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The effect of the challenging two handed rhythm tapping task to DLPFC activation

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Abstract

Using functional near infrared spectroscopy (fNIRS), we have been researching the effect of musical attention control training (MACT) on the prefrontal lobe, which is involved in attention control. We detected significant dorsolateral prefrontal cortex (DLPFC) activation during music-based tasks that included “dual task” elements. In this study, to elucidate which musical elements influence DLPFC activation, we focused on the effects of tempo of both handed Rhythmic tapping tasks (RTT), which including “dual task” elements. RTT with 3 different tempos, the easy (E) (slow tempo), intermediate (I) (moderate tempo), and difficult (D) (fast tempo) tasks, were developed. Then, the activation of the DLPFC was measured during each task. Our results detected a significantly stronger DLPFC activation during the (D) task than during the (E) task ($p<0.01$) or the (I) task ($p<0.01$). These results indicate that the difficulty of RTT can be adjusted by altering the tempo. Music-based tasks could be useful for cognitive training programs, even those for poorly motivated people with severe attention deficits through changing the difficulty level by changing the tempo.

Keywords: Music, Dual task, DLPFC, Rhythm, Attention functions, Cognitive rehabilitation

Introduction

Higher brain dysfunctions, such as attention deficits, memory deficits, and executive function deficits can inhibit activities of daily living and prevent individuals from returning to employment. In particular, executive functions can cause problems with reintegration into society (Lezak, 1995). In order to perform executive functions appropriately, individuals have to be able to efficiently and appropriately recruit attention functions, which are considered to form the basis of all cognitive functions (Matter, 2000). Therefore, improving attention functions is essential to the success of rehabilitation (Cicerone et al., 2000). Attention processing training (APT) mainly involves searching tasks and is considered to be a typical training method for attention function deficits (Sohlberg et al., 1987). Although the efficacy of these methods has been verified, sufficient motivation and certain attention functions are required to perform them. Therefore, training methods that motivate the participants to focus on the task and whose difficulty levels can be adjusted for each participant are required.

It is reported that music tasks that mainly involve auditory stimulation promote attention functions more efficiently than tasks that mainly involve visual stimulation (Loui et al., 2005). Therefore, music-based tasks could promote attention functions more efficiently than conventional training tasks, which mainly involve visual searching tasks. Moreover, music-based tasks motivate the participants more than other desk-based training tasks, and this is especially true for people with low self-motivation, attention function deficits, and severe cognitive deficits. Furthermore, Music-based tasks would also be easy to adjust the difficulty levels by changing the tempo and rhythm of the music involved.

Thus, we have been researching the effect of music on attention function through both clinical and basic studies.

In healthy participants, we have been researching the relationship between the characteristics of musical tasks and cerebral blood flow (CBF) by measuring the change in CBF in the dorsolateral prefrontal cortex (DLPFC) region of the prefrontal lobe, which controls attention functions, by using functional near infrared spectroscopy (fNIRS) (Abiru et al., 2011). In this study, we found that musical tasks involving “dual task” elements, such as singing during a rhythmic tapping task (RTT), strongly influence DLPFC activation (Abiru et al., 2011). However, we are not sure which elements of music, such as melody, tempo, harmony, and rhythm etc, influence DLPFC activation in fact. Among those basic elements of music, we thought rhythm can be easily understood for everybody since it is easy to play even by individuals without any musical experience and easy to include dual task elements. Therefore, we focused on rhythm to study. As basic rhythm pattern, bilateral rhythmic tapping tasks (RTT), which include dual task element by using both hands differently, was selected. Then, the difficulty level of RTT was adjusted by changing its tempo.

In this study, we researched the relationship between activation of the DLPFC region and the difficulty of rhythm-based dual tasks by adjusting the tempo in a step-by-step manner as a means of altering its difficulty level.

Methods

1. Participants

Thirty healthy participants with no physical or mental problems (9 males, 21 females; mean age: 22.03 ± 2.39; 26 right-handed), who met requirements in the following preliminary test, were selected from 34 undergraduate students, who applied in this study.

The preliminary tests by using the basic rhythmic tapping task (RTT) were implemented before this study since the difficulty level of rhythm varies from person to person. The basic RTT are shown in Figure 1-a). Four participants were excluded in the preliminary test due to: 1) failure to reach 90% success rate on the easy task (E) even after 3 minutes' practice or 2) ability to easily complete the difficult task (D), such as experienced musician.

Informed consent was acquired before study procedures began. This study was approved by Kyoto University Graduate School and Faculty of Medicine, Ethics Committee (C593). All participants were required to sign consent forms, which explained the purpose, methods, benefits, and disadvantages of this study and that their participation was voluntary, before participating in this study.

2. Rhythmic tapping task (RTT)

The basic rhythm pattern of RTT is shown in Figure 1-a). ●Indicates that an examiner hits the percussion Pad and ○ indicates the examiner does not hit the percussion Pad. To select the basic RTT, the RTT, which is the most participants were able to perform perfectly at a slow tempo but difficult with a faster tempo, was selected as RTT preliminarily.

