Dual pathway for controlling attention ability in the central nerve system

Yoshitada KATAGIRI1 Tomomi BOHGAKI2

1 Center for Information and Neural Networks, National Institute of Information and Communications Technology, Yamadaoka 4-1, Suita, Osaka 565-0871, Japan

ykatagiri@nict.go.jp

2 College of Nursing, Aichi Medical University, 1-1 Karimata Yazako Nagakute, Aichi 480-1195 Japan

[bohgaki@aichi-med-u.ac.jp](mailto:bohgaki@aichi-med-u.ac.jp)

**Abstract.** Activated areas in the brain necessary for attention processing have been identified by previous neuroimaging studies, however, dynamic neural mechanism for explaining complex attentional performances dependent on both task types and subjects still remains unclear. We here examined two types of continuous performance tasks (CPTs), SRT-CPT for testing simple reaction and AX-CPT for working memory to clarify the dynamic attentional mechanism. We found that statistical distribution of response time exhibited a composite function having two independent components. This indicates that attention could be controlled by dual attentional pathways switchable according to contexts. We finally presented a neural model with dual attentional pathways, taking into account background measurements of electroencephalogram and near-infrared hemoencephalogram. This model is useful for explaining the complexity of task- and subject-dependent attention performances.

**Keywords.** Attention, cognitive control, continuous performance test, electroencephalogram, near-infrared hemoencephalogram

Received: May 5 2014; Revised: July 12 2014,; Accepted: Sept. 1 2014

Ethics. Entire experimental protocols were approved by the ethics committee of Aichi Medical University

Funding. This work was supported by New Energy and Industrial Technology Development Organization and Grants-in-Aid for Scientific Research (25420236, 23593274) promoted by Japan Society for the Promotion of Science.

1. Introduction

Although attention ability is a primary function of the prefrontal cortex, it can be readily degraded by higher-order brain dysfunctions typically including dementia [1] and depression [2]. Functional magnetic resonance imaging (fMRI) studies [3, 4] have identified brain regions related to sustained attention which primarily include anterior cingulated cortex (ACC) associated with other regions to form cerebral attention networks [5]. Although recent intense progress in studies of default-mode networks predicts participation of dynamic cortical interactions in attention control [6], incredible discrepancy between measurement and theoretical simulation is an impediment to investigation of the whole picture to draw the cerebral attention scheme. In contrast with such theoretical approaches, clinical investigations under critical ambience provided a wide variety of evidence that attention ability is dependent on types of tasks and subjects [7]. Consequently, how the brain controls attention still remains complex and unclear. This study aimed to investigate the complexity of attentional behaviors for theoretically explaining the cerebral attention mechanism.

1. Experiments

A simple cognitive task using the nine numerical characters modified from Conners’ Continuous Performance Test (CPT) [8] was adopted to numerically evaluate sustained attention. Two types of tests were performed: one was a Simple Response Time test (SRT-CPT) where subjects were asked to promptly press a button when they recognized a numerical target letter (usually 7) on a display, and the other was a selective response test (AX-CPT) where subjects were asked to press a button only when recognized the target character combination such as 3-7 while withholding the response when they recognized any other characters. The SRT-CPT lasting for about 4 minutes consisted of 80 stimuli, while the AX-CPT lasting for about 17 minutes consisted of 40 targets involved in 400 stimuli in total.

Experiments were performed with 5 healthy young participants (females, age: 19-22 years). Electroencephalogram (EEG) with 21 Ag/AgCl electrodes sited according to the International 10-20 system (sampling frequency: 512Hz, resolution: 24bit) and near-infrared hemoencephalogram (NIR-HEG) at the forehead center were simultaneously recorded during the tests. EEG signals were analyzed using a fast Fourier transform (FFT) technique to generate time-series data of occipital (O1, O2) alpha-2 band (10-13 Hz) power extracted from the FFT data (rate: 32-SPS (samples/s), epoch: 1 sec). Such occipital EEG power stream reflects thalamic activity [9-10], therefore, it was defined as a fundamental brain activity index (FBA-index).

To explore the cerebral attention mechanism, the arousal level of subjects was modulated by using essential oils extracted from plants, which directly stimulate the entorhinal cortex via olfactory bulbs and thereby induce alteration in cognitive processes associated with attention. Such essential oils were introduced to subjects’ brain by inhalation. Entire experimental protocols were approved by the ethics committee of Aichi Medical University.

