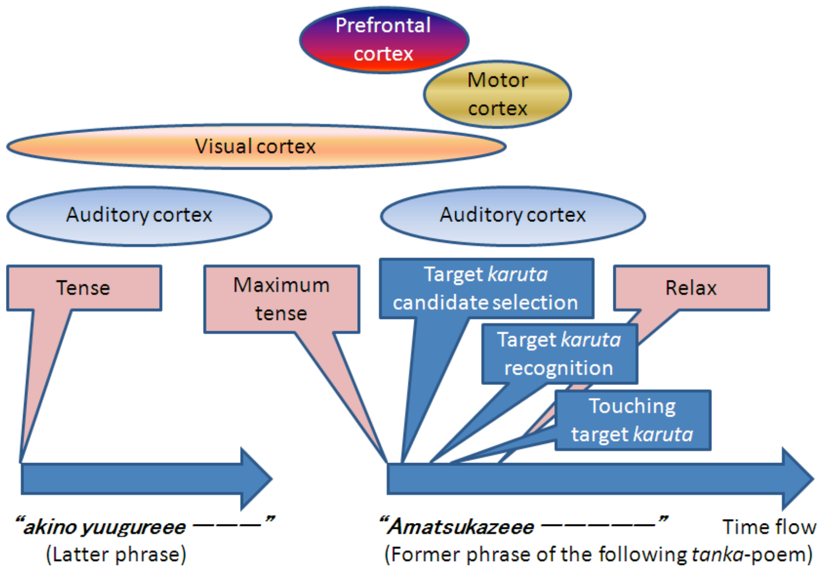

Figure 1: Hypothesized information processing in the brain (case of getting a *karuta*)

In order to realize the above actions, the brain of the player is assumed to be activated in the following order. Firstly, the visual cortex is activated while the player is watching the *karutas*, and as soon as the reciter begins to recite a latter phrase, the auditory cortex begins to be activated. After the end of the latter phrase, the activity of the auditory cortex temporarily stops during the one-second pause, and then as soon as the reciter begins to recite the following former phrase, this area begins to be reactivated. This pause period is the most important period that influences winning or defeat of the game. During this period, the brain of the player is assumed to instantly process high-grade information such as planning and applying tactics.

If we express the above-mentioned STP as functions of the brain, visual and auditory information processing, production of high-degree tactics and judgment in the prefrontal cortex, and motor control in the pre-motor cortex are all the functions of the "spirit", and the suitable combination of these functions is thought to yield "techniques". Furthermore, the function of pre-motor cortex that commands the movement of the arm and hand can be related to "physical strength", and listening to the reciter's voice with one's ears and watching the field with one's eyes correspond to the reception of visual and auditory information, so it can also be related to "physical strength".

3. MEASUREMENT OF INFORMATION PROCESSING IN THE BRAIN BY FNIRS

3.1. Overview of Experimental Method

Since players move their bodies largely in the *Hyakunin-Isshu karuta* game, we measured brain activities using an fNIRS that was robust against artifacts (noises) caused by their body movements. In this experiment, we used an optical topography system called ETG-4000 made by Hitachi Medical Corporation equipped in Doshisha University.

The brain activity is characterized by the firing of neurons. This results in active energy metabolism and causes secondary increase in blood volume to supply glucose and oxygen to the tissues. Thus, change in concentration of hemoglobin is an important index to know the brain activity. Two kinds of hemoglobin concentration, i.e., oxidized hemoglobin (oxy-Hb) and deoxidized hemoglobin (deoxy-Hb) were observed through this system [8].

3.2. Procedure for Experiment

3.2.1. Measuring Points

Since the fNIRS used in this experiment has 8 optical detectors that can measure at most 24 points, only a portion of the brain can be measured simultaneously. In this experiment, we therefore measured only prefrontal cortex that was responsible for the most important information processing to produce tactics for winning.

Figure 2 shows the status of fitting the probes to the head of a subject and the location of the measuring points as channel numbers. In this case, the auditory cortex, which is located around the temporal area, is out of the region of measurement. In this experiment, we therefore measure the activities only in the prefrontal cortex. The pre-motor cortex is also assumed to be included in the region of measurement.