Three different difficulty levels of RTT, were created according to the accuracy rate data obtained in the preliminary experiment:

(1) The easy task (E), in which 30 sets of the RTT were performed per minute at an accuracy rate of approximately 100%.

(2) The intermediate task (I), in which 60 sets of the RTT were performed per minute at an accuracy rate of approximately 80%.

(3) The difficult task (D), in which 80 sets of the RTT were performed per minute at an accuracy rate of approximately 50% (Figure 1-b).

The all participants watched each level of RTT task (E, I, and D) being performed on a monitor, which set up in front of them. In the monitor, the examiner's hands were visually and auditory showed, as an example. They then performed each task on an electronic rhythm instrument, an Octapad Digital Percussion Pad: ODPP (Roland SPD-30). ODPP had been set up in front of the participant so that the right and left sides of the ODPP produced different sounds. Preliminary sufficient practice of each task was implemented before the measurement of fNIRS. With watching the monitor, the participants then performed each task on the ODPP, while fNIRS measurements were obtained (Figure 2).

To avoid the learning process affecting their results, the researchers ensured that all participants understood the basic rhythm of the RTT and had practiced it fully before the experiment.

3. The percentage of correctly played RTT

In this study, gradual blood flow changes during each task (60 seconds) and the percentage of correctly played RTT were measured simultaneously. Calculation of the percentage of correctly played (E), (I), and (D) RTT tasks was recorded by a video camera. The number of correct RTT responses was counted by reviewing the video records after the experiments. As described in Figure 1-a), each RTT set was composed of 7 beats (○ or ●), and the beats to be played with the right and left hand were indicated by (○) and (●), respectively. All levels of RTT were performed with watching the monitor which showed the performance of examiner. Therefore, as a criterion of correct RTT, when all 7 beats were not delay and/ or when the number of RTT sets that were played correctly from example RTT showed through the monitor, the RTT were counted as the correct RTT set. Then, the number of RTT sets that were played correctly per minute was divided by the total number of RTT played per minute for each task level. Then, the quotient was multiplied by one hundred.

4. Prefrontal cortex measurement fields

It is reported that a circuit involving the DLPFC, prefrontal lobe, and cerebellum controls the accuracy of movements (Torriero et al., 2007). In this experiment, it was important that the participants implemented the task precisely as instructed to activate attention control functions. Therefore, we expect a circuit involving these areas of brain. However, we had to narrow down the target area of the brain since it is hard to observe the entire brain using our fNIRS system. Therefore, we focused on the DLPFC, which is considered to control movement accuracy through both motor control and cognition (Fregni et al., 2005; Sakai et al., 2006).

5. Measurement of prefrontal area activation

The activation of the prefrontal lobe during each task was compared by assessing the changes in brain blood flow induced by using fNIRS. We used the FOIRE-3000 fNIRS system (Shimazu Corporation, Japan). The units of this fNIRS are shown as arbitrary unit (a.u.). The different size and shape of each participant's head changed the length of the light path. Therefore, the relative changes in the oxyHb concentration in the resting stages were set as 0 a.u.. The stage of just before the each task was set as a criterion of resting stages. Through these quantitative measurements, the validity of comparison between subjects was reported (Plichta et al., 2006).The fNIRS measurement interval was set at 115 ms. The lowest line of probes was horizontally aligned with the frontopolar point [Fpz] of the International 10-10 System of Electrode Placement, which is the standard system for electroencephalographic measurements. Three probes each were placed on the right and left of the [AFz], and then a second line of probes was placed 30mm above the initial line of probes. Therefore, a total of 14 probes (19 channels); i.e., two rows of 7 probes, were employed (Figure 2).

Brodmann area 46, which is involved in the central executive system of working memory, was chosen as the target area within the DLPFC. However, the size and shape of each participant’s head were differed; therefore, it was difficult to confirm the area of the brain that had been activated using a head chart. Thus, the F3-F5 area (left DLPFC area) and F4-F6 area (right DLPFC area) were subjected to analysis since Okamoto et al. (2004) reported that these areas were considered to be closest to Brodmann area 46.

In addition, the channels in each area displayed the same waveforms. Therefore, the channel that displayed the lowest amount of noise among nearby channels was selected for the analysis (Figure 2). Therefore, once the target channels for each participant were set, it did not change among the different tasks for the same participant.

The change in the oxyHb concentration was used as a measure of neural activation, and the mean oxyHb concentration changes induced by each task were compared. Since the change in the oxyHb concentration indicates the degree to which a particular brain region is activated, a greater change in oxyHb indicates stronger activation of the relevant brain area (Plichta et al., 2006).

It would have been difficult to set up a control task since various factors influence DLPFC activation during simple tasks (or resting). Minati et al. (2011) reported that the first trial could easily have been influenced by mental tension and thus produced different results from the procedural trials. Therefore, we used the first trial as a dummy trial (DT) (tapping with the right and left hand in an alternating manner). The tempo of DT was same as E-level. Thus, the DT was set to help participants get used to the research procedure. Then, the accuracy rate and blood flow data were compared between the (E), (I), and (D) tasks.

