

Preferred Pace Tapping Activates the Frontal Lobe

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Background and aims : The purpose of the present study was to compare the activity of the frontal lobe when performing tasks at two paces by functional near-infrared spectroscopy (fNIRS). **Methods :** Fifty healthy students from A University participated in the study. Oxygenated hemoglobin (oxy-Hb) concentrations ($\Delta[\text{oxy-Hb}]$) were monitored during 30s finger-tapping with the non-dominant hand. There were two paces for finger-tapping : one pace the subject decided by themselves and the other pace given by metronome. The subjects answered a questionnaire after fNIRS measurement. **Results :** Performing tasks at Preferred Pace (PP) activates the frontal lobe of the orbito-frontal cortex area, and it tends to induce a feeling of difficulty, especially in females. **Conclusions :** Performing repetitive tasks at PP activates the frontal lobe. This finding will enable occupational therapists to select the subject's optimal pace according to the degree of attentional dysfunction. (Kitakanto Med J 2012 ; 62 : 271~276)

Key words : frontal lobe, finger-tapping, fNIRS, Preferred Pace, attentional dysfunction

I. Introduction and Purpose

Among higher brain functions affected by cerebrovascular disorders, attentional dysfunction due to frontal lobe injury is the most serious inhibitor of rehabilitation. The importance of choosing the appropriate type of problem for subjects to perform has been widely recognized.^{1,2} However, the optimal pace that subjects would use to perform a problem has not been examined to date. When a subject with severe attentional dysfunction has an inability to perform a problem due to restlessness, an occupational therapist can set the pace for the subject. However, if a subject is not severely affected, the occupational therapist may provide support so that the subject can perform the problem at the subject's own pace. The optimal pace for patients is considered to be best selected by the occupational therapist according to the degree of the attentional dysfunction, and physical movement pace of the subject.

Humans subconsciously choose a pace when per-

forming repetitive motions such as walking or tapping.³ This spontaneous setting of pace has been referred to as Preferred Pace (PP), and intra-individual consistency and inter-individual differences have been observed in PP.⁴ Some studies have reported that alertness and attention are associated with performing repetitive motions at PP.^{3,5}

Among the new methods of brain imaging, functional near-infrared spectroscopy (fNIRS) is a non-invasive, optical technique.⁶ fNIRS measures the changes in the concentrations of oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb), mainly in cerebral mixed venous blood.⁷ fNIRS is a cerebral function-measuring instrument that is suitable for rehabilitation performed over a wide range of subjects and environments.⁸

We hypothesized that evaluating subjects' frontal lobe activity when performing problems at various paces might help to identify the optimal pace for a subject with attentional dysfunction. To this end we investigated two paces : one pace decided by the sub-

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jects and another pace that was set externally.

II. Materials and Methods

1. Subjects

Fifty healthy students from A University participated in the study (age : mean, 21.2 years [SD 1.9] ; range, 18–30 years ; males, 23 ; females, 27). The Edinburgh Handedness Inventory revealed that there were 49 right-handed persons and one left-handed person.⁹ Informed consent was obtained prior to the study and the study was approved by the Institutional Review Board of Gunma University (accepted number : 23–6).

2. Tasks

The subjects were seated on a comfortable chair with their arms resting on their thighs. They rested their jaws lightly on the jaw-fixation stand to prevent any effects of head-tilt on the measurements.¹⁰ The subjects were required to perform finger-tapping with the non-dominant hand. Ito et al. previously suggested that the finger-tapping task performed with non-dominant hand is more sensitive for elucidating the characteristics of brain activation than tasks performed with the dominant hand.¹¹

There were two paces for finger-tapping : one pace was decided by the subjects and the other by an external metronome. Additionally, there were three variations of the former pace : PP, Preferred Slow Pace (PSP) and Preferred Fast Pace (PFP). PP was a spontaneous pace, PSP was a pace akin to walking slowly and PFP was the fastest pace the subject could perform. There were also three variations for the latter pace : Metronome Preferred Pace (MPP), Metronome Slow Pace (MSP) and Metronome Fast Pace (MFP). MPP was the same pace as PP, MSP was 30% slower than the pace of MPP and MFP was 30% faster than the pace of MPP. The subjects were required to perform the finger-tapping as precisely as they could

during the task periods. We counted the number of finger-tapping of the subjects of each tasks.