1. Results and discussion

Figure 1 shows a whole aspect of experimental results. We found that the sustained attention estimated by CPT tests was task dependent: the dependence was characterized by a negative correlation between SRT and AX response time in higher arousal levels (corresponding to a shorter SRT-CPT response time range) (Fig. 1**a**), while they represented positive correlation in lower arousal levels (corresponding t a longer SRT-CPT response time range). Consequently, a U-shaped correlation curve was obtained. The number of AX-CPT errors increased with the increasing arousal level (Fig. 1**b**). As the arousal level decreased, the SRT-CPT response time became longer. This attention performance decline was however accompanied with structural changes in histograms of response time: typical two lobes were identified (Fig.2). This indicated that attention is controlled via dual pathways. The time course of the SRT-CPT response time corresponding to Fig. 2**b** exhibited an extraordinary aspect where the response time alternately fluctuated (Fig. 3**a**) to form a stable track in a return map (Fig.3**b**). In contrast, we found a case where the AX-CPT performance was not inferior in response time as compared with the SRT-CPT performance (Fig. 4). This was evidence for a hypothesis that sustained attention is subject dependent. The neurophysiological responses as shown in Fig. 5 may explain the task dependence of attention: the SRT-CPT required right-dominant higher FBA-index while the AX-CPT required higher prefrontal cortex (PFC) activity with bilateral thalamic activities.



**Fig. 1**  Task-dependent performances of the continuous performance test (CPT). **a**: SRT-CPT vs. AX-CPT response time (**a**) and number of errors for AX-CPT as a function of SRT-CPT response time (**b**).



**Fig. 2** Histograms of SRT-CPT response time for various arousal levels: (**a**) high (**b**) medium (**c**) low.



**Fig. 3** Time course of SRT-CPT response time (**a**) and corresponding return map (**b**).



**Fig. 4** Histograms of SRT-CPT and AX-CPT for a subject exhibiting extraordinary quick AX responses.



**Fig. 5**  Neurophysiological responses during CPT performances. Fundamental brain activity (a), Asymmetry of FBA (b), and corresponding NIR-HEG signal (C).

We presented an example of a table (Table. 1) to explain how to include and format it. The table should be centered within the page. A blank line should be inserted after the table.

**Table. 1**  Example of a table and its formatting.

|  |  |  |  |
| --- | --- | --- | --- |
| Column title | Column title1 | Double column title | |
| Column title2 (sec) | Column title3 (%) |
| Cell text | 1 | 20.5 | 66 |
| 2 | 18.6 | 75 |
| Cell text | 1 | 18 | 13 |
| 2 | 17.6 | 29 |

In conclusion, the brain network model with dual pathways can explain various extraordinary attention responses dependent on tasks and subjects. We believe that this model can be extended to predicting alteration of attention ability caused by various physical and psychiatric disorders.

This work was supported by New Energy and Industrial Technology Development Organization and Grants-in-Aid for Scientific Research (25420236, 23593274) promoted by Japan Society for the Promotion of Science.

References

1. McGuinness B, Barrett SL, Craig D, Lawson J, Passmore AP.: Attention deficits in Alzheimer's disease and vascular dementia. J Neurol Neurosurg Psychiatry. 81(2), pp.157-159 (2010)
2. Boeker H, Schulze J, Richter A, Nikisch G, Schuepbach D, Grimm S.: Sustained cognitive impairments after clinical recovery of severe depression. J Nerv Ment Dis. 200(9), pp.773-776 (2012)
3. Tana MG, Montin E, Cerutti S, Bianchi AM.: Exploring cortical attentional system by using fMRI during a Continuous Perfomance Test. Comput Intell Neurosci. doi: 10.1155/2010/329213 (2010)
4. Kim C, Johnson NF, Gold BT.: Common and distinct neural mechanisms of attentional switching and response conflict. Brain Res. 1469, pp. 92-102 (2012)
5. Greicius MD, Menon V.: Default-mode activity during a passive sensory task: uncoupled from deactivation but impacting activation. J Cogn Neurosci. 16(9), pp. 1484-1492 (2004)
6. Sun G, Qian S, Jiang Q, Liu K, Li B, Li M, Zhao L, Zhou Z, von Deneen KM, Liu Y.: Hyperthermia-induced disruption of functional connectivity in the human brain network. PLoS One.8(4):e61157 (2013)
7. Gaoua N, Racinais S, Grantham J, El Massioui F.: Alterations in cognitive performance during passive hyperthermia are task dependent. Int J Hyperthermia.27(1), pp. 1-9 (2011)
8. Ballard JC: Computerized assessment of sustained attention: a review of factors affecting vigilance performance. J Clin Exp Neuropsychol. 18(6), pp. 843-863 (1996)
9. Laufs H, Kleinschmidt A, Beyerle A, Eger E, Salek-Haddadi A, Preibisch C, Krakow K.: EEG-correlated fMRI of human alpha activity. Neuroimage. 19(4), pp. 1463-1476(2003).
10. Sadato N, Nakamura S, Oohashi T, Nishina E, Fuwamoto Y, Waki A, Yonekura Y.: Neural networks for generation and suppression of alpha rhythm: a PET study. Neuroreport. 9(5), 893-897 (1998)