9th International Conference on Music Perception and Cognition
Alma Mater Studiorum University of Bologna, August 22-26 2006

Investigation of brain activation while listening to and playing music using fNIRS

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ABSTRACT
This paper describes our preliminary investigation on musical brain activities using fNIRS. We conducted two sets of experiments on musical activities: 1) a comparison of activities in subjects hearing music but not paying attention to it, listening to music actively, and playing music using an interactive performance interface called iFP, and 2) an investigation of the effect of sound and vibration, and effect of a steering eurhythmics session, featuring a Japanese drum set. We observed decreases in brain activation in the dorsal prefrontal cortex (DPFC) when the subjects listened to their favorite music and when they played music with the use of an interface with which they had been accustomed. The decrease is regarded as indicating an immersive or absorbed sensation. In the second experiment, we observed more brain activation in the DPFC and the temporal cortex while the subjects were beating a genuine Japanese drum compared with while they were beating a toy drum pad. We also obtained data that support the idea that interactive play activates the DPFC.

Keywords
Brain activation measurement, Performance, Listening

INTRODUCTION
A human being listens to and plays music, sometimes to be healed, feel relaxed, or concentrated, and sometimes even to raise morale for battle or religious services. Music has the power to inspire the mind and move the spirit. It is no wonder therefore that there have been plenty of investigations, mainly psychological ones, that have aimed at revealing how music affects people.

Recent studies using PET or fMRI have provided new findings on human brain mappings and functions related to musical activities (Blood et al. 1999, Zatorre et al. 2001, Koelsch et al. 2005). Since 2000, multi-channel fNIRS (functional near-infrared spectroscopy) has been practicable. fNIRS can measure brain activity more handily than PET or fMRI can. This paper introduces our preliminary investigation of measuring musical activities by using fNIRS. We conducted two sets of experiments. One was a study focusing on concentration toward music while subjects used a performance interface, where the difference between hearing music without paying attention to it, listening to music actively, playing music was examined. The other was on eurhythmics using a drum, where the effects of sound and vibration and the instructional session's procedure were investigated. In the following two sections, we describe the difference between hearing, listening to, and playing music and give an overview of fNIRS. After that, we describe the experiments comparing brain activities while subjects heard, listened to, and played music, and the investigations of the effect of "timber and vibration" of drums and eurhythmics session content. Finally, we discuss the possibilities for future studies and the problems of this study.

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ISBN 88-7395-155-4

MUSIC AND INNER EXPERIENCE

Listening, playing, and composing are fundamental activities of music. While there are plenty of studies that deal with any one of these activities, there are few researches that deal with more than two such activities together. This paper attempts to deal with listening, including casual hearing and paying active attention, and playing.

Listening is the most common way of enjoying music, and the sort of listening can be categorized in more detail. For instance, we will use the term "hearing" to refer to a listening manner in which the subject does not pay close attention to the music, i.e., as one might hear background music (BGM) played over supermarket speakers. Furthermore, we will use the terms "listening" and "analyzing" to refer to listeners paying closer attention to music. The difference between "listening" and "analyzing" is that the former is rather passive, whereas the latter is active, as one might try to solve a puzzle or acquire musical knowledge.

Playing music is another typical way of enjoying music. Music is embodied with physical movements. The enjoyment of playing music may be categorized in terms of self-expression, mastery of skills, and collaboration with other performers.

While they are listening to, playing, and even composing music, people feel pleasant; they are happily absorbed or immersed in their activity. Csikszentmihalyi named this sensation "flow" (Csikszentmihalyi 1975), pointing out this common sensation can be obtained in other creative activities and while playing sports and even working. Csikszentmihalyi also pointed out the balance of the capacity of the person concerned and the difficulty level of the problem is the key to him or her being in a "flow" state. Besides being useful from an academic viewpoint, Csikszentmihalyi's "flow" theory also has much influence in the "real world" of business and daily life. However, in order to elucidate flow scientifically, a lot remains to be done. We have to investigate which subsidiary conditions are crucial to get the sensation of flow, and moreover, we have to find objective ways to measure flow besides simply interviewing subjects about their inner experience.

