CEREBRAL BLOOD FLOW PATTERN SYNCHRONIZATION WITH TIME SEQUENCES OF MUSIC

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Abstract

We investigated the brain hemodynamics of musicians by means of near infrared spectroscopy. The hemodynamics related to musical recognition processes in the human brain were investigated by utilizing a system based on NIRS. Optical absorption at 690 - 830 nm in the frontal and temporal lobes was measured when the subject was exposed to musical stimulation. During the playing of a keyboard instrument such as a piano, the player's frontal lobe showed a clear and reversible decline in the level of blood flow. Apparently, the blood flow pattern in frontal region synchronized with the sequence of music following its composition along a time axis. The results also indicated that as well as structures in the sequences of the compositions, the level of musical training and the human-instrument interface affected the dynamics of blood flow, which reflected brain activity. However, synchronization of the blood flow dynamics with the musical structures of an individual composition was reproducibly observed in a specific pattern of changes in the blood flow in a human brain cortex.

Recently, neurological studies---fMRI, MEG, etc.---of a musical task provided us with a possibility of determining whether the functions of musical processing inside the brain are localized in a specific region (Avanzini et al., 2003; Zatorre et al., 2001). In addition, large numbers of studies have discussed the laterality of the human brain in the processes involved in recognizing music (Splacy, 1970; Nakada et al., 1998).
In addition to the above-mentioned physiological studies, which directly access the brain, psychological approaches to musical recognition have a long history (de Laat et al., 1985; Kuwano et al., 1994; Nakajima et al., 1983; Raiford et al., 1971; Srulovicz et al., 1983), and the effects of acoustic properties on mental processes have provided us with fundamental and significant information.
Alternatively, recent physiological techniques utilizing near-infrared spectroscopy (NIRS) have become one of the conventional methods for psychological investigation because the subjects do not need to close their eyes and can perform the tasks in a normal manner (Chance et al., 1977; Hoshi et al., 1993). Therefore, it is thought that NIRS is an adequate method for monitoring human brain activity while a person is creating music by using his/her body and a musical instrument. Hemodynamic data, which are the dynamic behavior of the physiological parameters of blood in brain tissue, include oxyhemoglobin, deoxyhemoglobin, total blood flow, etc.
In the present study, musical recognition processes in human cortices were investigated by utilizing an NIRS system. During active listening to music, the dynamics of the blood flow in the frontal and temporal lobes were obtained from subjects including both professional and amateur musicians. The obtained time course of the parameters associated with cerebral blood

flow showed a specific blood level pattern that depended on each of several musical compositions.

Method

An NIRS system, a one-channel non-invasive oxygen monitor (Shimadzu, OM-100AS) was utilized. The system transported near-infrared light by a pair of optical fibers, one of which was the emitter and the other was the detector. The emitter and detector were placed on the surface of forehead or temple of a subject. The distances between the optrodes was 25 - 30 mm, and the condition provided an NIR light exposure down to approximately 15 - 20 mm.
In the study on active music listening tasks, i.e., playing instruments to perform music, NIR light measurement was carried out on 18 subjects (7 females and 11 males, 5 professional musicians and 13 amateur musicians).
In the present report, we discuss the hemodynamics of the subjects during the playing of one of the following four tunes (Music-A, B, C, and D) by piano, electone, vocal with san-shin (shamisen), and mandolin, using commercial music or data.

Music-A: Classical piano piece: “Nocturne” Op. 9.2 (F. Chopin)
Music-B: Jazz-fusion: “Treasure-island”(T-SQUARE), arranged by M. Ueno (YAMAHA Music Co.)
Music-C: Okinawa folk song: “Asadoya Yunta” (traditional)
Music-D: An oldies song

We obtained written informed consent from each subject prior to the measurements. All measurements were designed and carried out under the supervision of the local ethics committee of Chiba University.

