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Effects of Real/Virtual Musical Performance on a Time Sequential Oxy-hemoglobin Pattern in Frontal Cortex

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ABSTRACT

The present study investigated hemo-dynamics in the brain related to music processing to clarify the mechanism for distinguishing between a real musical image with physical movement and a virtual musical image. The frontal cortex of each subject was optically measured using one-channel near-infrared spectroscopy (NIRS) to compare changes in oxy-hemoglobin during certain musical tasks. Time course of oxy-hemoglobin in the right frontal lobes was measured for subjects asked to play a familiar piece of classical music with an instrument such as a piano or violin. The oxy-hemoglobin pattern of a subject asked to imagine the music based on memory alone, without either auditory stimulation or physical movement, showed partial synchronization with patterns of one performing a musical piece. Thus, the pre-frontal hemo-dynamics for virtual musical imaging most likely simulates those for real musical imaging in the same individual.

KEYWORDS: hemo-dynamics, musical performance, virtual musical imaging, NIRS, frontal cortex

INTRODUCTION

Present brain science frequently focuses on the activity of the prefrontal cortex of the human brain in the analyses of attention during learning processes [1-2]. A newly obtained procedure of the process should have a large impact not only in literature and science courses, but also in music courses. The physiological measurement of the process probably provides a new approach to the methodology used for musical education.

On the other hand, a topic that has been attracting a lot of attention, the brain-machine-interface (BMI) [3-6], was investigated by researchers from a wide spectrum of disciplines such as cognitive neural science and biomedical engineering.

The newly developed BMI technique based on EEG, fMRI, NIRS, etc. are expected to open new horizons for research into applications of music for education and clinical rehabilitation.

In the present study we investigated the physiological parameter, cortical hemo-dynamic activities in the frontal brain, by utilizing an NIRS system to explore brain activity which imitates the pattern of real musical performance when the brain with body can imagine the real musical performance. We obtained hemo-dynamic patterns in the right frontal regions of subjects who were doing a real and a virtual (imaginary) musical performance with a musical instrument, such as a piano or violin.

METHODS

We measured hemo-dynamic patterns of five amateur musicians who could play the piano or violin and one professional pianist. The experimental plan of the study was authorized by the bioethics committee in the Faculty of Education, Chiba University. Written informed consent was obtained from each of the subjects prior to the experiment.

The piece of music used for the real/virtual task was a piano piece, "La candeur, Op.10, in C-dur" composed by F. Burgmuller. The musical structure of the "La candeur" consisted of three parts: A, B, and C, as shown in Fig. 1. The musical parts A and B were repeated in the sequence, A1-A2-B1-B2. Each of A1~B1 consisted of eight measures, while B2 had seven measures and skipped the last measure of B1, which was the 16^{th} measure of the song.

The length of tune which was performed by each individual subject ranged from 85 sec to 125 sec. During the task, which included pre- and post- rest periods, oxy-hemoglobin (oxyhem), deoxy

-hemoglobin and total hemoglobin levels were obtained by a one-channel non-invasive NIRS system (Hamamatsu Photonics, NIRO-120). We set the center of a pair of optrodes at the midpoint of F4 and F8 on the right side of the forehead of a subject based on the international 10-20 system. The effect of such physical movement as neck inclination was monitored with a camera. Both video and audio recording were captured during the tasks, and the audio data were correlated with the NIRS data for the purpose of quarrying the oxyhem-patterns fitted in a fragment of musical structure. Subjects were asked to slightly elevate the middle finger of their right hand at the end of parts A1, A2, B1, and B2 in the case of an imaging task. The imaging task proceeded with imaging the creation of a tonal image in the same velocity as reality and having the subjects close their eyes in a calm environment.

RESULTS

The hemo-dynamic patterns revealed peaks of 10 to 20-seconds that were reproducible at specific points during the same musical piece with both a piano and a violin.

Figure 1 shows an example of the oxyhem pattern in the time course of the right frontal lobe (F4-F8) of subject MI when the amateur pianist performed the tune, “La candeur”. The sequence of arrows shown in the bottom of the figure is the musical structure of the “La candeur”. The pattern in Fig. 1 contained various kinds of frequencies. We analyzed and categorized the patterns into low frequency (LF) patterns of 0.1Hz~0.05Hz and very low frequency (VLF) patterns of less than 0.025Hz as shown in Table I. The LF patterns can be more precisely categorized into four types of I~IV. The pattern in parts A and B was determined by the boundary of sections in four-measure-length. In the case of the data shown in Fig. 1, we obtained Type I in A1 and in the center of C where the music had an imperfect cadence, four waves of Type IV in B1-B2. The relatively higher peaks in B1 formed two VLF patterns the configuration of which corresponded to Type VI of the lower panel in Table I.