The topic of this paper is related with a search for subsidiary conditions of flow and its physiological measurement. This paper investigates the mental difference between hearing, listening, and playing, while changing subsidiary conditions that may affect naïve sensations during a musical activity. Two of the subsidiary conditions dealt with this paper are the delicate nuance of the performance and the performance interface. Positiveness, i.e., having a positive attitude toward music, which is regulated with hearing, listening and playing, may be an additional subsidiary condition. The experiment used an original performance interface called iFP, referring to an expressive performance template. iFP provides a controller for the intention level of the player and a model performance. The player can choose a PC keyboard, a musical keyboard, or hand gestures as the input device or method.

Another important subsidiary condition related to flow in a musical activity is "sound together with vibration." iFP is an electrical instrument, and thus, it is not suitable to verify the effect of this condition. Thus to inspect the effect of sound together with vibration, we conducted experiments using drums. These experiments also served to analyze the effect of "collaboration with others", which is another important condition related to flow.

We used fNIRS for the physiological inspection of the naïve sensation. The next section describes the characteristics and gives an overview of fNIRS.

BRAIN ACTIVITY MEASUREMENT

Physiological measurements are good for verifying subjective introspection results. Brain activity is a most promising measure for what a subject is thinking and feeling. Changes in oxyhemoglobin (oxyHb) and deoxyhemoglobin (deoxyHb) reflect changes in neuro-physiological activity, and as a result, may be used as an index of brain activity (Jueptner et al. 1995, Hoshi et al. 2001). One type of equipment that can measure oxyHb is fMRI. fMRI has proven to be a useful tool for studying human brain activity including listening to music. However, neither fMRI nor PET is suitable for the measurement of brain activities when the subjects are moving, for instance, as they play music. Unlike fMRI, the recently developed fNIRS does not require subjects to be still. It is a promising tool for measuring brain activity accompanied with gestural actions. Table 1 compares representative brain activity measurement systems. The merits of fNIRS are as follows: it is 1) non-invasive; 2) it does not overly restrict the subjects' movement; and 3) it enables real-time observation of brain activity.

Principle of fNIRS

In an organism, near-infrared light is penetrative, whereas visible light is strongly diffusive, as shown in Figure 1. fNIRS detects the relative ratio of oxyHb and deoxyHb by measuring the quantity of the diffusive part of the near-infrared light irradiated through the skull and onto hemoglobin in blood vessels of the cortex (Eda et al.1999).

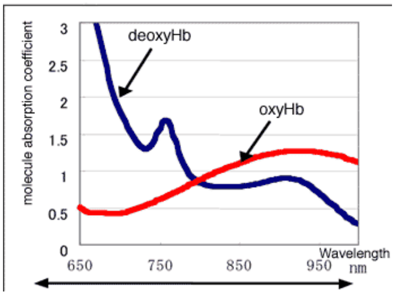


Figure 1. Molecule absorption coefficient of near-infrared light.

For the experiments described in the following section, we used an OMM2001, manufactured by Shimadzu Corporation, that provides multiple-point measurement. Figure 2 shows the appearance of the probes attached to the head.

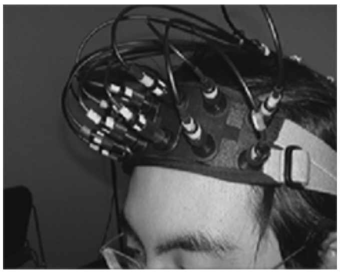


Figure 2. Wearing near-infrared transmitter and receiver.

Figure 3 shows a sample of the output of the OMM2001. Increases and decreases in oxyHb correspond to the activation and deactivation of brain activity at the measured point, respectively.

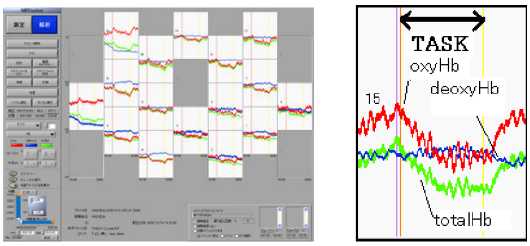


Figure 3. Example of OMM2001output.

fNIRS Results of Previous Work

Among the studies using fNIRS, some assessments of the so-called game-brain syndrome (Dill & Dill 1998, Anderson & Bushman, 2001) are relevant to our research. Matsuda et al. reported that oxyHb in the dorsal prefrontal cortex (DPFC), that is the activation level, falls when subjects play video games (Matsuda & Hiraki 2004, Matsuda & Hiraki 2006). In well-designed experiments, Matsuda et al. explain the causes of the oxyHb decrease in the DPFC. They show that 1) visual processing manipulation suppresses brain activity in the DPFC; 2) solo game play does not require the player to monitor others' mental process; and 3) skilled game players no longer are required to learn movement strategies in response to new visual information.