The task consisted of 30-second finger-tapping and a subsequent 20-second rest. The alternating sequence for the pace of finger-tapping was PP, PSP, PFP, MPP, MSP and MFP (Table 1).

The subjects answered a questionnaire immediately after the measurement of fNIRS was completed. We asked subjects the impression through the finger-tapping tasks and they replied it freely.

3. fNIRS recording

A 16 channel fNIRS device (Spectratech OEG-16, Spectratech Inc., Tokyo, Japan) was used to monitor changes in oxy-Hb and deoxy-Hb concentrations ($\Delta[\text{oxy-Hb}]$ and $\Delta[\text{deoxy-Hb}]$). The concentrations of hemoglobin were measured using two wavelengths (770nm, 840nm) with a source-detector distance of 25mm and a time resolution of 0.76Hz. The OEG-16 device was attached around the Frontal pole zero (Fpz) position of the international 10–20 system of electrode placement that serves as the recognized standard for scalp Electroencephalogram (EEG).¹²

4. fNIRS data analysis

We analyzed $\Delta[\text{oxy-Hb}]$ in response to the stimuli because oxy-Hb is believed to be the most sensitive indicator of changes in cerebral blood flow detected by fNIRS measurements.¹³

The parameters for measurement were set as follows : pre-time, 5s ; post-time, 20s. The baselines for the measurements were corrected using a linear fitting method, connecting the pre- and post-time baselines. For each task, we used linear fitting and corrected with the baseline. $\Delta[\text{oxy-Hb}]$ were smoothed with a 3.25-second moving-average filter.

$\Delta[\text{oxy-Hb}]$ of the subjects while they performed six types of finger-tapping tasks (PP, PSP, PFP, MPP, MSP and MFP) were averaged for each of the 16

Table 1 Sequence order of finger-tapping tasks with non-dominant hand.

Finger-tapping pace	Time		Task
The pace the subject decided by themselves	20s	rest	
	30s	1) Preferred Pace (PP) : the spontaneous pace	
	20s	rest	
	30s	2) Preferred Slow Pace (PSP) : the pace akin to walking slowly	
	20s	rest	
	30s	3) Preferred Fast Pace (PFP) : the fastest pace the subject could perform	
The pace given by metronome	20s	rest	
	30s	4) Metronome Preferred Pace (MPP) : the same pace as PP	
	20s	rest	
	30s	5) Metronome Slow Pace (MSP) : the pace that is 30% slower than MPP	
	20s	rest	
	30s	6) Metronome Fast Pace (MFP) : the pace that is 30% faster than MPP	
	20s	rest	

channels. Analysis of variance (ANOVA) was conducted to determine the difference in $\Delta[\text{oxy-Hb}]$ among the six pace tasks. A non-paired t -test was conducted to examine whether there was any gender difference of $\Delta[\text{oxy-Hb}]$ during PP. The IBM SPSS Statistics 19 software (IBM, Tokyo, Japan) was used for analysis and the level of significance was taken as 5%.

5. Questionnaire data analysis

Data obtained from the questionnaire survey were analyzed using a qualitative-inductive method.

III. Results

1. fNIRS data

Finger-tapping at the pace decided by the subjects (PP, PSP and PFP) tended to consume more $\Delta[\text{oxy-Hb}]$ than any of the other paces (MPP, MSP and MFP). Analysis by ANOVA revealed that $\Delta[\text{oxy-Hb}]$ during PP were significantly greater than MFP in 3/16 channels (ch6, $p=0.04$; ch12, $p=0.00$; ch13, $p=0.02$) (Fig. 1a-1c). These channels are located adjacent to the orbito-frontal cortex area of the frontal lobe (Brodmann area 10, 11, 12) (Fig. 2).¹⁴ Also, in female subjects, ANOVA analysis revealed that $\Delta[\text{oxy-Hb}]$ during PP and MFP were significantly different in one channel (ch6: $p=0.01$).