Results and Discussion

Performance on musical keyboards

In the case of playing keyboard instruments, the typical hemodynamic response in the human brain was a decrease in the blood flow level or oxyhemoglobin level in the regions of the frontal lobe (F3, F7, Fz, F4, F8).
Figure 1 shows the time course of oxyhemoglobin during six repetitions of a piano piece (music-A) whose length was 4 to 5 min. During each time, both the oxyhemoglobin and total blood level decreased after the music started, then returned to their original levels during the latter part of the piece. Both parameters shifted higher but the deoxyhemoglobin level remained constant after the second trial. Thus, the shift was not only attributed to an artificial trend but also to a physiological response in the brain. It was remarkable that the behavior of the oxyhemoglobin level was reproducible. According to the players' introspection, we speculated that the decline was caused by absorption while playing the music (active listening); the same phenomenon was observed in passive listening tasks.
In the present study, we observed other significant and remarkable hemodynamic phenomena when the blood flow level in the right frontal lobe was compared with that of the right temporal lobe, particularly at the point (T4) near the auditory cortex. Figure 2 shows the time courses of optical absorbance at 805 nm, which were measured at both the right frontal and temporal lobes when a subject played a tune (Music-B) on an electone (YAMAHA EL-150) during a fixed time length.

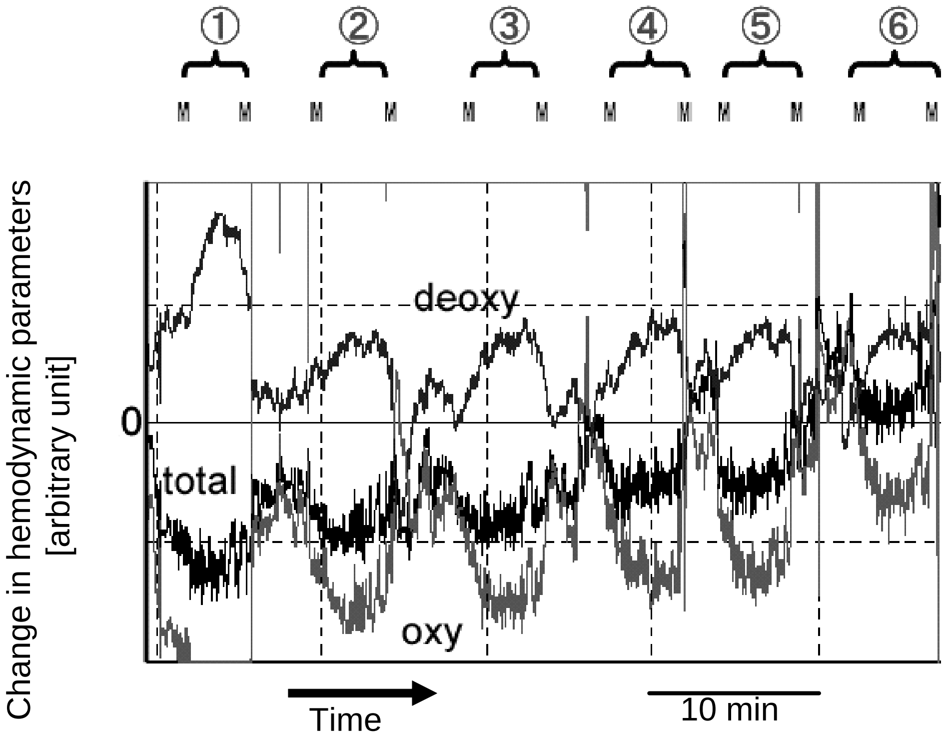

Fig. 1. Reproducible changes in hemodynamic parameters (deoxyhemoglobin, total blood flow, and oxyhemoglobin) of left frontal lobe (midpoint between F7 and F3) while an amateur pianist was playing a piano piece (Music-A) six times. "M" in the upper part of the graph indicates the beginning or end of the performance, and the bracket indicates the length of the music.

