The Change of Event Related Hemodynamics and Event Related Potentials in Frontal Lobe caused by modified PVSAT

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Abstract

This paper discusses “attention” in cognitive function by analyzing hemodynamics and potentials while performing modified paced visually serial addition test (mPVSAT). The test needs higher-order attention i.e. selective attention, which is evaluated by event related hemodynamics and event related potentials in our study.

1 Introduction

In psychophysiology, attention is well known as the most fundamental function to process cognitive performance in brain. Sohlberg and Mateer’s attention process model classifies its hierarchy into five levels: focused, sustained, selective, alternating and divided attention. In the process of cognitive control by attention, the brain keeps necessary information temporarily and handles the problem [1]. This process associates with function included in working memory, and it is in Broadmann’s Area 9 and 46 [2].

The attentional function corresponds to the neural activity. When nerve activity is evoked, oxygen and glucose are used to produce energy in the active area. The capillary reaction that occurs at that moment is called neurovascular coupling (NVC) [3]. According to the mechanism of NVC, it is necessary for our research to evaluate brain blood flow in the form of oxygenated hemoglobin concentration (Oxy-Hb). Oxy-Hb can be measured by near-infrared spectroscopy (NIRS) and is also known for its usefulness for mental diseases such as depression [4]. In addition to this fact, a change of electrical potentials in brain is caused by various mental activities by external or internal stimulus. Generally, the primary signal (neural activity) which is produced by stimulation to brain evokes secondary signal (e.g. blood flow). The interval between these two signals is approximately 0.5s. This mechanism is recognized that neural activity and brain blood flow are related closely each other [5].

In our previous researches, time series of Oxy-Hb are evaluated and the volume in left dorsolateral prefrontal cortex (DLPFC) at frontal lobe increased, when subjects perform paced auditory serial addition test (PASAT) which relates to auditory attention [6]. After that, we also have focused on visual attention in addition to auditory attention.

All the approaches concerned with hemoglobin concentration are described by event related hemodynamics (ERHs). On the other hand, Event related potentials (ERPs) is an electrical phenomenon which is regarded as a cognitive and judgement process of endogenous sensory information. Endogenous component is measured by subtraction method which offsets exogenous component. In ERP measurement, Oddball task is a famous auditory paradigm as simple stimulation classification task which discriminates target stimulus from standard stimulus[7].

Referring to these previous works, our research in this paper uses modified paced visual serial addition test (mPVSAT) as an experiment of the paper and consider ERHs and ERPs for attentional control tasks.

2 Experimental Methods

In this research, the experiments were performed in a shield room in order to block noises: sounds and light stimuli. The data were obtained from 14 healthy subjects (10 males and 4 females, age range 20 to 22 years). All subjects were well informed, and they consented to all conditions of the experiment prior to start it. This study has been approved by the Ethics Committee for Human Research at Kokushikan University.

2.1 Modified PVSAT

Attention disorder is one of the more serious troubles related to various higher-order cognitive functions. The PASAT developed by Gronwall to evaluate and judge attention disorders in neuropsychology. It is included in Clinical Assessment for Attention (CAT) that is standardized and issued in 2006 by the Japan Society for Higher Brain Dysfunction. The original PVSAT, paced visual serial addition test, adopted in the experimental task of this paper, was visualized PASAT by Fos LA et.al.[8].

When measuring brain function, it is difficult to obtain accurate data while performing PASAT or PVSAT. Because these tasks need utterance, the data may often in-
clude artifacts or noises. Therefore, we propose modified PVSAT, “mPVSAT” in short, that let a subject judge true or false of answer only in mind without uttering. In mPVSAT, true answers indicate control task which is appearance rate of 80%. False answers, on the other hand, indicate rare task which is appearance rate of 20%. In addition, the subjects are ordered to count a number of false answers to focus on this task. Herewith, we expect that mPVSAT is able to extract complex endogenous component deriving from focused attention, working memory and selective attention by instantaneous judgement of errors.

In this paper, mPVSAT of the interval 1s and the display time 0.5s is adopted as experiment. The number of question & answer is 100, then total time for task is 150s (Fig.1).

![Fig.1 The method of mPVSAT](image1)

2.2 Near Infrared Spectroscopy

The type of NIRS used for this experiments is wearable optical topography system (WOT-100, Fig. 2(a)) manufactured by HITACHI HIGH TECHNOLOGIES. By using this NIRS equipment, three kinds of hemoglobin concentration (Oxy-Hb, Deoxy-Hb, Total-Hb) in cerebral cortex are measured with the sampling rate set at 5Hz. Subjects put NIRS probe on their frontal lobe and keep his/her head unmoving during the experiment.

2.3 Electroencephalogram

EEG is obtained by MUSE brain system manufactured by DIGITAL MEDIC (Fig.2(b)), whose sampling rate is 1000Hz. Subjects put EEG sensor on their Cz position referring from the international 10-20 positions (Fig.2(c,d)). In analyzing the data of ERHs and ERPs, some pretreatments are needed in advance.

![Fig. 2 Instruments for measurement of brain activity](image2)

3 Analysis Technique

As shown in the previous section, 2 kinds of measurements can be observed for mPVSAT. They are hemoglobin concentration and EEG. Hemoglobin concentrations are measured at 16 channels but only 5Hz, whereas EEG is given by 1000Hz but only 1 point (Cz). In order to analyze these data with irregular properties, the authors use some techniques in addition to the normal statistics. Because there are comparatively many channels in NIRS, the method including data reduction step is adopted. The method applied in this paper is hierarchical components analysis, HDA [7], which consists of the principal components analysis and multivariable autoregressive modeling technique. Autoregressive modeling is also used for EEG as basic analyzing method.