A block design (10 sec. (rest) – 60sec. (task) – 10 sec. (rest)) was used for the measurement sessions. A total of 4 blocks (60sec. x 4 blocks; total: 240 sec), which were composed of one DT and the three RTT tasks (E, I, and D) were performed one after the other (Figure 3).

To avoid learning effect and fatigue, preliminary sufficient practice of each task was implemented before the measurement of fNIRS. Since the three tasks (E, I, and D) were all composed from the same basic RTT, and the difficultly level of each task (E, I, and D) was determined by its tempo. In addition, to avoid the influence of task’s order, 30 participants were allocated to 3 groups (Pattern 1, 2, and 3), which first order was different each other (Fig. 3).

6. Analysis of data

The collected blood flow data were systematically transformed according to standardized methods using the analysis software included with the fNIRS system. Then, the data for each task were saved in text format and opened in MS Excel. The point, when the DT finished, was revised to [0] on the total data line, and then mean values were calculated.

SPSS version 20 (IBM, Japan) was used for statistical analyses ($p<.05$). Friedman test was used for the percentage of correct played RTT in each task. Two-way ANOVA was used for the comparison of the brain activation and order. Tasks and orders were as fixed factor. Activations were as dependent factor. As multiple comparison, Tukey's test was applied.

7. Limitation of fNIRS

The fNIRS data would have been influenced by various factors other than the tasks. Therefore, the tasks and data collection would have to have been performed in a strictly controlled manner in order to allow the investigators to determine which factors were associated with each change detected by the fNIRS system. However, it is unlikely that data obtained from such a strict research environment would be applicable to clinical situations. Therefore, in this study, creating a research environment that closely mirrored the clinical setting was considered to be the highest priority.

In addition, unlike other measurement methods, such as fMRI, there are no well-established methods for analyzing fNIRS data. The method we employed in this study was chosen because it allows quantitative comparisons of fNIRS data. However, the spatial resolution of fNIRS is lower than that of fMRI, and there are difficulties with the strict localization of brain areas, such as locating individual Brodmann areas of the brain. Furthermore, it is impossible to compare fNIRS data between participants since the distance from the surface of the head to the cortex of the brain and the percentage of light absorbed differs depending on the angle of the device. However, after considering these limitations we decided to use fNIRS for our measurements due to its advantageous characteristics, such as the reduced burden it places on participants and the fact that it allows measurements to be obtained continuously during tasks involving movement.

Results

1. The percentage of correct played Rhythmic Tapping Task (RTT) in each task

The percentages of correctly played RTT in each task are shown in figure 4. The median was 99 (range from 92 to 99) in (E), and 98 (70 to 98) in (I), and 83 (26 to 92) in (D).

In the Friedman's test, the percentages of correctly played RTT were significantly different ($p < 0.01$), and following paired test was also significantly different between (E) and (I) ($p < 0.01$), (E) and (D) ($p < 0.01$), as did the comparison between (I) and (D) ($p < 0.01$) (Figure 4).

2. A representative participant's waveform data of each task and pattern

A representative participant's waveform data for the oxyHb changes observed during each task (E, I, and D) on each pattern (1, 2, and 3) are shown in Figure 5. As the tempo of the rhythm increased, the waves associated with it became a larger-mountain-shape, and increasing the tempo also resulted in wider activation of both the right and left DLPFC, regardless of the order in which the tasks were performed (patterns 1, 2, and 3).

3. Comparison of the brain activation induced by each task

The comparisons of the brain activation induced by each task are shown in Figure 6.

In the Left DLPFC, the mean oxyHb concentration ± standard error of mean (SEM) of E task was 0.18 ± 0.16 a.u. in (pattern 1), 0.14 ± 0.27 a.u. in (pattern 2), and 0.58 ± 0.39 a.u. in (Pattern 3). I task was 0.54 ± 0.13 a.u. in (pattern 1), 0.45 ± 0.16 a.u. in (pattern 2), and 0.35 ± 0.33 a.u. in (Pattern 3). D task was 1.93 ± 0.14 a.u. in (pattern 1), 1.59 ± 0.27 a.u. in (pattern 2), and 1.57 ± 0.39 a.u. in (Pattern 3). The main effect of task was statistically significant ($F(2,81)=24.58$, $MSE=17.60$, $p<0.01$, $\eta^2=0.37$). The main effect of order was not significant ($F(2,81)=0.30$, $MSE=0.22$, $p=0.74$, $\eta^2=0.01$). The interaction of task and order was not significant ($F(4,81)=0.61$, $MSE=0.43$, $p=0.66$, $\eta^2=0.02$) (Figure 6). The multiple comparison demonstrated significant differences between E and D ($p<0.01$), I and D ($p<0.01$), but not between E and I.