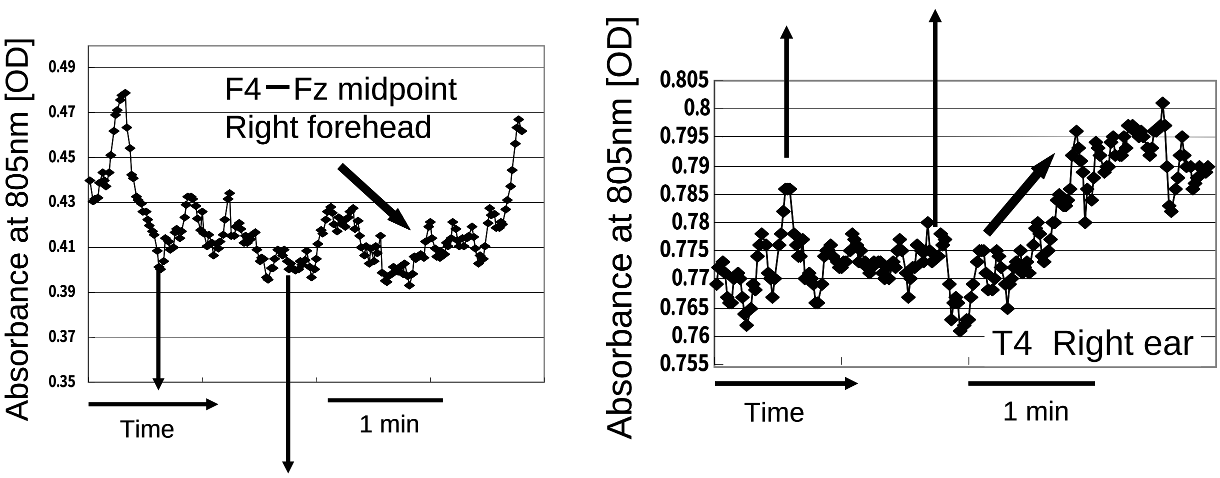

Fig. 2. Comparison of blood flow level (represented by optical absorbance at 805 nm) at a point on the right frontal lobe to a point on the right temporal lobe while playing music on a keyboard (Music-B). The two vertical arrows indicate where the positive/negative peaks of both lobes occurred at the same position.

In general, the degree of absorbance represented the level of blood flow. The frontal region showed the same hemodynamic behavior, the valley pattern, as did the data in Fig. 1. Both absorbance graphs showed typical positive/negative peaks while the subject was playing. Comparing both hemodynamic patterns (left panel, right frontal lobe; right panel, right temporal lobe) in Fig. 2 indicated that the two kinds of time-dependent patterns were synchronized with each other; the several positive peaks in the left panel corresponded with the negative peaks in the right panel and vice versa. In addition, the end of the music showed a long-term decrease in absorbance at the frontal lobe corresponding to the long-term increase at the temporal lobe. The changes are highlighted by the slanted arrow in Fig. 2. The results indicated that the blood flow level in the right frontal region correlated with the activity in the temporal region where auditory processing was in progress. The detailed mechanism behind the phenomena is unclear at present. However, there should be collaborating neural activities in the affected regions and the activities should be reflected in the synchronization of the blood flow dynamics between the two regions.

Vocal performance and performance on string instruments

In contrast to the hemodynamics of musical performance on keyboard instruments, vocal performances or performances on string instruments exhibited an increasing blood flow level tendency (or oxyhemoglobin level). Figure 3 shows an example of oxyhemoglobin dynamics in the left frontal region (midpoint of F3 and F7) with a vocal and a kind of shamisen, san-shin, which is a traditional string instrument in Okinawa, which is played by plucking the strings. In the experiment of Fig. 3, an amateur singer of traditional Okinawa music sang a song (Music-C) and played the san-shin. The music involved a prelude, five vocal sections, four interludes, and a postlude. Distinctly and reproducibly, an increase and a decrease in oxyhemoglobin level appeared in the vocal and non-vocal sections, respectively.
The experiment was accompanied with a task of playing the same musical sequence by san-shin without singing, and the obtained hemodynamic pattern was not consistent. Playing Music-C only by san-shin provided a pattern conjugating a long-term increase and short-term decreases. Perhaps, the pattern of left-frontal hemodynamics in the vocal/san-shin performance was produced by a combination of the processing of both the voice and string instrument.

