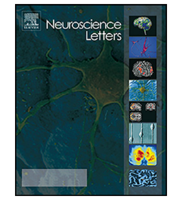
Neuroscience Letters 573 (2014) 30–34

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet



Brain activity during the flow experience: A functional near-infrared spectroscopy study

Kazuki Yoshida [a,b], Daisuke Sawamura [g], Yuji Inagaki [d], Keita Ogawa [c], Katsunori Ikoma [e], Shinya Sakai [f,*]

[a] *Division of Health Sciences, Graduate School of Health Sciences, Hokkaido University, Japan*
[b] *Department of Occupational Therapy, Faculty of Human Science, Hokkaido Bunkyo University, Japan*
[c] *Department of Rehabilitation, Hokkaido University Hospital, Japan*
[d] *Department of Rehabilitation and Physical Medicine, Graduate School of Medicine, Hokkaido University, Japan*
[e] *Department of Rehabilitation Medicine, Hokkaido University, Japan*
[f] *Department of Functioning and Disability, Faculty of Health Sciences, Hokkaido University, Japan*
[g] *Department of Occupational Therapy, School of Rehabilitation Sciences, Health Sciences University of Hokkaido, Japan*

HIGHLIGHTS

- We used fNIRS to examine brain activity in the prefrontal cortex during a flow state.
- This is the first study to measure brain activity during flow in a natural environment.
- There was significant activation of the VLPFC, FPA, and DLPFC during the flow state.
- Flow may be associated with prefrontal functions such as emotion and reward processing.

ARTICLE INFO

Article history:
Received 27 February 2014
Received in revised form 24 April 2014
Accepted 6 May 2014
Available online 13 May 2014

Keywords:
Flow experience
fNIRS
Brain activity
Prefrontal cortex
Video game task

ABSTRACT

Flow is the holistic experience felt when an individual acts with total involvement. Although flow is likely associated with many functions of the prefrontal cortex (PFC), such as attention, emotion, and reward processing, no study has directly investigated the activity of the PFC during flow. The objective of this study was to examine activity in the PFC during the flow state using functional near-infrared spectroscopy (fNIRS). Twenty right-handed university students performed a video game task under conditions designed to induce psychological states of flow and boredom. During each task and when completing the flow state scale for occupational tasks, change in oxygenated hemoglobin (oxy-Hb) concentration in frontal brain regions was measured using fNIRS. During the flow condition, oxy-Hb concentration was significantly increased in the right and left ventrolateral prefrontal cortex. Oxy-Hb concentration tended to decrease in the boredom condition. There was a significant increase in oxy-Hb concentration in the right and left dorsolateral prefrontal cortex, right and left frontal pole areas, and left ventrolateral PFC when participants were completing the flow state scale after performing the task in the flow condition. In conclusion, flow is associated with activity of the PFC, and may therefore be associated with functions such as cognition, emotion, maintenance of internal goals, and reward processing.

1. Introduction

Flow is the holistic experience that occurs when an individual acts with total involvement [1]. Flow is a psychological state that is characterized by a high level of attention with a low sense of effort, low self-awareness, and a sense of control and enjoyment, and occurs during the performance of tasks that are challenging but matched in difficulty to the skill level of the individual [2,3]. The state of flow has been studied in a wide range of tasks, from chess playing to rock climbing, and is described in remarkably similar terms across activities.

Understanding the brain activity that occurs during a state of flow is critical to understanding the state of absorption and optimal performance, yet the brain activity that occurs during a state of flow has not been investigated in detail. A positron emission

* Corresponding author at: Department of Functioning and Disability, Faculty of Health Sciences, Hokkaido University, Sapporo, N-12 W-5 Kita-ku, Sapporo 060-0812, Japan. Tel.: +81 11 706 3388; fax: +81 11 706 3388.
E-mail address: sakai@hs.hokudai.ac.jp (S. Sakai).

http://dx.doi.org/10.1016/j.neulet.2014.05.011
0304-3940/

tomography (PET) study revealed a positive correlation between flow proneness in daily life and dopamine D2 receptor availability in the dorsal striatum [4]. This study suggested that flow proneness is associated with dopaminergic transmission in the dorsal striatum, which is associated with reward processing, impulse control, and positive affect [5,6]. Klasen et al. [7] used functional magnetic resonance imaging (fMRI) to evaluate brain activity during flow and demonstrated increased activity in midbrain reward structures as well as a complex network of sensorimotor, cognitive and emotional brain circuits during a state of flow. However, the level of flow was not assessed, and it is not clear whether participants were able to enter a full state of flow when their heads were fixed in the magnetic resonance scanner. In addition, the brain areas that were activated included a large motor network (including the cerebellum and motor and premotor areas) and may have been confounded by the motor requirements of the experimental task.