In the right DLPFC, the mean oxyHb concentration ± SEM of E task was 0.40 ± 0.12 a.u. in (pattern 1), 0.93 ± 0.30 a.u. in (pattern 2), and 0.37 ± 0.32 a.u. in (Pattern 3). I task was 0.80 ± 0.13 a.u. in (pattern 1), 0.70 ± 0.18 a.u. in (pattern 2), and 0.12 ± 0.42 a.u. in (Pattern 3). D task was 2.05 ± 0.11 a.u. in (pattern 1), 2.08 ± 0.22 a.u. in (pattern 2), and 1.67 ± 0.24 a.u. in (Pattern 3). The main effect of task was statistically significant ($F(2,81)=31.57$, $MSE=19.05$, $p<0.01$, $\eta^2=0.41$). The main effect of order was not significant ($F(2,81)=0.35$, $MSE=0.21$, $p=0.71$, $\eta^2=0.01$). The interaction of task and order was not significant ($F(4,81)=2.20$, $MSE=1.33$, $p=0.08$, $\eta^2=0.06$) (Figure 6). The multiple comparison demonstrated significant differences between E and D ($p<0.01$), I and D ($p<0.01$), but not between E and I.

Discussion

The relationships between the percentage of correctly played RTT and DLPFC activation in each task are discussed below.

In a comparison of the percentages of correctly played RTT between each task, significant differences were detected between (E) and (D) ($p<0.01$), (E) and (I) ($p<0.01$), and (I) and (D) ($p<0.01$).

In a comparison of the DLPFC activation induced by each task produced the almost same results except between (E) and (I). In a comparison of (E) and (I), there was no significant difference between the activation of the right or left DLPFC. However, in comparisons of (E) and (D) ($p<0.01$), and (I) and (D) ($p<0.01$), significantly increased activation was observed in both the right and left DLPFC individually during the more difficult tasks (D) (Figure 6).

It is considered that the activation of DLPFC, observed in this study, is induced by executive attention system of working memory, since many studies have reported that the increase of simple repetitive movements does not activate DLPFC (Jancke et al., 2000; Lutz et al., 2000; Chen et al., 2006; & Bengtsson et al., 2009).

Due to the characteristics of fNIRS, it is hard to derive rigorous conclusions from our data; however, in this restricted situation, we would like to consider the following topics: how the characteristics of each task activated the DLPFC, why both the right and left DLPFC were activated, and the challenges for future clinical research thrown up by our findings regarding the relationship between the percentage of correct RTT and DLPFC activation during each task.

1. The characteristics of the rhythmic tapping task (RTT) that activated the DLPFC

The RTT used in this study required the participants to simultaneously tap different rhythm with their right and left hands, which indicates that the basic RTT was included “dual tasks” element in this study. According to Low et al. (2009), “dual tasks” activate the DLPFC by gradually increasing the workload placed upon it. In this study, the percentage of correctly played RTT was lower in (D) than (E) or (I), even though all tasks included “dual task” elements. This indicates that (D) increased the workload by faster the tempo, and which leads more activation of the DLPFC.

In addition, Shallice (1982) explained that the early stage of learning (in high difficulty situations) activates the supervisory attention system (SAS), which controls the precise execution of tasks through active attention control, and then activates the DLPFC. In this study, we considered that (D) also activated the SAS since (D) required the participants to produce accurate movement execute the RTT precisely under the situation of the faster the tempo which requires active attention control.

Therefore, we considered that (D) activated the DLPFC, which is involved in the executive attention system and the SAS, due to its characteristic of the controls the precise execution of tasks through active attention control.

2. Why were both the right and left DLPFC activated?

Vogh et al. (2007) reported that the main roles of the left DLPFC are observing new information and making preparations for movement and that the main role of the right DLPFC is supervising movement during tasks, such as playing the guitar. In this study, the left DLPFC would have been activated when the subjects were obtaining information about the new rhythm through observing the monitor and preparing for tap the rhythm, and the right DLPFC would have been activated when the subjects were supervising their tapping themselves during each RTT.

In addition, Hatakenaka et al. (2007) reported that the early stage of learning new movements (in difficult situations requiring concentration) is considered to involve strong activation of the entire prefrontal lobe. In this study, (D), which most strongly activated the DLPFC, required the participants to tap 80 sets of the RTT per minute. In other words, (D) involved the greatest amount of complex movements, in addition to observing, preparing, and supervising of the movement, in the strict time regulation. Therefore, it indicated that the combination of complex motor learning, executive attention system of working memory in the certain time regulation for (D) also resulted in the strong activation of both the right and left DLPFC.

However it was impossible to compare the each task’s value of right and left DLFPC directly since the individual probe was not measured same value between right and left DLPFC in measurement method of NIRS in this study. As challenges for the future, it is required to consider direct comparison of right and left

DLPFC by setting basic ratio between frontal lobe and temporal lobe.

3. Summary and clinical challenges for the future

According to the results of this study, tasks with a faster tempo and not high accuracy rate activate the DLPFC more than slower and easier tasks. It is considered that tasks that require great focus to increase accuracy would activate the DLPFC, which is involved in the executive attention system of working memory and the central executive system of the SAS, more than tasks that are so easy that they quickly become routine.

During the performance of (D), in addition to observing new information and preparing for movement, which engaged the left DLPFC, and the element of supervision, which engaged the right DLPFC, the increased amount of motion also resulted in the strong activation of both the right and left DLPFC.