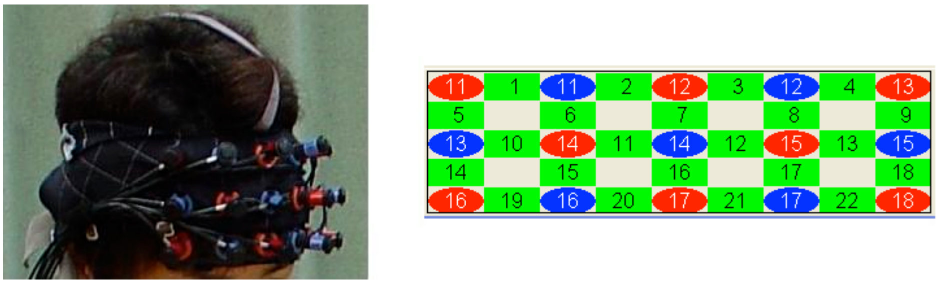

Figure 2: Positions of probes (left) and channel allocation (right)

Red ovals denote positions of illuminators, blue ovals denote positions of detectors, and green rectangles denote measuring points and the numbers inside the rectangles denote channel numbers. This allocation is a view from the subject and the upside corresponds to the forward of the subject's brain.

3.2.2. Subjects and a Reciter

Four subjects participated in this experiment: two A-class (highest-rank class) players A1 and A2 and two C-class (third-highest-rank class) players C1 and C2. An A-class authorized reciter HT recited *tanka*-poems. Each subject and his/her counterpart played one match, so in total measurements were conducted during four-match games.

3.2.3. Method of the Game in Experiment

Although the fNIRS is robust for electronic artifacts, it can be sensitive for blood flow caused by body movements. To avoid artifacts and movements of the probes due to the body movements, *karutas* were arranged on a table instead of Japanese-*tatami*-mat and the players sat on the chairs and asked not to move largely during the game. The probes were fitted to a player's head. The other player did not wear the probes since there was only one set of probes. All the games were recorded by a fixed video camera.

A series of tasks from No.1 to No.3 described below were executed until the end of a match. During this execution, oxy-Hb, deoxy-Hb, etc. were measured.

1. A signal of beginning of recitation – beginning of recitation and start of measurement

   Measurement starts at the beginning of reciting the latter phrase of the *tanka*-poem whose former phrase the reciter has just finished reading.

2. A signal of marking the following former phrase – marking of beginning

   Marking is done at the beginning of the following former phrase. The reciter recites the former phrase and the subject or the counterpart gets a *karuta*.

3. Players wait for about 15 seconds after the end of reciting the former phrase.

   Players finish rearranging the *karuta* and prepare for the next game during this period. This period is also a time for resting their brains.

4. EXPERIMENTAL RESULTS

4.1. Characteristics All through the Games

In this section, we discuss the tendencies of oxy-Hb values for the 4 subjects all through the match. Figure 3 left shows time-varying contours of oxy-Hb and deoxy-Hb values all through one match for subject A1 (the first match) and Fig. 3 right shows those for subject A2 (the third match). Both subjects were A-class players.

From the figure, we knew that the contour of oxy-Hb in each channel was subject-dependent. One of the characteristics common to all the players was that a peak of the oxy-Hb was observed in every cycle of one-unit game of taking one card (one poem-reading unit). This cycle corresponded to the cycle of "tense → maximum tense → relax" in the mind of the players, which might be interpreted that the player's tense was at a maximum around

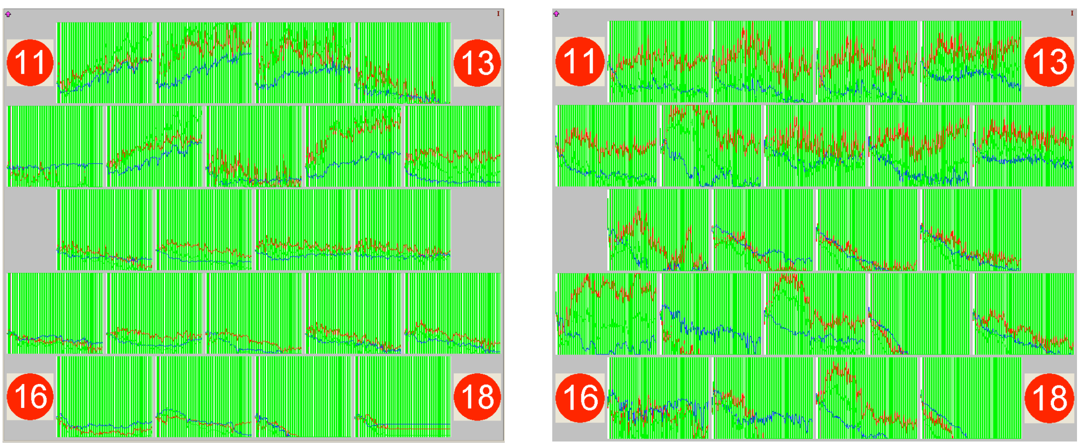

Figure 3: Contours of oxy-Hb (red curves) and deoxy-Hb (blue curves) all through the match (left: subject A1, measuring time 21 min, and right: subject A2, measuring time 23 min)