Figure 2 shows a comparison of oxy-hemoglobin patterns in a real performance and imaging of “La candeur”. The upper panels in Fig. 2 show the results of the analyses of LF components, Type I~IV. In each of these types, the appearance probability, which was calculated by counting each type in subject KT, is shown. The subject repeated the real performance task and imaging task 7 and 5 times, respectively. The results indicated that Type II frequently appeared in A1~A2 both in real and imaginary performances. Also, the Type I pattern was similar to that of part C.

We traced the oxy-hemoglobin pattern with long time-ranged components and illustrated it at the bottom of Fig. 2. The patterns with a frequency of less than 0.025Hz were generally similar to parts A1, B1 and C for both cases, real and imaginary performances.

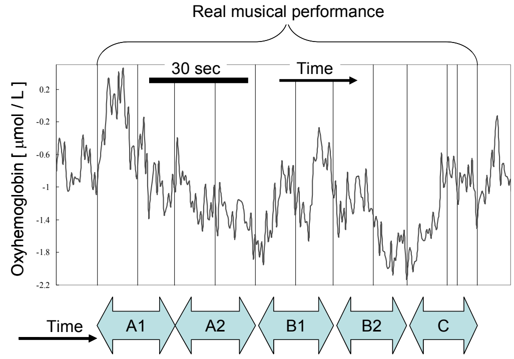
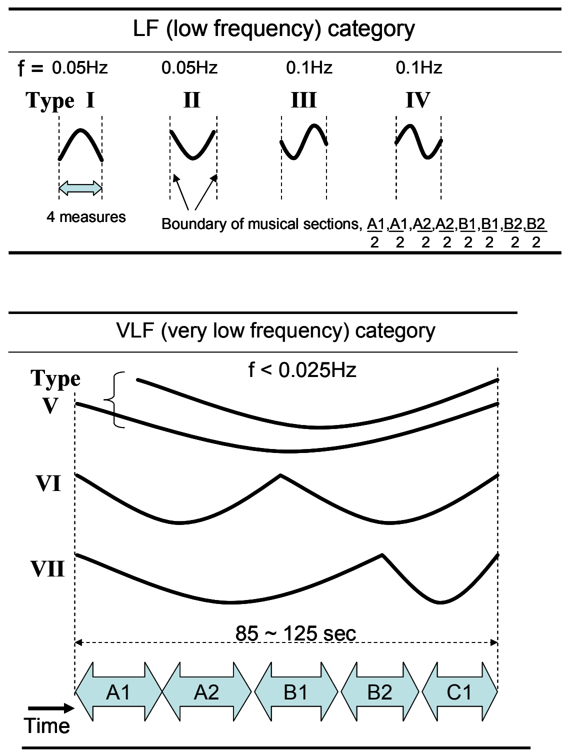


Fig. 1. An example of the time-sequential oxy-hemoglobin pattern in the right frontal lobe (F4-F8) while performing “La candeur” on the piano. Bottom sequence with arrows: musical structure of the piano piece “La candeur”.

Table I. Categorization of the oxy-hemoglobin patterns by individual frequency. In the LF (low frequency) category, Type I~IV patterns were identified by boundaries of musical sections the length of which was four musical measures. In the VLF (very low frequency) category, Type V~VII patterns were identified by a long-term-change in the oxyhem-level.



As the same tendency was observed in other subjects, our analysis was switched to focus on the VLF components (Type V ~ VII) and Type-I peak in parts A, B and C. Figure 3 illustrates the VLF components, Type V ~ VII in two data samples. The top panel is that of a virtual musical performance and its VLF pattern was categorized as Type VII. It was distinct that peaks in parts B1 and B2 had an effect on the VLF pattern formation. An emergence of intense peaks in B1 and B2 resulted in the patterns being categorized into Type VI and VII.

In the performance by two amateur pianists and one professional pianist, the probability of VLF components appearing and the Type-I peak in the beginning, middle, and end the song was obtained as shown in Figure 4. The parameters exhibited reproducibility in both cases, real and imaginary performance, and were similar to trans-tasks.

It should be noted that imaginary performances produced the Type VII pattern more frequently than the Type VI pattern, while real performances generated the Type VI oxyhem-pattern, as shown in the bottom panel of Fig. 4.

DISCUSSION

In our previous study, changes in oxy-hemoglobin that were characteristic with musical information in the time-axis frequently occurred during a task of listening to music without apparent physical movement. The characteristic features in oxyhem-patterns were i) a drop in oxyhem-level while listening to music and ii) the appearance of a full-width positive peak for 10~20 sec. The latter feature frequently appeared in a specific part of the piece, namely the climax or the “sabi” as denoted in music.