Nittono et al. (1999) reported that the capacity of working memory, which controls the DLPFC, varies from person to person although tasks with a high difficulty level activate the frontal lobe more strongly than tasks with a low difficulty level. Thus, to ensure that the DLPFC is effectively activated in each participant, it is important to set a difficulty level for them. However, if the task was too difficult to perform, even after making an effort, they would just give up. Therefore, it is important to set the task which is comfortably difficult for each participant.

To adjust the difficulty level in “dual tasks” for each participant, music-based tasks would be easy to do. It is because music-based tasks are easy to add and decrease the element to adjust, such as the tempo or whether they only require one hand, etc. This make possible therapists to develop a task that most participants will be able to perform with effort comfortably.

The difficulty level in this study was set by acceleration of tempo of RTT but that also lead the increase of the amount of motion to beat RTT in each task. Therefore it was actually not clear which factor increases the activation of DLPFC, whether it was the amount of motion or acceleration of tempo. Therefore, re-examining the task setting would be required in the future. Although simple comparison between the amount of motion and acceleration of tempo would not make sense due to the characteristic of DLPFC.

In addition to adjusting the difficulty level of a task, individual personality traits and attitudes toward tasks also influence DLPFC activation. For example, some people work through tasks at maximum effort, even during very easy tasks; on the other hand, other people employ the minimum effort, even during difficult tasks. Therefore, to decrease the effects of such factors, it is important to observe individual personal traits. Preliminary observations would help to recognize individual personal traits, such as the type of directions that would encourage individual participants to expend a sufficient amount of effort or focus on a task. It is important to do as much as possible to adjust the difficulty levels of tasks so that they match the personality traits of the participants.

In this study, the participants were all young and healthy. Therefore, our findings might not be applicable to the clinical setting because the difficulty level of each task would also be influenced by the disease status of the participants, such as whether they were suffering from higher brain dysfunction or dementia. With clinical populations it would be necessary to adjust the difficulty level of attention training tasks for each participant in the future.

Conclusions

Training programs for higher brain dysfunction have to be performed in a low stress environment and be enjoyable and interesting. Music is stimulating, even for poorly motivated individuals with low cognitive function. In addition, it is comparatively easy to set the difficulty level of music-based tasks for each participant by adjusting the tempo, rhythm, and/or the number of hands, etc. Therefore, we consider that music-based tasks would be useful for frontal lobe rehabilitation since it is motivating, and easy to set the comfortable difficulty level to stimulate this area of the brain more than other easy fun tasks.

Through continuous clinical research, we would like to develop an attention-training program that is suitable for a wide range of participants and makes use of the effects of music on the prefrontal lobe, which is closely involved in attention functions.

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Figure legends

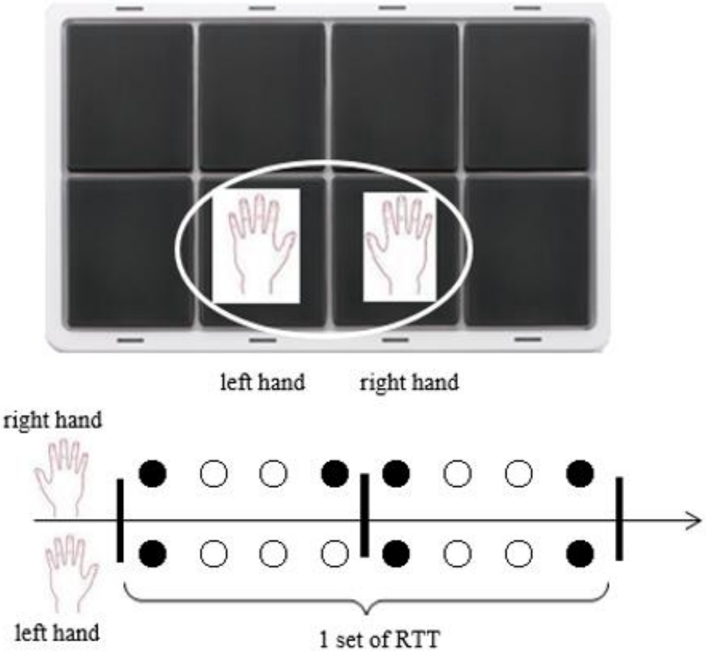
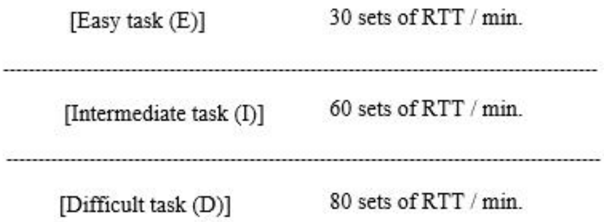


Figure 1-a)

Octapad Digital Percussion Pad (ODPP) and the basic rhythm pattern of Rhythmic tapping task (RTT)



[Easy task (E)]	30 sets of RTT / min.
[Intermediate task (I)]	60 sets of RTT / min.
[Difficult task (D)]	80 sets of RTT / min.