Anatomically, the prefrontal cortex (PFC) has connections with the anterior cingulate cortex and limbic regions, such as the amygdale, that process emotion [8]. Functionally, the dorsolateral PFC (DLPFC) is involved in attention and concentration [9,10], the frontal pole area (FPA) is involved in the simultaneous performance of multiple tasks, particularly the maintenance of high-order internal goals during the performance of other sub goals [11,12], and the orbitofrontal cortex is involved in the processing of emotion, reward, and subjective pleasantness and unpleasantness [13]. It is assumed that flow is closely related to attention, emotion, and reward [2,3]; functions that are processed by the prefrontal lobe. However, the association between flow and activity in the prefrontal lobe has not directly been investigated.

Functional near-infrared spectroscopy (fNIRS) can be used to noninvasively monitor cerebral hemodynamics. fNIRS is less vulnerable to head and body motion artifact than fMRI, has greater temporal resolution, and can be performed while subjects perform tasks in a natural and comfortable environment. fNIRS is therefore an ideal method by which to evaluate brain activity during the flow experience. The aim of this study was to describe the activity of the PFC during flow and to examine the role of prefrontal areas in the flow experience.

2. Methods

2.1. Participants

Twenty right-handed healthy university students (10 females) participated in this study (age range, 21–25 years; mean ± standard deviation age, 22.3 ± 1.2 years, mean duration of education, 15.3 ± 1.2 years). No participants had any neurological or psychiatric history, or any medical history affecting their cognitive function. The Ethics Committee of the Faculty of Health Sciences at Hokkaido University approved the study protocol (approval number 12-91) and all participants provided written informed consent.

2.2. Experimental task

The Tetris® computer game was used as the experimental task. In this game, blocks of seven different shapes fell at a constant speed in a random order. Participants were required to manipulate the position of these blocks using keys on a computer keyboard. The playing field was 14 cells wide by 24 cells high, and each game ended when the blocks were stacked to the top of playing field.

The task was performed under two different conditions designed to induce psychological states of boredom and flow. In the boredom condition the level of skill required to complete the game was much lower than that of any healthy young person. The blocks descended at a rate of one cell every 1200 ms. In the flow condition the level of skill required to complete the game was matched to the skill level of the participant. The blocks initially descended at a rate of one cell every 800 ms, and this decreased by 33 ms every 20 s. Participants were also given the option of accelerating the falling speed of the blocks by pressing the down arrow key. Participants received an explanation of the game and practiced the game under the flow condition for 2 min before beginning the experiment.

2.3. Evaluation of flow state

The flow state scale for occupational tasks was used to evaluate flow state. The scale has 14 items, each rated on a seven-point Likert scale, and measures comparative change in flow state with good reliability and validity [14].

2.4. Experimental procedure

The experiment was conducted in a block design in which the experimental task was performed four times: Twice under the boredom condition and twice under the flow condition. The order of the conditions was counterbalanced as follows: flow-boredom-flow-boredom or boredom-flow-boredom-flow. Each block lasted 6 min and consisted of four parts: (1) Participants read the flow state scale for 30 s and responded "undecided" to each item, (2) Participants performed the experimental task for 4 min, (3) Participants completed the flow state scale in 1 min, and (4) Participants rested while looking at a monitor for 30 s. The total imaging time was 24 min.

2.5. fNIRS

fNIRS was performed using the multichannel fNIRS optical topography system (LABNIRS, Shimadzu Corporation, Kyoto, Japan) with three wavelengths of near-infrared light (780, 805, and 830 nm). Samples were recorded every 57 ms. fNIRS probes were arranged in a 5 × 7 matrix of 17 illuminating probes and 18 detecting probes arranged alternately with an inter-probe distance of 3 cm, resulting in 58 channels. The probes were positioned over the PFC. Probe 8 (between channels 3 and 4) was placed over Fpz, and the midline of the matrix (channels 10, 23, 36, and 49) overlapped the medial line (Fig. 1). fNIRS optode positions and several scalp landmarks (Cz, Nz, and right and left pre-auricular points) were digitized using a three-dimensional magnetic space digitizer (FASTRAK; Polhemus, Colchester, VT, USA). Probabilistic registration [15] was used to register fNIRS data to Montreal Neurological Institute standard brain space through the international 10–20 system. The optical fNIRS data were analyzed according to the modified Beer–Lambert-Law [16] to quantify changes in oxygenated hemoglobin (oxy-Hb), deoxygenated hemoglobin, and total hemoglobin concentration [17]. All analyses were performed on the change in oxy-Hb concentration.

2.6. Statistical analysis

fNIRS data were analyzed using the NIRS-SPM toolbox [18] to identify general regions of activation. Two comparisons were made: (1) the 20 s prior to the start of the experimental task vs. the 30 s after the end of the experimental task, i.e., when participants were completing the flow state scale before and after performing the task, and (2) the first 30 s of task performance vs. the last 30 s of task performance. Activated channels were grouped into six regions of interest (ROIs) using LABNIRS, as described by Yanagisawa et al. [19]. Briefly, the estimated anatomical location of each channel was determined according to the LBPA40 multichannel atlas [20] and three or four neighboring channels were combined to form each ROI. The ROIs were the left DLPFC (L-DLPFC), left ventrolateral PFC