The present study exhibited similar results in the performance of real music. VLF components showed a long term decrease during the real task, and spontaneously strong oxyhem-peaks were observed at parts B1~B2 where there was development in the musical structure.

We expected either, or both, the LF (0.05~0.1Hz) or VLF (<0.05Hz) pattern categories have a similarity between real and virtual musical performances. The experimental results indicated that VLF components in virtual performance possibly reflect the properties of that of real performance, while LF components had less correlation between the real and musical-image tasks.

The suggestions we obtained are consistent with evidence that BMI with NIRS needs half a minute to determine Yes/No categories by the hemo-dynamic behavior in the cerebral cortex.

The data presented in the figures were obtained when the subjects were sitting. Similarly, we collected the same kind of data when the same subjects were standing. The hemo-dynamic patterns of both the violinist and pianist performing while standing showed a slight increase in oxyhem-level, in comparison to that while sitting; however, the aforementioned features in VLF patterns and peaks in part B remained in the standing experiments. Therefore, hemo-dynamics in the brain of the musical performer may respond to brain activity involved in music processing rather than activity involving the autonomic nervous system.

Our approach of using time-sequential oxy-hemoglobin patterns to evaluate musical recognition and body sensation may be applicable to both musical education and music therapy.

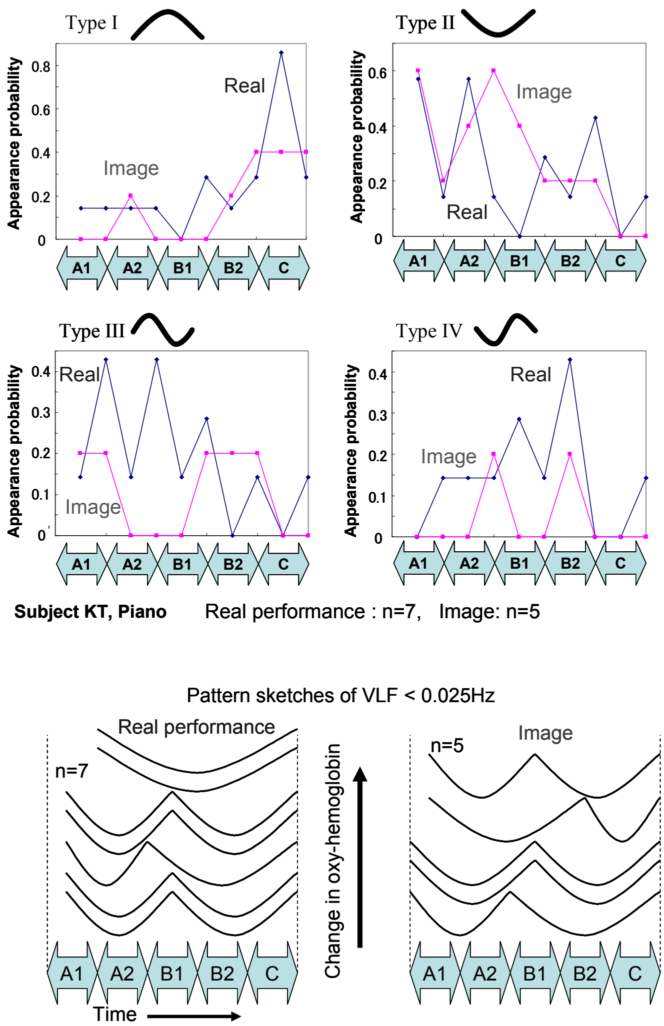


Fig. 2. A comparison of oxy-hemoglobin patterns in a real performance and imaging of “La candeur”. Upper four panels: appearance probability of LF components, Type I~IV. Appearance probability = counts of each types / total experiment number of the subject. Bottom two panels: oxy-hemoglobin pattern with long time-ranged components.