Kawashima et al. investigated the effect of video games on brain activity in detail, by changing the game genre (Kawashima 2005). According to their report, when subjects play a shooting game and a rhythm, brain activity in the frontal cortex decreases. In contrast, when a player plays a puzzle game, the activity increases. They also reported that when an experienced player plays a puzzle game, the activity in the frontal cortex decreases.

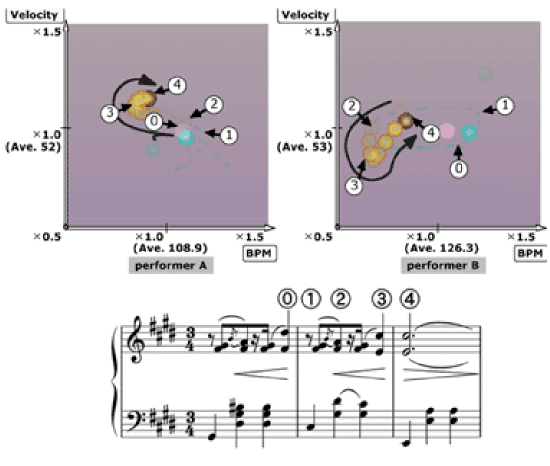
EXPERIMENTS USING iFP

This section describes experiments on the expression template, interfaces, and hearing, listening, and playing using iFP. First, we give an overview of an original performance interface, iFP; then, we describe the experimental results.

The mechanism of activation / deactivation of the frontal cortex has not been revealed yet. Besides the examples introduced above, there are other studies that show activation / deactivation of the frontal cortex when a subject is relaxed, in meditation, or immersed in playing a game (Davidson & Irwin 1999, Tamakoshi et al. 2006, Mathiak & Weber 2006). In a series of experiments using iFP, the measurement area of the brain was targeted in the DPFC including Fz regulated by the international 10-20 system of electrode placement.

Performance Interface: iFP

iFP is an interface for playing expressive music, as it refers to a pianist's expressiveness with its tapping-style interface (Katayose et al. 2004). MIDI-formatted expressive performances played by pianists were first analyzed and transformed into performance templates (See Figure 4), where deviations from the canonical description were separately described for each event. Using one of the templates as a skill complement, an instrumentalist can play music expressively over and under the beat level.



ISBN 88-7395-155-4

Figure 4. Performance templates (a part). We can see differences between performances played by two pianists educated in music college.

The iFP scheduler allows players to mix their own intensions and expressiveness into the performance template. An iFP performer can experience the thrill of virtuosity; he/she is allowed to vary the weight parameters dynamically with sliders, each of which is multiplied with deviations in tempo, dynamics, and delicate nuances within the beat (See Figure 5). That is, iFP provides functions for controlling the intention level of the player and the model performance. iFP also provides a morphing function that interpolates and extrapolates two different expressive performance tem-plates of the musical piece.

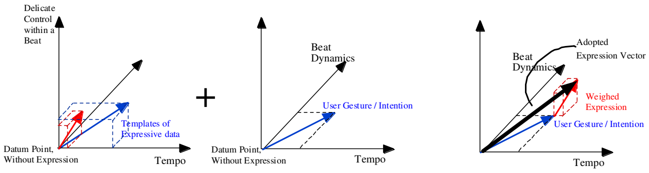


Figure 5. Conceptual overview of performance calculation. Performance data are given by a mixture of the player's intention and expressiveness described in the performance template. In this three-dimensional space, the vertical axis denotes the variance of deviations of all notes within the beat.

As for the peripheral interface, the player can chose PC keyboards, a musical keyboard, or conducting interface based on capacity sensing (see Figure 6).

The experiments using iFP were on 1) listening vs. performing, 2) effect of using the performance template, and 3) the effect of the interface.

Figure 6. Gestural interface based on capacity sensing.