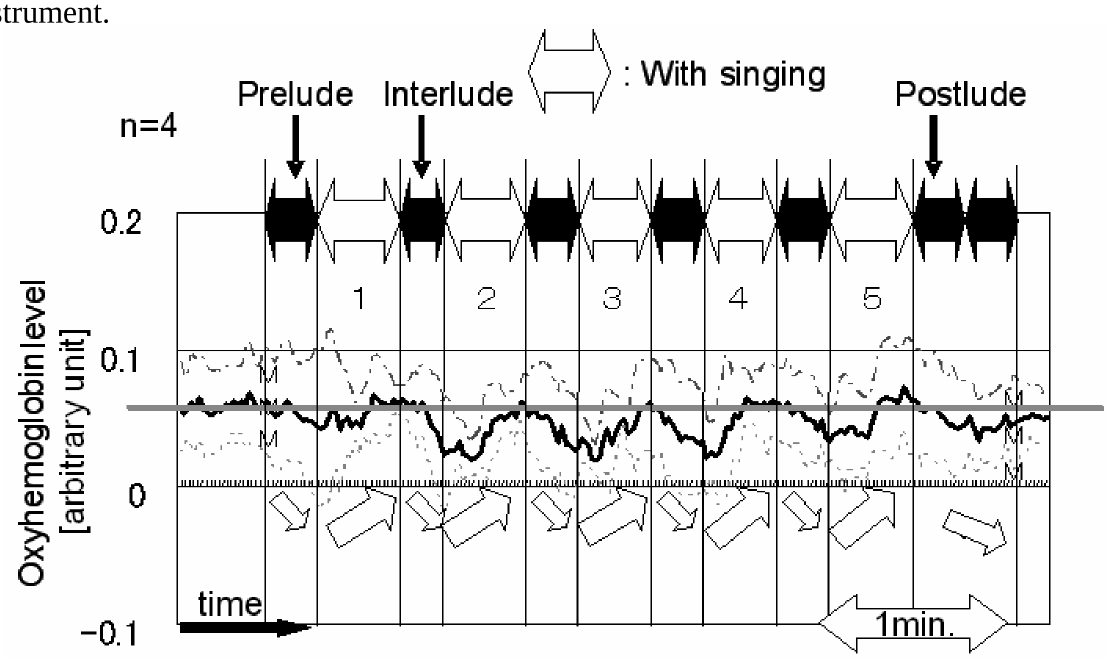

Fig. 3. Oxyhemoglobin dynamics in left frontal region (midpoint of F3 and F7) with vocal and a type of shamisen, san-shin. The mean±SD is shown (n=4). The arrows at the bottom indicate the tendency of change in the oxyhemoglobin level. Prerecorded san-shin music was streamed to indicate the time.