the peak of oxy-Hb. This characteristic was consistent with the past experimental result [6]. Another characteristic common to subjects A1 and A2 was that oxy-Hb values in the front parts of the prefrontal cortex were greater than those in the back parts of the prefrontal cortex and were sustained until the end of the game. This suggests that various high-degree thinking continued all through the match. On the other hand, oxy-Hb values tended to decrease in many back parts of the prefrontal cortex as the game progressed. This tendency suggests that motor controllability decreased due to fatigue caused by repeated body movements. However, this tendency was not observed in some parts for some players, which might be caused by the factors such as difference in progress of games, difference in players, etc.

The tendencies of oxy-Hb in the front part of the prefrontal cortex of the other two subjects (C-class payers) were common to those of the A-class players in that a peak of the oxy-Hb was observed in every cycle of one-unit game of taking one card (figures are omitted).

4.2. Differences in the Brain Activities Depending on Situations

This subsection investigates brain activities for a specific A-class player (A3) by classifying situations into the following three cases: the subject has gained a *karuta* (gained), the counterpart has gained a *karuta* (lost), and there is no target *karuta* (empty).

4.2.1. Oxy-HB in Each Situation

As described in the previous subsection, oxy-Hb values in one match were different depending on the part of the brain. Figure 4 shows several examples of mean values and standard deviations of the peak values of oxy-Hb in a cycle from the beginning of reciting a latter phrase to the end of reciting the following former phrase over one match depending on the three situations.

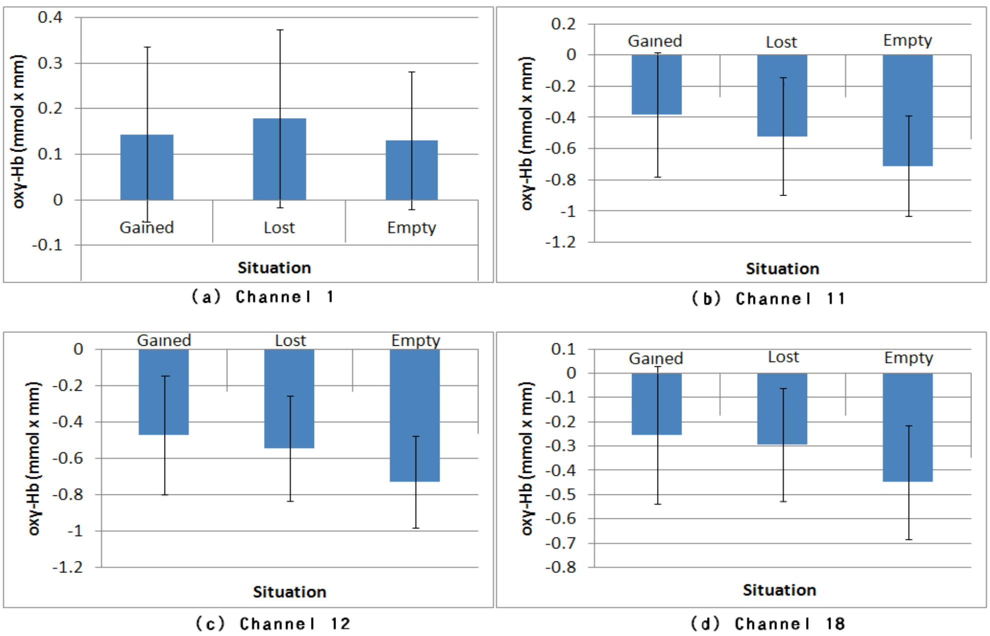

Figure 4: Mean values of oxy-Hb peak values over one match depending on the three situations: “gained”, “lost” and “empty” (examples of subject A2)
In the figure, the lengths of error bars denote standard deviations.

As seen from the figure, although no difference was observed in the mean values of peak oxy-Hb in channel 1, those in the case of "gained" tended to be the greatest and those in the case of "empty" tended to be the smallest in channels 11, 12, and 18. Furthermore, whether there were differences or not between in the cases of "gained" and "lost" was critical in channels 11 and 12.

4.2.2. Statistical Test Results

We therefore conducted Student's *t*-tests to verify whether significant differences were observed or not between different situations. Figure 5 shows the test results.