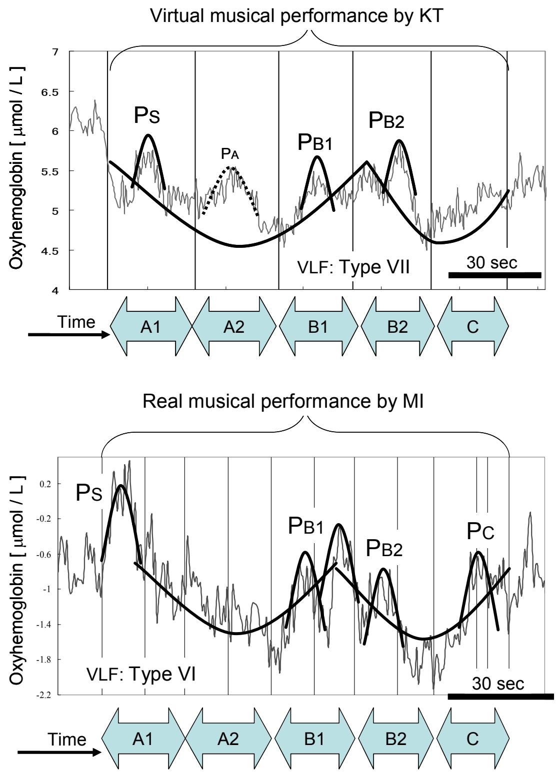


Fig. 3. Illustrations of the VLF components, Type VI ~ VII, and Type-I peak in parts A, B1 and C, in two data samples. PS: peak in the early part A1, PB1: peaks in part B1, PB2: peaks in part B2, PC: peaks in part C.

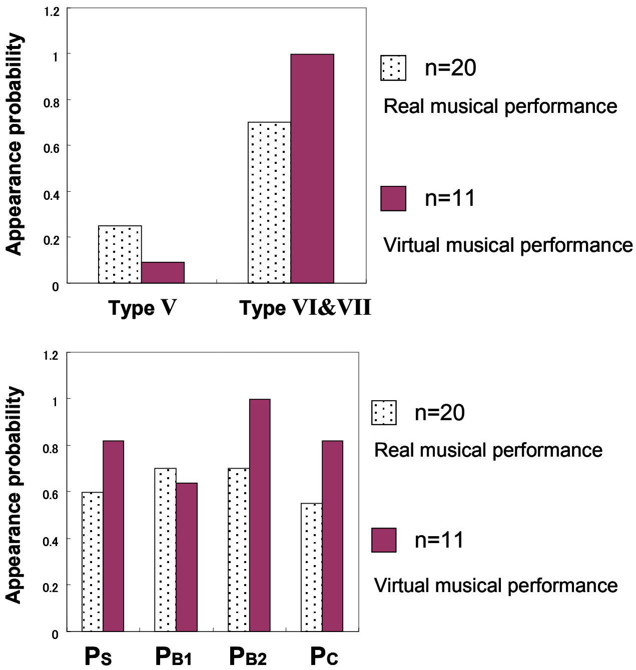


Fig. 4. Probability of VLF components appearing (Type V, VI+VII) and Type-I peak at the beginning (part A), middle (Part B1 and B2), and end (part C) of the performed music.

CONCLUSION

We measured right frontal hemo-dynamics of musicians by one-channel NIRS. The observed oxy-hemoglobin patterns were then synchronized to the structures of the musical task, a piano piece, "La candeur".

Both amateur and professional musicians, who played the piano or violin, had induced typical oxyhem-patterns in their right frontal lobe (midpoint of F4 and F8).

The induced oxy-hemoglobin pattern with long-time-ranged components with a frequency of less than 0.025Hz had a similarity in the beginning, middle, and ending part C of the performed music between real and imaginary performances.

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REFERENCES

[1] C. Suzuki, T. Tsukiura, H. Mochizuki-Kawai, Y. Shigemune, T. Iijima, "Prefrontal and medial temporal contributions to episodic memory-based reasoning", *Neuroscience Research*, vol. 63(3), pp.177-183, 2009.

[2] K. Rubia, A.B. Smith, R. Halari, F. Matsukura, M. Mohammad, E. Taylor, and M.J. Brammer, "Disorder-specific dissociation of orbitofrontal dysfunction in boys with pure conduct disorder during reward and ventrolateral prefrontal dysfunction in boys with pure ADHD during sustained attention", *American Journal of Psychiatry*, vol. 166(1), pp.83-94, 2009.

[3] N. Birbaumer and L.G. Cohen, "Brain–computer interfaces: communication and restoration of movement in paralysis", *Journal of Physiology*, vol. 579(3), pp 621–636, 2007.

[4] R. Sitaram, H. Zhang, C. Guan, M. Thulasidas, Y. Hoshi, A. Ishikawa, K. Shimizu, and N. Birbaumer, "Temporal classification of multichannel near-infrared spectroscopy signals of motor imagery for developing a brain–computer interface", *NeuroImage*, vol. 34, pp. 1416–1427, 2007.

[5] Z. Haihong and G. Cuntai, "A Kernel-based Signal Localization Method for NIRS Brain-computer Interfaces", in *Proceedings of the 18th International Conference on Pattern Recognition* (ICPR'06), 2006.

[6] K. Utsugi, A. Obata, H. Sato, T. Katsura, K. Sagara, A. Maki, H. Koizumi, "Development of an Optical Brain-machine Interface", in: *Proceedings of the Engineering in Medicine and Biology Society* (EMBS 2007), 29, pp. 5338-5341, 2007.