Figure 1-b)

Each level of RTT

Figure 1-a)

Upper part of Figure 1-a) showed an electronic rhythm instrument, an Octapad Digital Percussion Pad: ODPP (Roland SPD-30), was set up in front of the participant. The ODPP had been set up so that the right and left sides produced different sounds. The participants just hit the 2 pads of ODPP which circled with white line. The lower part of Figure 1-a) showed the basic rhythm pattern of RTT. ●Indicates that an examiner hits the percussion Pad and ○ indicates the examiner does not hit the ODPP. The basic rhythm pattern of RTT was the same for all levels.

Figure 1-b)

30, 60, and 80 RTT sets were performed per minute for the easy (E), intermediate (I), and difficult task (D), respectively.

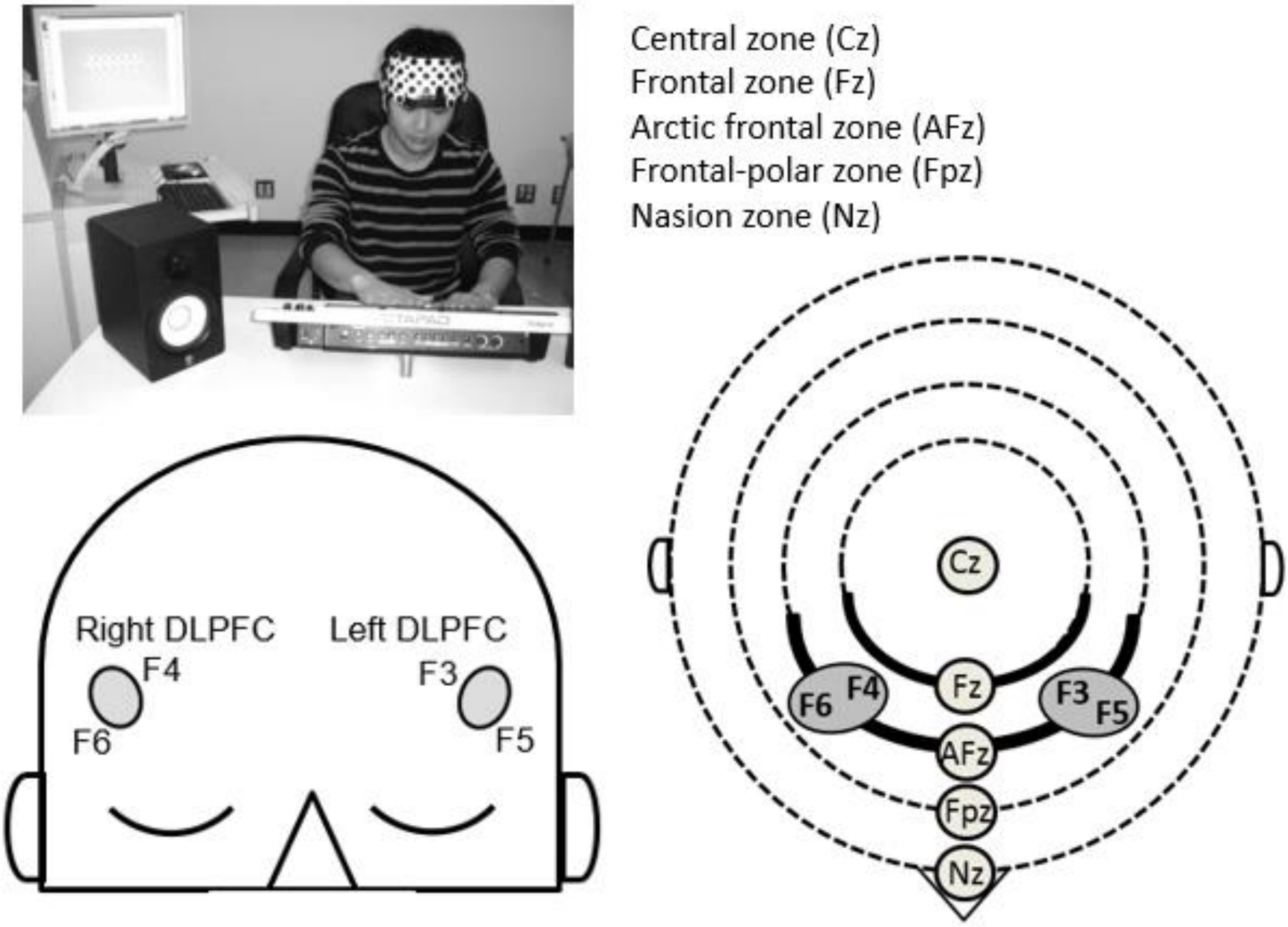
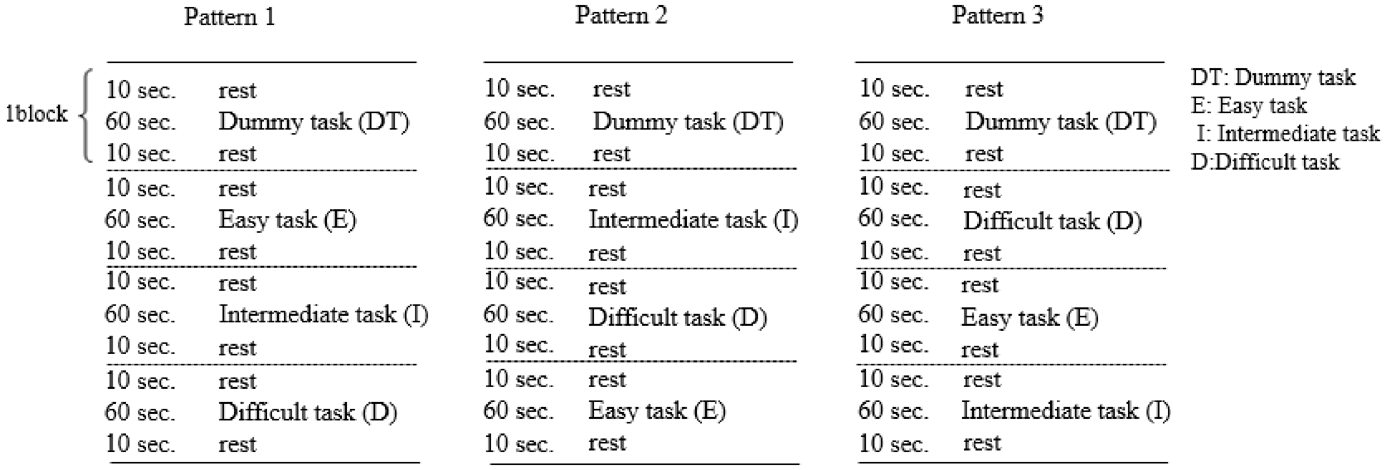