Expression and Interface

Figure 7 shows the results of experiments investigating the effect of using an expressive performance template of the song *"When you wish upon a star"* and comparing input interfaces, for a subject (***subject A***) who answered, "The expressive performance template contributes to both expressiveness and controllability." This subject had been educated in music, and had received her Master of Music degree from a music university. We can see the decrease in oxyHb when the subject played with the expressive performance template. The decrease was most salient when she used the expression template and the conducting interface. These results correspond very well to reports of the subjects' introspection regarding pleasantness and sensation of absorption / immersion (Okudaira et al. 2004). The right data were obtained when the sensor went wrong. It is interesting to see the response of the subject when something unexpected happened.

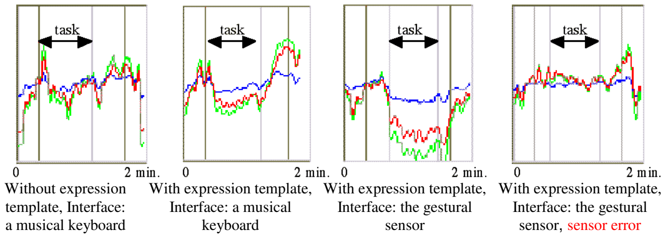


Figure 7. Brain activity measured with fNIRS while subject played "*When You Wish upon a Star*" using iFP. Arrows show the duration of the performance. A single emitting source fiber was positioned at Fz in DPFC.

Hearing, Listening and Playing

Figure 8 compares activities of hearing, listening, and playing of music ***(subject A)***. The music was the same piece as in the expression and interface experiment. oxyHb was lower when the subject listened to the music and played with the iFP. The decrease was more salient with the iFP. The right data were obtained when the subject was shaking her hands without playing with the iFP. These results also corresponded very well to reports of the subjects' introspection.

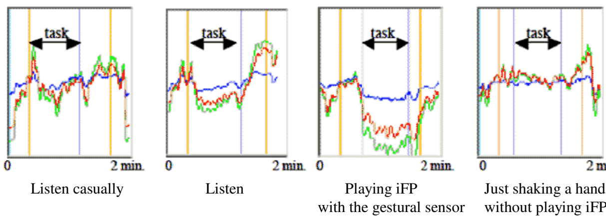


Figure 8. Brain activity measured with fNIRS while subject was listening to music or playing with the iFP.

We also conducted the same experiment on another subject (***subject B***), who is experienced in playing the organ, who answered, "The expressive performance template contributes to expressiveness but not to controllability." The results were the same as those of the first subject, except for using the conducting interface (See Figure 9). In contrast, oxyHb increased while using the conducting sensor. The subject had reported that it was difficult to control the conducting sensor. It seems that the subject became obliged to "think" how to control the conducting sensor.

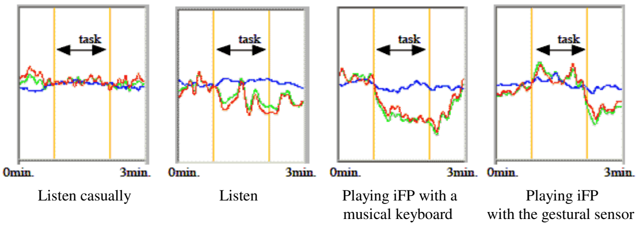


Figure 9. Brain activity of ***subject B*** who reported "it was difficult to control the conducting sensor."

Music Experience vs. Favorite Music

Next, we conducted experiments measuring hearing vs. listening for additional subjects who was educated at a music university (***subject C***), a person who was not educated at a music university but who was experienced in playing music (***subject D***), and a musically inexperienced person (***subject E***). The results for the experienced subjects for "*When you wish upon a star*" were the same as those of ***subject A*** and ***subject B***; that is, the decrease in oxyHb was more salient when they listened to rather than just heard the music. As for **subject E**, however, little change in oxyHb was observed, for both hearing and listening.

Next, we investigated the effect of music preference. The subject (***subject D***) was asked to grade five pieces of music on a five-grade (like <-> dislike) score, and we measured the brain activity while he listened to these pieces. Figure 10 shows the result. The left is the average for three pieces judged "like" (ranked more than 3 on the scale) and the right is average for the rest. The decrease in oxyHb was more salient when the subject listened to his favorite music.

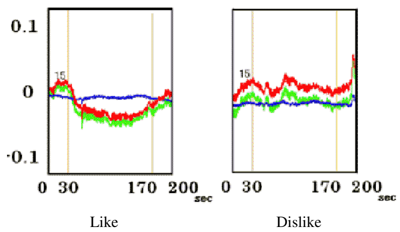


Figure 10. Activities of subject while listening to his favorite music and listening to music he didn't like.