3.1 Autoregressive Modeling

Autoregressive (AR) model is used as one of the standard analytical technique to present stochastic process. The model is given by (1) for single dimension case.
Hierarchical Decomposition Method

Hierarchical decomposition is one of the multivariable AR modeling techniques including principal components analysis (PCA). The method constructs a data vector using multivariable measurements \( X \) and the resultant \( T \) is matrix of principal components. This step changes the data matrix (row size \( M \)) to smaller matrix (row size \( P \)). The number of channels \( P \) is selected by certain level of contribution rate, which we apply the threshold of \( M^{-1} \) in this paper.

\[
X = C^WT \tag{3}
\]

The next step, resultant matrix \( T \) is modelled by autoregressive form. MAR model (4) of the temporal components \( T_{p,s} \) is determined by minimizing the sum of squared residual values (5).

\[
T_{p,s} = R_{p,s} + \mu_p + \sum_{q=1}^{P} \sum_{l=1}^{L} A_{q,p} T_{q,s-l} \tag{4}
\]

\[
R_{s,MLAB} = \sum_{p=1}^{P} \sum_{s=1}^{S} R_{p,s}^2 \tag{5}
\]

\( \mu_p \) denotes a mean value, \( R_{p,s} \) denotes a residual value and \( A \) is a three-dimensional matrix of estimated model parameters given by Yule-Walker equation (2). \( L \) is the model order estimated by Akaike’s Information Criteria (AIC).

The 3\(^{rd} \) step and 4\(^{th} \) step are needed because the model is not unique in the above step. The 3\(^{rd} \) is to seek transformation matrix which orthonormalizes the innovations \( R_{p,s} \). If we denote it as \( K \), new temporal components and new estimates are given by the following equations (6)(7).

\[
T' = KT \tag{6}
\]

\[
A_i^T = KA_i^T K^{-1} \tag{7}
\]

However, transformation by \( K \) still does not fully resolve the non-uniqueness problem. The 4\(^{th} \) step is to search for a rotation whose transformed temporal components consistent with the hierarchical structure. If \( Q \) is denoted as transformation matrix here, \( Q \) is obtained iteratively via a procedure similar to Jacobi matrix diagonalization.

Finally, HD components are chosen by using the transformation \( Q \) as (8) and (9), where \( T_{HD} \) represents HD components decided from the data vector \( X \).

\[
T_{HD} = QT' \tag{8}
\]

\[
A_{HD}^T = QA_i^T Q^{-1} \tag{9}
\]

If succeeded, estimates of HD components \( A_{HD} \) are of upper triangular form, which means the weights for feed-forward interactions. The lower triangular elements characterize feedback interactions. The diagonals are the self-driving weights describing the contribution to itself.

4 Results & Discussions

First, mPVSAT score is shown by Fig.3. False answer appeared at the rate of 20% in mPVSAT. In this experiment, no subject could discriminate it perfectly. It was interesting that only 3 subjects (A, H, L) answered over 20%. The result suggests that mPVSAT concerns attentional function.

Original measurement results of subject-A are shown by Fig.4. According to the reference stimulus, EEG shows periodical big amplitude. However, the amplitude does not show the difference between rare (false) and frequent (true). On the other hand, transition of Oxy-Hb shows slow change which are similar to the periodical integral of EEG.

Next we calculate ERPs and ERHs by taking ensemble average of each event signal. From Fig.5 to Fig.8, ERP and ERH for 1.2s (depicted from 0.2s before the event started) are shown, where line of the light color is the result of Rare stimulus.
Fig. 4 Original measurement of EEG and Oxy-Hb

Fig. 5 ERP for subject-G

Fig. 6 ERH for subject-G

Fig. 7 ERP for subject-M

Fig. 8 ERH for subject-M

Fig. 9 ERPs for some subjects

Fig. 10 Average of ERHs for each channel, subj-I

Then, average of ERHs for each channel of subject-I is shown in Fig. 10, where the upper figure describes the average of Oxy-Hb for rare stimulus. The middle describes the average for frequent stimulus and the lower describes
showed small order around 5. The results for subject (K to N) are shown in Fig.11. The difference between rare and frequent stimulus were not clear in order, but some model showed small order around 5.

Next, AR model is estimated by the data length 1500 (=1.5s) and shifted at the length 100 (=0.1s) from the beginning to an end to ERPs. The results for subject (K to N) are shown in Fig.11. The difference between rare and frequent stimulus were not clear in order, but some model showed small order around 5.

As for ERPs, HD method is applied and the number of principal components and contribution rate of the 1st component are summarized in Table.1. Mostly, the model is of 1st or 2nd order, which is very simple. But only 2 subjects are 3rd order model with very low contribution rate of the 1st component. Hierarchically decomposed components are shown in Fig.12.

Table.1 The number of principal components and contribution rate of the first component

| Principal component | A | G | H | I | K | L | M | N |
|---------------------|---|---|---|---|---|---|---|---|
| Contribution rate (%) | 88 | 92 | 93 | 55 | 52 | 84 | 90 | 85 |

5 Conclusions

In this paper, mPVSAT is used for attentional control task. It is the modified version of PVSAT concerning visual stimulus. Comparing with PASAT or PVSAT, the task performance process is more complicated and difficult. Evaluation by ERP indicates the late positive deflection than P300, and by ERH, remarkable response is observed especially for incorrect answer.

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