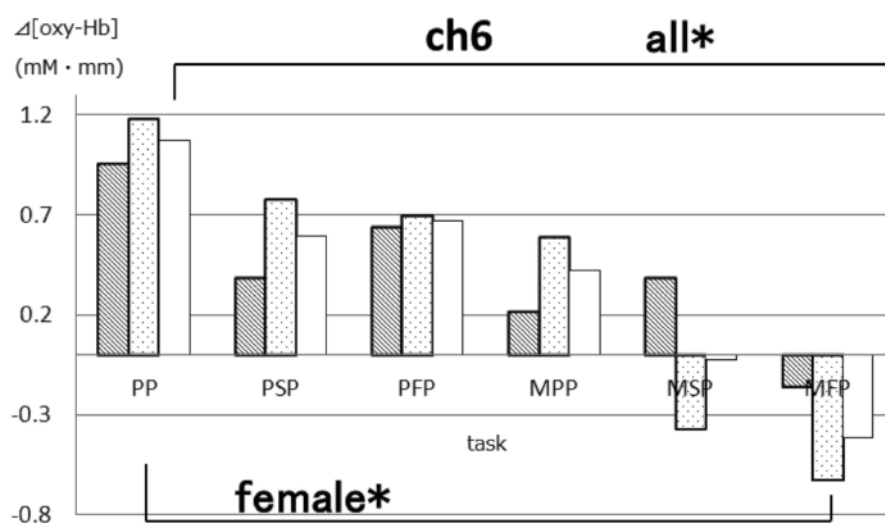


Fig. 1a $\Delta[\text{oxy-Hb}]$ in male (dashed), female (dotted), and all subjects (white) in ch6. $\Delta[\text{oxy-Hb}]$: oxygenated hemoglobin concentrations. ANOVA: Analysis of variance, $p < 0.05$

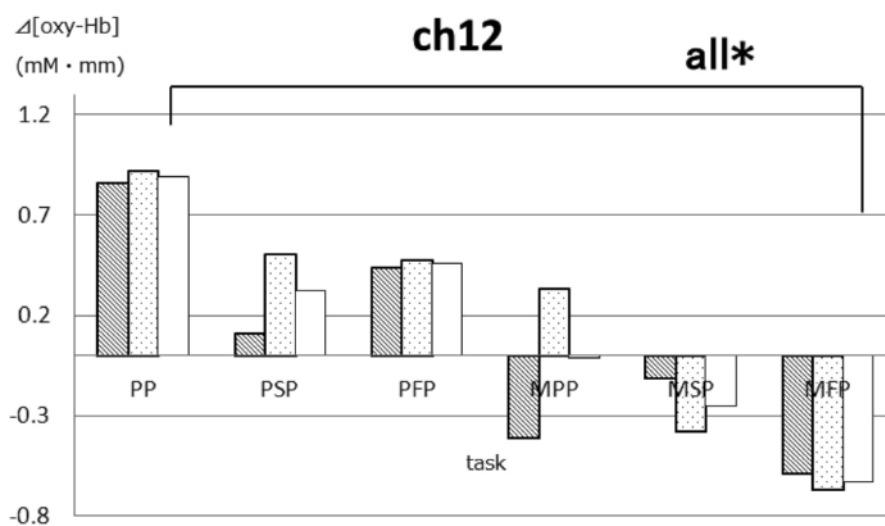


Fig. 1b $\Delta[\text{oxy-Hb}]$ in male (dashed), female (dotted), and all subjects (white) in ch12. $\Delta[\text{oxy-Hb}]$: oxygenated hemoglobin concentrations. ANOVA: Analysis of variance, $p < 0.05$

There was not any gender difference of $\Delta[\text{oxy-Hb}]$ during PP ($p=0.96$).