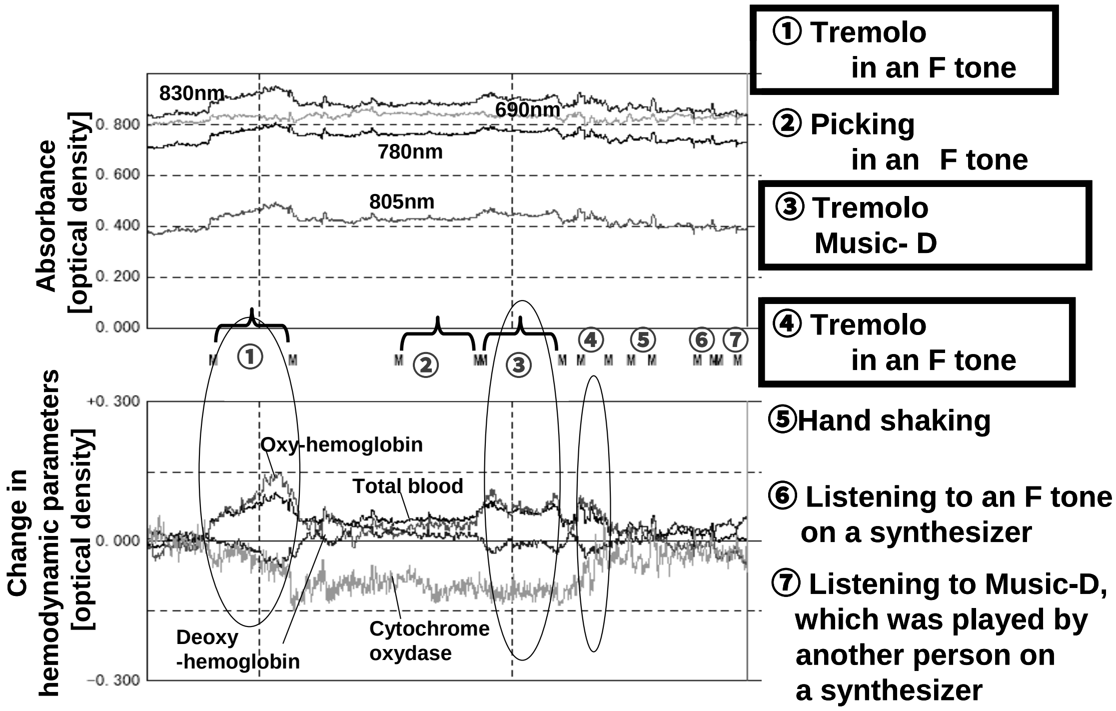

Fig. 4. Effects of sound style of mandolin on the hemodynamics of the left frontal lobe, midway between F3 and F7. Top panel: time course of optical absorbance at four wavelengths with mandolin tasks. Bottom panel: time course of hemodynamic parameters, which was calculated using absorbance at four wavelengths.

We also observed that the tone synthesis by string instruments frequently increased the musician's frontal blood level while handling the instrument. The mandolin, viola, violin, guitar, Tsugaru-shamisen, and niko all showed examples supporting this hypothesis; playing the strings with two hands generates an elemental effect that increases the volume of blood or oxyhemoglobin in the frontal lobe, near positions F3, F7, or F4, F8 in the 10-20 system.
Figure 4 shows the case of playing the mandolin. The bottom panel shows the time course of the hemodynamic parameters, which were calculated using the absorbance at the four wavelengths shown in the top panel. The point of measurement was midpoint between F3 and F7 in the left frontal lobe. The subject, a right-handed mandolin player, continuously performed the seven tasks shown in the right of Fig. 4. A distinct phenomenon was the increase in blood flow level and oxyhemoglobin level while playing the mandolin strings in tremolo style. The three tasks with tremolo are indicated by a large circle in the time course of the hemodynamic parameters in Fig. 4. The results indicate that only playing in tremolo style enhanced both parameters---blood flow level and oxyhemoglobin level---while there was no distinct change while the player picked the mandolin, shook his hands, or listened to a synthesized tone that resembled the mandolin's tremolo.

The data with the other stringed instruments showed a tendency toward an increased blood flow level while the subjects controlled the pitch with their fingers. One possible mechanism for the observed increase of the blood parameters in the frontal lobes, which is close to the region of the so-called working memory, was pitch control both in the brain and in the fingers.

The string instruments required the control of adjusting the string vibration pitch by using the player's ear. Another mechanism considered was timing control because the players of these kinds of string instruments must control each of their hands individually.

Conclusions

In the present study, the effects of musical performance on the physiological parameters of blood behavior in the human brain, particularly in the frontal lobes, were investigated by means of near infrared spectroscopy.

The hemodynamics in the frontal lobes showed synchronization with sequences of music in playing musical keyboards such as piano and electone. The pattern of the time course of the blood flow level in the right frontal lobe (F4-F8) became opposite to that of the pattern in a position (T4) on the right temporal lobe.

Musical performances with string instruments or voice provided data that showed the enhancement of blood level or oxyhemoglobin level while the player (singer) was controlling the generation of tones.

Acknowledgements

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