Fig. 2. Measurement environment and the relationship between the locations of the probes and areas of the brain.



	Pattern 1		Pattern 2		Pattern 3	
1block	10 sec.	rest	10 sec.	rest	10 sec.	rest
	60 sec.	Dummy task (DT)	60 sec.	Dummy task (DT)	60 sec.	Dummy task (DT)
	10 sec.	rest	10 sec.	rest	10 sec.	rest
	10 sec.	rest	10 sec.	rest	10 sec.	rest
	60 sec.	Easy task (E)	60 sec.	Intermediate task (I)	60 sec.	Difficult task (D)
	10 sec.	rest	10 sec.	rest	10 sec.	rest
	10 sec.	rest	10 sec.	rest	10 sec.	rest
	60 sec.	Intermediate task (I)	60 sec.	Difficult task (D)	60 sec.	Easy task (E)
	10 sec.	rest	10 sec.	rest	10 sec.	rest
	10 sec.	rest	10 sec.	rest	10 sec.	rest
	60 sec.	Difficult task (D)	60 sec.	Easy task (E)	60 sec.	Intermediate task (I)
	10 sec.	rest	10 sec.	rest	10 sec.	rest

DT: Dummy task
E: Easy task
I: Intermediate task
D:Difficult task

Fig 3. The order of the task.

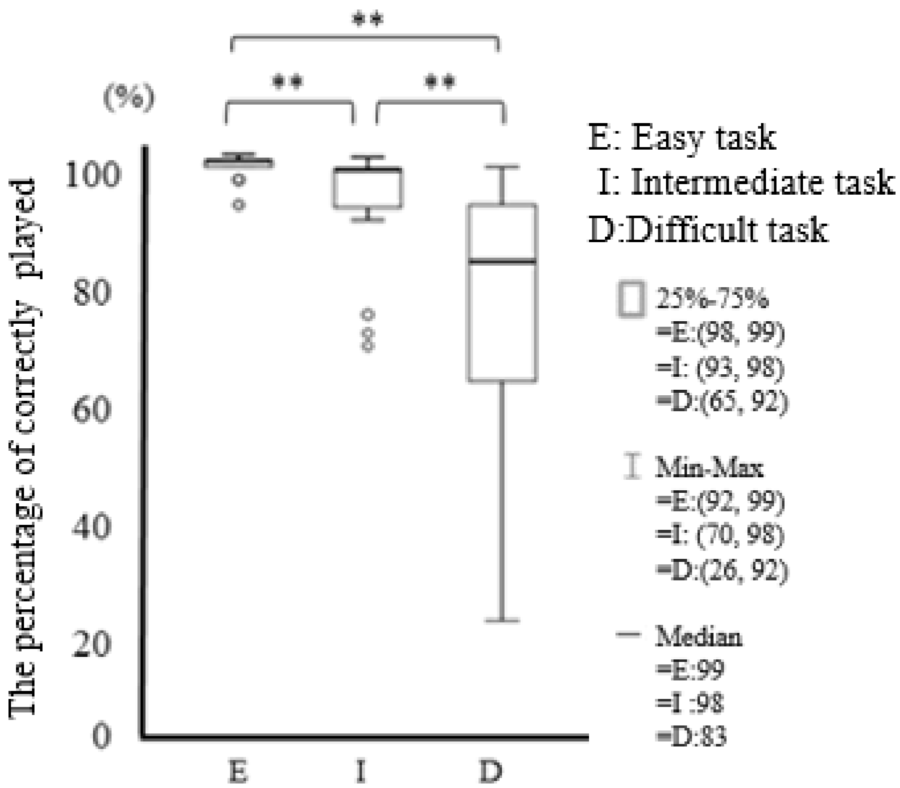


Fig 4. The percentage of correctly played rhythmic tapping task (RTT). The box plot of the bottom and top of the box indicate the first and third quartiles, and the band inside the box indicates the median. Then ends of the whiskers represents the minimum and maximum value within the half time of the top and bottom value of box. ○ indicates outlier. ***p*<0.01.