EXPERIMENTS USING DRUMS

The history of drums is the longest of any musical instrument. Drums have been used in religious events and for raising the morale of warriors before combat. Recently, drums have been used for rehabilitation training, eurhythmics, and video-game entertainments such as "Taiko-no-Tatsujin" (Master of Drumming) [2] manufactured by NAMCO ltd.

It is empirically known that the sound of drumming affects the bodies and feelings of animals. Moreover, the applicational range of drums is expanding.

In this section, we examine the effect of sound and vibration and the instructional session's procedure on brain activities (Yamaoka et al 2006).

Timber and Vibration

Both timber and direct vibration affect the human body and mind. But it is difficult to judge which of these primarily affects brain activity. As the first step of our investigation, we measured subjects' brain activity under drastically changing conditions in an experiment comparing the effect of real Japanese drums (diameter: 60 cm, height: around 80 cm) with a toy elastic game pad for the "Taiko-no-Tatsujin" (Master of Drumming). The game pad is not equipped with a resonator. The vibrations sensed in the body as well as the sound sensed by the ear are quit different.

One task set was designed as a sequence of a preceding rest (20 s), task [n] (30 s) and a succeeding rest (20 s). Each task [n] was a combination of (three rhythm types) * (genuine drum / game pad). We repeated the task set, changing the order, and obtained four data for each rhythm. The number of subjects was five (two males, three females, right-handed). The fNIRS holder covered the DPFC and the temporal lobe, as shown in Figure 11.

We observed a larger increase in oxyHb in the temporal lobes of four of the five subjects when they beat the genuine drum, compared with when they beat the game pad. oxyHb in the DPFC of three of the four was also higher with the genuine drum. Figure 12 shows a typical case. As for one of the four, the oxyHb in the DPFC decreased while she beat the genuine drum, while it was level while beating the pad. The remaining one subject's oxyHb increased at the almost all measured positions, when she beat either the genuine drum or the pad.

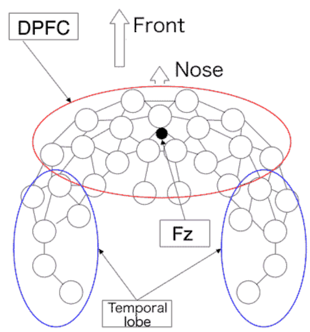


Figure 11. Location of detectors.

[2] http://en.wikipedia.org/wiki/Taiko:_Drum_Master

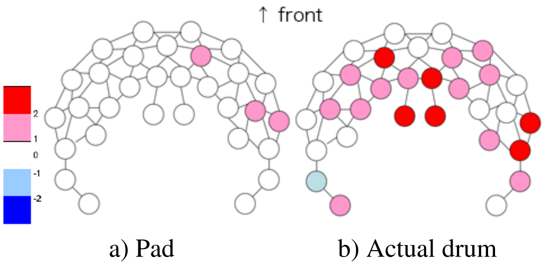


Figure 12. Typical brain activity in a subject beating genuine drums (red activated, blue deactivated.)

Session Procedure

This experiment was an attempt to search for events that are related to changes in oxyHb and deoxyHB in a series of eurhythmics sessions. DPFC activity was monitored in subjects who participated in the eurhythmics session using a special big drum. Figure 13 shows an image of the session.

Figure 13. Eurhythmics session.

The instructional process included a session comprising a subject and a trainer (solo task) and a group session (group task). We left the contents the session to the trainer's discretion, except for the rhythm type to be used in the session. A 10 min. solo task was followed by the 25 min. group task. As a whole, the change in oxyHb was obviously bigger in the group, even after excluding artifacts.

In the group session, we observed a salient increase in oxyHb at the right and left detectors around fz, around 600 seconds after the start of the session. Figure 14 shows the magnification of the data. The upper line corresponds to the oxyHb index. The jump edges are artifacts. Even if these edges are excluded, we can obviously see an increase in oxyHb.