2. Questionnaire data

Out of 50 students, 11 subjects (male 3, female 8) reported difficulty in maintaining a constant pace when performing the finger-tapping exercises decided by themselves.

IV. Discussion

1. Difference in $\Delta[\text{oxy-Hb}]$ between PP and MFP

$\Delta[\text{oxy-Hb}]$ in the orbito-frontal cortex were significantly greater during PP than MFP, indicating that the orbito-frontal cortex region is sensitive to the finger-tapping tasks that comprise various paces.

There are reports suggesting that performing a task at PP depends on alertness and attention. Naruse investigated resting frontal EEG asymmetry of alpha-1 (8-10Hz) and alpha-2 (10-13Hz) waves, P300 ampli-

tude and latency during performing a continuous forearm rotational movement at PP.³ Frontal EEG asymmetry of alpha-1 waves were significantly and positively correlated with resting frontal EEG before performing the task at PP, suggesting that frontal neural activity may have an influence on the selection of PP.³ Furthermore, Naruse also suggested that greater relative left frontal activation are also associated with the selection of speed.³ Sakatsume et al. devised a simple test for attentional function consisting of continuous finger-tapping at a constant pace.⁵ The test, applied to 333 brain-damaged subjects, revealed that subjects demonstrating difficulty with this task were more numerous among the right-brain-damaged group with mental symptoms than in any other groups.⁵ The authors suggest that a characteristic of this test is that differences between established speed and actual speed of movement are compared consistently and are continuously revised.⁵ They conclude that attentional func-

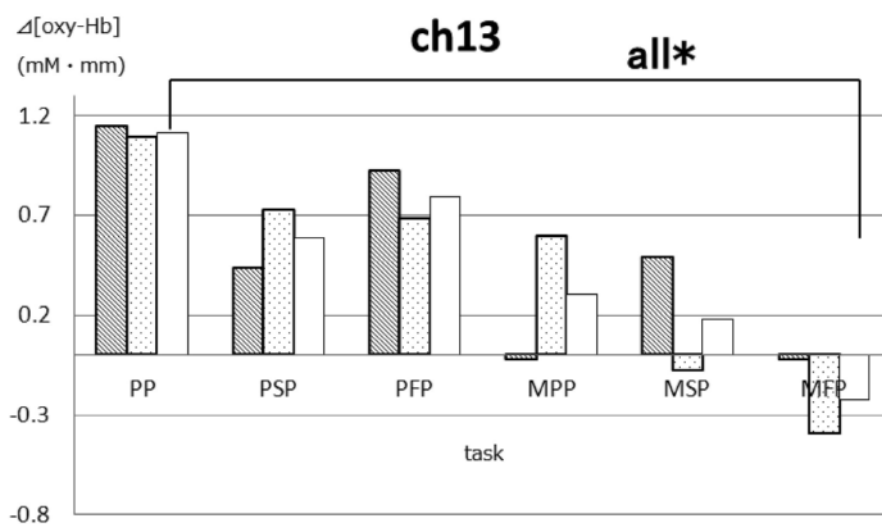


Fig. 1c $\Delta[\text{oxy-Hb}]$ in male (dashed), female (dotted), and all subjects (white) in ch13. $\Delta[\text{oxy-Hb}]$: oxygenated hemoglobin concentrations. ANOVA: Analysis of variance, $p<0.05$

