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RESEARCH ARTICLE

Prefrontal hemodynamic responses and the degree of flow experience among occupational therapy students during their performance of a cognitive task

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Abstract

Purpose: Although flow experience is positively associated with motivation to learn, the biological basis of flow experience is poorly understood. Accumulation of evidence on the underlying brain mechanisms related to flow is necessary for a deeper understanding of the motivation to learn. The purpose of this study is to investigate the relationship between flow experience and brain function using near-infrared spectroscopy (NIRS) during the performance of a cognitive task. **Methods:** Sixty right-handed occupational therapy (OT) students participated in this study. These students performed a verbal fluency test (VFT) while 2-channel NIRS was used to assess changes in oxygenated hemoglobin concentration (oxygenated hemoglobin [oxy-Hb]) in the prefrontal cortex. Soon after that, the OT students answered the flow questionnaire (FQ) to assess the degree of flow experience during the VFT. **Results:** Average oxy-Hb in the prefrontal cortex had a significant negative correlation with the satisfaction scores on the FQ. **Conclusion:** Satisfaction during the flow experience correlated with prefrontal hemodynamic suppression. This finding may assist in understanding motivation to learn and related flow experience.

Key Words: *Cognition; Hemodynamics; Near-infrared spectroscopy; Occupational therapy; Prefrontal cortex*

INTRODUCTION

Recently, there has been an increase in students with low motivation to learn in schools of occupational therapy (OT) in Japan. As a result, improving the motivation to learn among OT students is one of the most important issues in OT education. The most desirable type of learning motivation is intrinsic motivation, and one of the concepts most closely related to intrinsic motivation is flow [1,2]. The concept of flow is defined as the point in the experiential state that occurs when the learner approaches a state of optimal performance during the performance of a task [3]. This condition occurs when attention to a task is very strong and is accompanied by satisfaction and pleasure [1]. Flow experience has been found to have a significant positive correlation with health-related quality of life among OT students [4]. The frequency and quality of flow experience during daily life have been found to be correlated with psychological tendencies among OT students [5,6]. Furthermore, flow experience is effective in reducing subjective stress among OT students because of their absorption in a task, sense of pleasure, and experience of satisfaction [7], which affect brain activity. In addition, flow experience has been found to have a significant positive correlation with motivation to learn [1]. Students with a higher frequency of flow experience in daily life have a high degree of learning motivation for schoolwork and participation in overall college life, and have a positive focus on future occupations [2]. Therefore, flow experience can promote learning by affecting students' willingness to learn.

Although flow experience has a positive association with motivation to learn, the biological basis of flow experience is

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poorly understood. An accumulation of evidence on the underlying brain mechanisms related to flow is necessary for a deeper understanding about the motivation to learn. Dietrich proposed the transient hypofrontality hypothesis [8], which suggests that energy consumption in the prefrontal cortex (PFC) is automatically suppressed during flow experience [9] because energy sources available to the brain are limited. Dietrich hypothesized that if specific systems are used by the prefrontal regions, a state of transient hypofrontality can occur because flow experience can suppress specific systems [9]. I believe that it is necessary to conduct further empirical studies that use neuroimaging methods to test this hypothesis. The use of near-infrared spectroscopy (NIRS) to measure brain function has increased considerably in recent years. It is a noninvasive, painless, and less costly procedure to perform than magnetic resonance imaging (MRI) or positron emission tomography. Verbal fluency tests (VFTs) have been used frequently as cognitive tasks in previous studies using NIRS [10,11]. Because VFTs can be performed without special stimulation media, they are suitable for use with NIRS, in which measurements are obtained under nearly silent conditions [10,11]. However, no study has elucidated the relationship between prefrontal activity and flow experience using NIRS and VFTs. Therefore, the purpose of this study is to use NIRS to measure brain activity and to use a questionnaire to elucidate the relationship between PFC activity and the degree of flow in OT students during VFT.

METHODS

Participants

This was a cross-sectional study of 60 healthy right-handed OT students (mean age, 19.52 ± 0.96 years; 38 males and 22 females). Written informed consent was obtained from each participant before the study, which was approved by the institutional review board of Kibi International University.