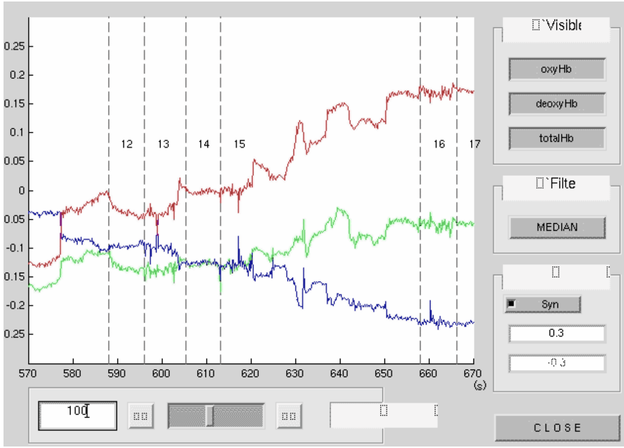


Figure 14. OxyHb and deoxyHb at the Fz, in a group session.

We inspected what was happening in the video. Around part 15, the trainer let each member beat in response to the opposite side's member (the beats were successive). The subject's countenance looked as if they felt delighted and pleasant.

To sum up the results of this experiment, the increase in oxyHb in the DPFC seems to be correlated with the difficulty level of the task and the subject's countenance regarding delightfulness and pleasantness.

DISCUSSION

Although the interpretation of deactivation in the Fz itself is still controversial, the experimental results using iFP suggested that the activation level in the DPFC tends to decrease in accordance with the subjects' feeling of pleasantness and absorption / immersion. This phenomenon well corresponds to Matsuda's studies that investigated brain activity while subjects played video games (Matsuda et al. 2006). Our data supports the possibility that the order of oxyHb decrease in the DPFC may be an indicator of inner sensation regarding absorption / immersion. In addition, we may say that skill in using the interface, preference for the target music, and positive attitude in regard to the task all influence the sensation.

Previous studies have suggested that the activation level of the DPFC decreases when humans play a musical game in which players compete for the most accurate beat timing. In contrast to the above assertion, we obtained data that show brain activity in the DPFC is activated when the subjects beat a genuine drum, and when they enjoy interactive play. There is a possibility that brain activation level in the DPFC of the players' playing a musical video game increases when the player uses the actual drum instead of tan elastic game pad, and if there is an audience. It is unwise to analyze every video game and every music activity as if they were alike. We have to consider the conditions in more detail.

We think that there are two kinds of pleasantness that human can feel when they are engaged in musical activities. One is pleasantness accompanied with the sensation of being uplifted. The other is pleasantness with the sensation of absorption or immersion in the activities. In future studies, we may use fNIRS to classify the type of pleasantness being experienced. At present, we are just at the starting point of our investigation. We have to repeat the experiments and also elaborate the experimental plans as to whether it induces the cause and the result. We also have to interpret the meaning of the increase / decrease in oxyHb in terms of mental processes and brain functions.

SUMMARY

This paper described our preliminary investigation on musical brain activities using fNIRS. We conducted two sets of experiments on musical activities: 1) experiments using a performance interface, and 2) experiments using Japanese drums. In the first experiments, we observed a decrease in brain activity in the DPFC when the subjects listened to their favorite music, and when they played music with an interface of which they were accustomed. The decrease in brain activity in the frontal cortex is regarded to correspond to the sensation of immersion. In the second experiments, we obtained data that support the notion that the activation in the frontal lobe and in the temporal lobe is stronger while beating genuine Japanese drums compared with beating a toy drum pad. Our experiments are only in the preliminary stage. We would like to continue them and obtain more data to verify our hypotheses.

ACKNOWLEDGMENTS

Authors would like to thank Mr. K. Okudaira, Mr. Y. Mori, Mr. A. Yamaoka, Mr. K. Suda, Dr. M. Hashida, Mr. K. Toyoda, Mr. K. Noike and Taiko Center Corporation for their assistance to continue this research. This research was partially supported by the MEXT Grant-in-Aid for (B) Scientific Research 16300073 2004-2005, JAPAN, PRESTO “Intelligent Cooperation and Control” JST, JAPAN, and CREST “Foundation of technology supporting the creation of digital media contents”, JST, JAPAN.

REFERENCES

Blood, A. J., Zatorre, R. J., Bermudez, P., & Evans, A. C. (1999). Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions, *Nature Neuroscience, Vol. 2, No. 4*, 382-387.

Zatorre, R. J., & Peretz, I. (Eds.) (2001). *The Biological Foundations of Music.* Annals of The New York Academy of Sciences, Vol. 930, The New York Academy of Sciences.