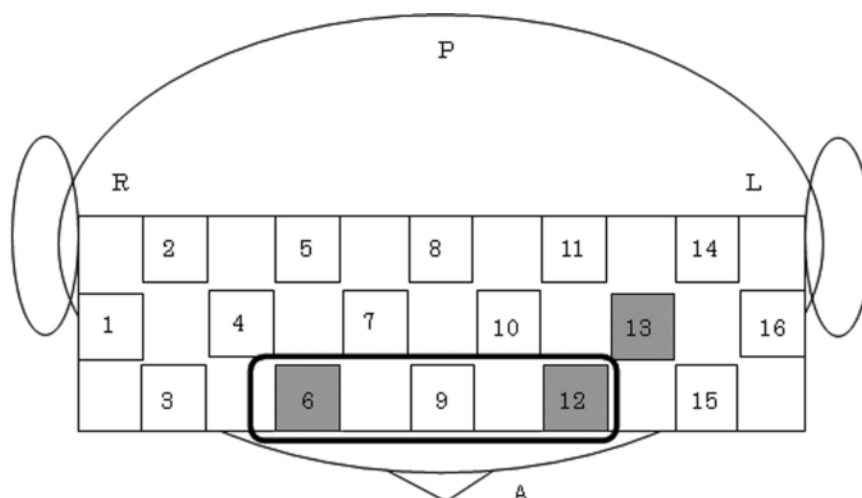


Fig. 2 The location of the fNIRS (functional near-infrared spectroscopy) channels.

tion is more seriously disturbed in cases of right-brain damage than left-brain damage.⁵

According to Kato et al., attentional functions govern various behaviors required for social activities and contribute to unify behaviors.¹⁵ Attentional function is the base of all mental neural activity, and attentional dysfunction influences that activity.¹⁵ According to the literature, there are at least three components of attentional function: focused attention, sustained attention and divided attention. Focused attention is the ability to respond to one of many stimuli.¹⁵ Sustained attention is the ability to continue responding to a certain stimulus during constant stimulation over time. Divided attention is the ability to distribute attention over two or more stimuli at the same time.¹⁵

Of these attentional functions, focused attention is localized in the orbito-frontal cortex.^{6,15} In the present study, finger-tapping at PP activated the orbito-frontal cortex more than MFP. When performing repetitive tasks at PP, one has to select that pace by oneself, and subsequently to adjust and maintain that pace. We think that focused attention is important at this time, and that the orbito-frontal cortex is activated.

From the results of the questionnaire, many of the subjects experienced difficulty with maintaining a constant speed when they performed finger-tapping at a pace that they decided by themselves. Moreover, PP, PSP and PFP tended to consume more $\Delta[\text{oxy-Hb}]$ than MPP, MSP and MFP. From these data, we observed that performing repetitive tasks at a self-determined pace activates the frontal lobe, and tends to generate a feeling of difficulty. In addition, $\Delta[\text{oxy-Hb}]$ during PP were not gender-related, although more females than males reported feeling that the task was difficult.

2. Application to rehabilitation

The present study describes how occupational therapists can set the subject's optimal pace progressively according to the degree of the attentional dysfunction associated with the frontal lobe injury when the subject performs repetitive tasks. Also, the occupational therapist can select a speed adapted to the stage of the subject rehabilitation. If the subject has severe attentional dysfunction, there is a method to allow the occupational therapist to try an initial pace and then to gradually reduce it. If the subject's attentional dysfunction is not too severe to perform a task at his or her own pace, the occupational therapist should lend support so that the subject could perform the task. The exercise will activate the subject's orbito-frontal cortex and promote attentional function. During this

time, it is necessary for the occupational therapist to pay attention to the fatigue of subjects. When subjects are female, this point is particularly important.

3. Limitations of this study and issues for the future

The main limitation of this study is that subjects were all healthy university students. Secondly, the task was limited to a simple and repetitive motor task. Studies encompassing a greater variety of subjects and tasks will be needed to realize the potential of this study. Finally, because a slow pace task had a tendency to affect the pace of the next task,¹⁶ randomization of the tasks was difficult, and the number of times measurements were taken was only once. Given these limitations, we will have to reduce the number of tasks and repeat measurements several times in subsequent studies. In addition, we also aim to conduct many-sided evaluations using not only fNIRS, but also another optical technique, like EEG.

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