Task performance

The task performance procedure was based on the methods used in previous studies [12,13]. The task performance consisted of a 30-s pre-task baseline period, 60-s VFT, and a 30-s post-task period that were conducted while the participant was seated in a chair. The participants were instructed to keep their head immobile as much as possible, to keep their eyes open, and to refrain from speaking. A block design was used in which a target object presented at baseline was repeated 3 times, alternating with a challenge task. During the pre- and post-task periods, the participants were instructed to repeat the following Japanese vowels: (/a/, /i/, /u/, /e/, and /o/) slowly, during each period. These repetitions were intended to correct the problems with the fluency task data caused by vocalization. During the VFT, the participants were instructed to generate as many Japanese words as possible, beginning with a designated syllable. In this study, 3 initial syllables (1: /a/, /o/, /to/; 2: /ha/, /ka/, /se/; 3: /ta/, /i/, /ki/) were presented to participants in a counterbalanced order, and each syllable was changed every 20 s during the 60-s task. During the VFT, participants changed syllables every 20 s to reduce the time during which they remained silent or gave up on the task. The average total number of correct words during the VFT was used to measure task performance.

Near-infrared spectroscopy

A 2-channel NIRS machine (PocketNIRS; DynaSense Inc., Hamamatsu, Japan), operated at 735 nm, 810 nm, and 850 nm in the infrared light spectrum, was used to measure the relative changes in the concentrations of oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb), according to the modified Beer-Lambert law [14]. Adhesive sheets were used to place 2 probes on the foreheads of participants and were centered on the Fp1 and Fp2 positions according to the international 10/20 system. Each probe contained an emitter optode and a detector optode located 3 cm apart. The Fp1 and Fp2 positions were projected onto the left and right PFC regions, permitting the NIRS to provide a robust measure of hemodynamic changes within a depth of approximately 3 cm [15]. This study focused on (oxy-Hb) because increases in (oxy-Hb) are assumed to reflect cognitive activation more directly than decreases in (deoxy-Hb), as evidenced by the stronger correlation with the blood oxygenation level-dependent signal, measured using the functional (f) MRI [16]. This study defined prefrontal activation as the difference between the average (oxy-Hb) level during the pre-task period and that during the task period.

Flow questionnaire

The flow questionnaire (FQ) [17], which assessed the level of the flow state experienced by the participants during the VFT, consists of 22 items that use a 7-point scale to describe the state or mood experienced while participating in the activities. A higher score indicates a deeper flow state (highly excited state). This questionnaire consists of 6 subcategories: emotional aspects (pleasant, joyful, proud, etc.), satisfaction (total, satisfactory, etc.), activity (aggressive, animated, etc.), concentration (enthusiasm, forgetting oneself, etc.), loss of self-consciousness (relaxed, free, etc.), and sociability (friendship, togetherness), for which average scores were obtained. In the present study, the participants answered the FQ after they had performed the task.

Table 1. Scores on the flow questionnaire among the occupational therapy students during the performance of a cognitive task

Variable	Mean ± SD
Emotional aspects	4.2 ± 0.7
Satisfaction	3.8 ± 0.8
Activity	4.4 ± 0.8
Concentration	5.2 ± 0.9
Loss of self-consciousness	4 ± 0.9
Sociability	4 ± 0.9

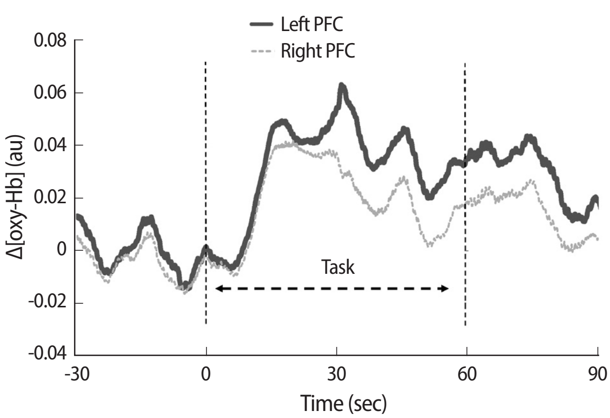

Fig. 1. Representative plot of oxy-Hb changes in the PFC during the verbal fluency test measured using near-infrared spectroscopy. oxy-Hb, oxygenated hemoglobin; PFC, prefrontal cortex.

Data analyses

Descriptive statistics were calculated for each variable. I analyzed the relationships between the FQ score, task performance, and changes in (oxy-Hb) during the task. Pearson correlations were calculated to examine the strength and direction of the relationship between the variables. IBM SPSS ver. 19.0 (IBM Co., Armonk, NY, USA) was used for all analyses. The results are presented as mean ± SD, and a 2-sided P-value of < 0.05 was considered to indicate statistical significance.

RESULTS

Correlation between the flow questionnaire results and oxygenated hemoglobin changes during the task

The average FQ scores are presented in Table 1. Changes in oxy-Hb during the task are shown in Fig. 1. The mean left PFC and right PFC changes in oxy-Hb were 0.013 ± 0.018 au and 0.012 ± 0.018 au, respectively. As presented in Table 2, oxy-Hb changes during the task were negatively correlated with the FQ satisfaction scores in channel 1 (left PFC: r = -0.349, P = 0.006) and channel 2 (right PFC: r = -0.304, P = 0.018). The left PFC and right PFC (oxy-Hb) changes during the task did not correlate with the other subcategory scores of the FQ (r, -0.197 to 0.079; P-value, 0.132 to 0.959).