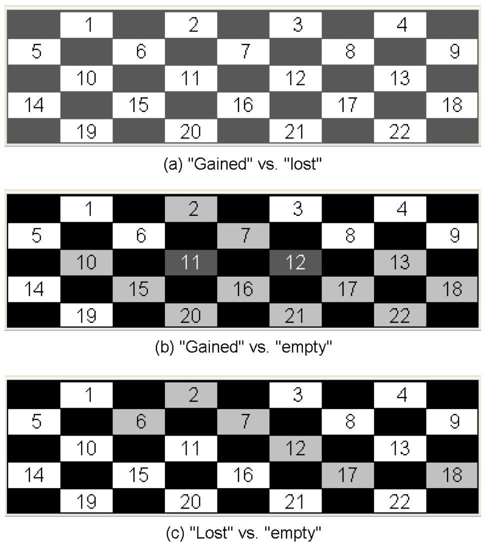

Figure 5: Statistical test results (subject: A2)

Dark-gray channels: significantly different ($p<0.01$), light-gray channels: significantly different ($p<0.05$), white channels: not significantly different.

As seen from the figure, significant differences were observed between in the cases of "gained" and "empty" and between in the cases of "lost" and "empty" in several parts of the prefrontal cortex. Specifically, significant differences were observed in more parts between in the cases of "gained" and "empty" than in the cases of "lost" and "empty". However, no significant difference was observed between in the cases of "gained" and "lost".

Although we cannot discuss definitely since each channel has some dispersion in the observed parts due to differences in the size of subjects' heads, the parts around channels 16, 20, and 21 may correspond to the pre-motor cortex.

As has been discussed in the previous subsection, the reasons for this significant increase in oxy-Hb values when the player had taken the *karuta* might be the production of high-degree tactics in the prefrontal cortex, command of body movements in the pre-motor cortex, etc.

In the case when the counterpart had taken the *karuta*, the situation might be further divided into the following two cases: (1) although the player tried to get the *karuta*, the counterpart had got the *karuta* quicker than the player, and (2) the player had forgotten to remember the target *karuta* and could not find it. The reason why the parts were fewer where there were significant differences between in the case of "lost" and "empty" than between in the case of "gained" and "empty" might be that the data in the case of (2) was included in the data of "lost". That is, in the case of (2), the front part of prefrontal cortex was assumed to be less active.

The reason why the prefrontal cortex was less active when there was no target *karuta*, on the other hand, was assumed to be that less higher-grade information processing was done and the body movements were smaller than in the case that the player or the counterpart had taken the *karuta*.

The above results were consistent with the information processing cycles in the brain as shown in Fig. 1, in which high-degree reception, cognition and processing of auditory information and quick body movements were repeated in the case that a player took a *karuta* during the play. Analysis for other subjects has not yet been done and is left as a future work.

5. CONCLUSIONS

Measurements have been conducted for 4 players using an optical functional brain imaging (fNIRS) aiming at clarifying information processing in the brains of players during playing the *Hyakunin-Isshu karuta* game. The analysis of the measured data has been done and the results have shown the following.

1. One of the characteristics common to all the players has been that a peak of the oxy-Hb values has been observed in every cycle of one-unit game of taking one card (one poem-reading unit). This cycle corresponds to the cycle of "tense → maximum tense → relax" in the mind of the players. Oxy-Hb values in the front parts of the prefrontal cortex have been greater than those in the back parts of the prefrontal cortex and have been sustained until the end of the game. This has suggested that various high-degree thinking continues all through the game.

2. The results of investigation for one A-class (top-grade) player about brain activities depending on situations have shown that there are significant differences ($p<0.01$ or $p<0.05$) in many parts between when the player has taken the karuta and when there is no target karuta. There are also significant differences ($p<0.05$) in several parts such as front parts of the prefrontal cortex between when the counterpart has taken the karuta and when there is no target karuta. There is, however, no significant difference in any parts between when the player has taken the karuta and when the counterpart has taken the karuta. The reasons for this significant increase in oxy-Hb values when the player has taken the karuta may be the production of high-degree tactics in the prefrontal cortex, command of body movements in the pre-motor cortex, etc.

The above results are consistent with the information processing cycles in the brain, in which high-degree reception, cognition and processing of auditory information, and quick body movements are repeated in the case that a player takes a karuta during the play.

The *Hyakunin-Isshu karuta* game is a good example of such activities that human intelligence, *kansei*, exercise, etc. are systematically activated including body movements. Our findings are expected to lead to clarifying the essence of human high-degree spiritual activities such as fine art, sports, etc. Our final goal of study is to clarify such essence in terms of *kansei*.

Future studies will be to continue further analysis of variations of oxy-HB values for other players in details, as well as to conduct measurements in other areas of the brain such as visual cortex, auditory cortex, etc. to clarify information processing in the brain, and furthermore, some other measuring method such ERP should also be introduced.

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