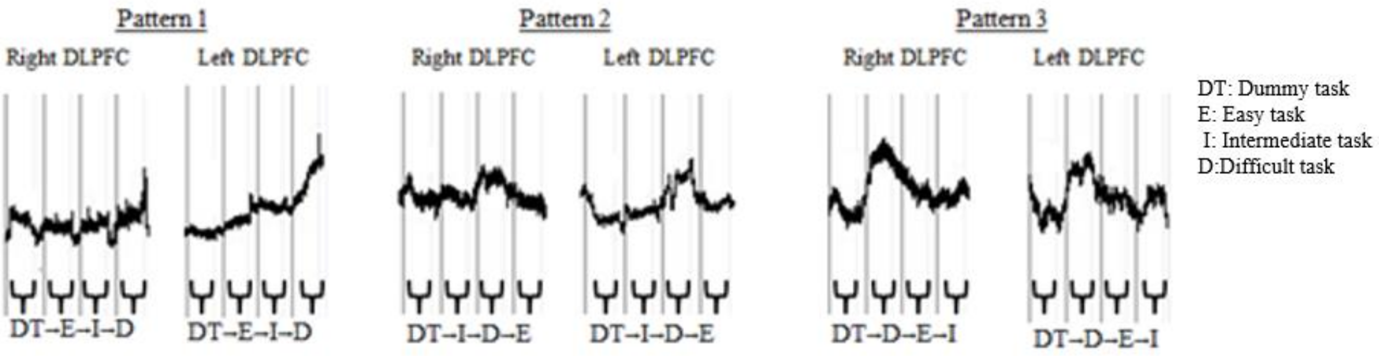


Fig 5. Waveform data of DLPFC for the OxyHb changes of a representative participant observed during each task.

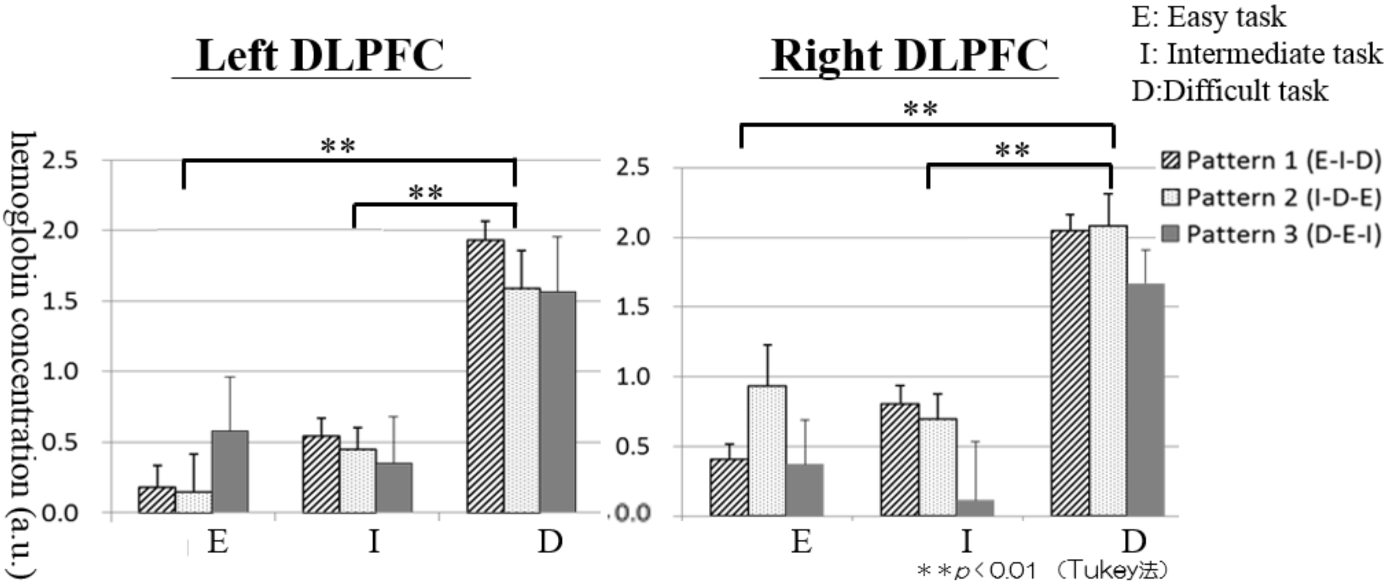


Fig 6. The mean OxyHb concentration changes during each task. Error bar indicates SEM.