Table 2. Correlations between the flow questionnaire and oxy-Hb changes among occupational therapy students during the performance of a cognitive task

Variable	Left PFC	Right PFC
Emotional aspects	-0.117	-0.152
Satisfaction	-0.349**	-0.304*
Activity	-0.054	-0.06
Concentration	-0.185	-0.197
Loss of self-consciousness	0.007	-0.112
Sociability	0.079	-0.094

PFC, prefrontal cortex.
*P < 0.05, **P < 0.01.

Table 3. Correlations between the flow questionnaire and task performance among the occupational therapy students

Variable	Correlation coefficient (R)
Emotional aspects	0.263*
Satisfaction	0.456**
Activity	0.358**
Concentration	0.272*
Loss of self-consciousness	0.083
Sociability	0.293*

*P < 0.05, **P < 0.01.

Correlation between flow questionnaire and task performance

The average number of generated words during the VFT was 14.7 ± 3.9 (range, 7.7 to 25). As indicated in Table 3, the students' task performance was significantly correlated with the five FQ subcategories (r, 0.263 to 0.456; P-value, 0.00 to 0.042), except the loss of self-consciousness category.

Correlation between age, sex, task performance, and oxygenated hemoglobin changes during the task

The left and right PFC changes during VFT did not significantly correlate with age (left PFC: r = 0.013, P = 0.919; right PFC: r = 0.043, P = 0.742), sex (left PFC: r = 0.101, P = 0.441; right PFC: r = 0.152, P = 0.245), or task performance (left PFC: r = -0.077, P = 0.557; right PFC: r = -0.081, P = 0.540).

DISCUSSION

I found that oxy-Hb changes in the PFC during the students' performance of the task was negatively correlated with the FQ satisfaction scores. These results indicate that some brain activity associated with flow experience causes the suppression of oxy-Hb in the PFC during task performance. Therefore, our results, which were determined using a measure of brain function, support the hypothesis of Dietrich [9] that energy consumption in the PFC is suppressed automatically during the flow experience. These findings suggest the possibility that PFC activity is suppressed during a feeling of satisfaction gained during the performance of a task. A recent fMRI study, which showed a negative correlation between flow and neural activity in the medial PFC and the amygdala, found a low correlation between task difficulty and activation of specific functional brain regions [18]. The spatial resolving power of the NIRS is inferior compared to the fMRI; therefore, it is not surprising that I found relatively small correlations. Although NIRS is less costly than fMRI, there exists the possibility that it may not be possible to measure state differences accurately using NIRS, which is an important issue.

I also found that task performance correlated significantly with most of the FQ subcategories. Flow is experienced when a high-level task is balanced with high-level skills, and when intrinsic rewards are generated [1]. Therefore, the task used in this study may have been highly relevant and suitable for this group of participants.

I also found that activation of the PFC did not correlate significantly with task performance. These results suggest that task performance was not related to a high degree of oxy-Hb changes in PFCs of the participants. Our results support those of Kameyama et al. [19], who found that the effects on oxy-Hb were not significant for VFT performance in healthy subjects.

This study has some limitations that should be taken into consideration. First, the participants were from a local area of Japan; therefore, further examination covering a wider geographica area is required. Second, the cross-sectional nature of our study precluded a firm conclusion regarding the causal relationship between PFC activation and flow experience. Third, the NIRS instrument that I used had only 2 channels; therefore, the brain areas that I could measure were limited. In the future, multi-channel NIRS should be used to measure other brain areas. Fourth, Dietrich proposed that transient hypofrontality might occur as a trade-off mechanism between 'conscious' processing in PFC to 'automatic' (unconscious) processing in the basal ganglia with extensive practice [8]. However, participants performed the task only 3 times in the present study. Another limitation of the study design was that the task included only a VFT. Moreover, clarifying and defining the parameters, such as 'less-flow' and 'over-flow' conditions, would enable us to make an accurate comparison. Further research is required with respect to the study design.

In conclusion, I investigated the relationship between flow experience and brain function using NIRS and a VFT. Satisfaction with the flow experience correlated with prefrontal hemodynamic suppression. This finding may facilitate a deeper understanding of the motivation to learn and its relationship to flow experience.

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CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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SUPPLEMENTARY MATERIAL

Audio recording of the abstract.

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