Koelsch, S., Fritz, T., Schulze, K., Alsop, D., & Schlauga, G. (2005). Adults and children processing music: An fMRI study, *NeuroImage, Vol. 25,* 1068-1076.

Csikszentmihalyi, M. (1975) *Beyond Boredom and Anxiety*. Jossey-Bass Publishers.

Jueptner, M., & Weiller, C. (1995). Does measurement of regional cerebral blood flow reflects synapticactivity? - Implications for PET and fMRI, *Neuroimage, 2*, 148-156.

Hoshi Y, Kobayashi N, Tamura M. (2001). Interpretation of near-infrared spectroscopy signals: a study with a newly developed perfused rat brain model, *Journal of Applied Physiology, 90,* 1657-1662.

Eda, H., Oda, I., Ito, Y. et al. (1999). Multi-channel time-resolved optical tomographic imaging system. *Review of Scientific Instruments, 70,* 3595-3602.

Dill, K., & Dill, J. (1998). Video game violence: A review of the empirical literature. *Aggression and Violent Behavior, 3*, 407-428.

Anderson, C. A., & Bushman, B. J. (2001). Effects of violent games on aggressive behavior, aggressive cogntion, aggressive affect, physiological arousal, and prosocial behavior: A meta-analytic review of the scientific literature. *Psychological Science*, 12, 353–359.

Matsuda, G. & Hiraki, K. (2004). Prefrontal cortex deactivation during video game play. *Gaming, Simulations and Society: Research Scope and Perspective*, Springer-Verlag Tokyo, 101-109.

Matsuda, G., & Hiraki, K. (2006) Sustained decrease in oxygenated hemoglobin during video games in the dorsal prefrontal cortex: A NIRS study of children. *Neuroimage, 29*, 706-711.

Kawashima, R. (2005). Fundamental Studies on Effect of Video Game for Brain. *Hayao Nakayama Foundation for Science & Technology, and culture Annual Report, No. 13*, 15-16. (in Japanese)

Davidson, R.J., & Irwin, W. (1999). The functional neuroanatomy of emotion and affective style. *Trends in Cognitive Sciences, 3*, 11-21.

Tamakoshi, S., Takahashi, T., Terao M., Sawai, D., Imanishi, A., Morimoto, F., Yagi, A., & Katayose, H. (2006). A study in the entertainment of fighting video game measured by fNIRS : a comparison vs. human and vs. computer. *IPSJ SIG Technical Reports, 24, 2006-EC-3*, 35-41. (in Japanese)

Mathiak, K., & Weber R. (2006). Toward brain correlates of natural behavior: fMRI during violent video games. *Human Brain Mapping*, Published Online: 20

Katayose, H., & Okudaira, K. (2004). iFP A Music Interface Using an Expressive Performance Template. *Enter-*

tainment Computing 2004, Lecture Notes in Computer Science, Vol. 3166, 529-540. Springer.

Okudaira, K. Hashida, M. & Katayose, H. (2004). A Study of Immersion in Music -Expansion of Skill and Somatic Interaction-. *Proc. Entertainment Computing 2004*, IPSJ Symposium, 39-44. (in Japanese)

Yamaoka, A., Mori, Y., Suda, K., Hattahara, S., Kuramoti, T., Hashisa, M., & Katayose, H. (2006). Investigation of brain activity while beating a Japanese-drum using fNIRS, *IPSJ SIG Technical Reports, 24, 2006-EC-3*, 29-34. (in Japanese)

Table 1. Comparison of brain activity measurement systems

	fMRI	fNIRS	PET	EEG	MEG
Physics	Electromagnetic	Absorption of Infrared light	Gamma rays	Voltage	Magnetometry
Measurement Target	OxyHb	OxyHb, deOxyHb	Metabolism in Brain	Voltage of the Brain surface	Magnetometry of Brain surface
What is understood?	Activation Area Secondary response	Activation Area Secondary response	Activation Area Primary response	Activation Area Primary response	Activation Area Primary response
Reconstruction of 3D	Yes	No	Yes	No	Yes
Time resolution order	Second	Second	Minute	1/1000 Sec.	1/1000 Sec.
Characteristics	Accuracy	Simple	Accuracy	Price, Data accumulation	Speed
Usability	Not good	Good	Not good	Good	Not Good
Spatial Resolution	Good	Not Good	Fair	Not Good	Fair
Time resolution	Not good	Fair	Fair	Good	Good