Severity of AD/HD symptoms and efficiency of attentional resource allocation

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Abstract

This study investigated the mechanism that underlies the inefficient allocation of attentional resources in Attention-Deficit/Hyperactivity Disorder (AD/HD). The P300 event-related brain potential (ERP) was elicited from 24 healthy adults using a visual three-stimulus oddball paradigm (standard, 70%; target, 15%; non-target, 15%) and the degree of their AD/HD symptoms was assessed by using AD/HD symptom scales. Target stimulus was a circle and standard stimulus was an "X". Two task conditions were defined according to the non-target stimulus type (typical or novel): a triangle for the typical condition and colored non-repetitive novel stimuli for the novel condition. In both conditions, target and non-target elicited P300s. A ratio of non-target P300 to target P300 amplitude was used to assess the efficiency of attentional resource allocation; low ratio indicates the efficient allocation of attentional resource. The correlation analysis revealed a strong positive correlation between the AD/HD symptom score and the P300 amplitude ratio in the typical condition ($r = .80$), while only a weak positive correlation was observed in the novel condition ($r = .23$). The present study found that the commonality of task-relevant and task-irrelevant information, rather than the stimulus novelty of task-irrelevant information, induces the inefficient allocation of attentional resources in AD/HD.
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Attentional resource allocation is crucial for recognizing the significance of various events which occur in the external environment. However, since attentional capacity is not infinite, an efficient allocation of limited attentional resources is important to achieve a goal-directed behavior. If task-irrelevant information consumes valuable attentional resources, task-relevant information may not be processed sufficiently. Thus, the inefficient allocation of attentional resources could lead to a failure of goal-directed behavior.

Attention-Deficit/Hyperactivity Disorder (AD/HD) is one of the most common childhood disabilities and is characterized by developmentally inappropriate symptoms of inattention, impulsivity and hyperactivity [1,3], which persist into adulthood [21]. Extensive studies have shown that children and adults with AD/HD perform worse than normal controls on broad range of cognitive and attentional tasks, such as the go/no-go task, stop-signal task, and oddball task. They often show a longer response time, a lower hit rate, and a higher false positive rate (e.g., [11,22,27]), all of which indicate that the cognitive mechanism of AD/HD may be associated with the inefficient allocation of attentional resources. However, the mechanism that underlies the inefficient allocation of attentional resources in AD/HD has not yet been elucidated.

It has been known that attentional resources could be allocated not only for task-relevant but also for task-irrelevant information, which often interferes with the task-relevant processing and tends to occur to infrequent task-irrelevant information (e.g., [8]). The inefficient allocation of attentional resources could be due to several factors. One factor is the commonality of task-relevant and task-irrelevant information, which controls the allocation of attentional resources for not only task-relevant but also task-irrelevant information [2,31], and thus task-irrelevant information would deplete attentional resources. Another factor is the stimulus novelty of task-irrelevant information, which provides a strong draw for attention, and thus novel information would be allocated attentional resources even if it is task-irrelevant [9]. It

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has not yet been elucidated which factor induces the inefficient allocation of attentional resources in AD/HD. The main purpose of the present study was to clarify this issue.

We investigated the correlation between the severity of AD/HD symptoms in healthy young adults and the efficiency of attentional resource allocation in two different conditions of an infrequent target detection task; one in which the infrequent non-target is a typical stimulus like the target and frequent standard stimuli, and another in which the non-target is a highly novel stimulus. Wodushek and Neumann [33] demonstrated that a study for non-diagnosed adults could provide rich information regarding the cognitive mechanism of AD/HD by using AD/HD symptom scale. Since most previous studies have been based on a between-groups design (e.g., AD/HD versus normal control, or low versus high AD/HD symptom group), there are no studies that directly examined the correlation between the AD/HD symptom score in non-diagnosed adults and their neural activities regarding the attentional resource allocation. The present study examined this correlation directly.

To elucidate the neural mechanism of attentional resource allocation, several studies have used the event-related brain potential (ERP). One of the most widely studied ERP components is P300 or P3 [25,28,29]. This component is usually obtained with the so-called "oddball paradigm", which is based on the random occurrence of infrequent stimuli that are embedded in a train of frequent standard stimuli. In a classical oddball paradigm, or "two-stimulus" oddball paradigm, a participant has to respond to each infrequent target stimulus by pressing a button or by silent counting. Target stimuli elicit P300, which is a large positive-going potential that has a maximum amplitude over parietal scalp electrode sites with a peak latency of about 300–600 ms, depending on the stimulus modality and task difficulty [14,23]. It has been considered that the amplitude of P300 reflects the allocation of attentional resources [18,32], and its peak latency reflects the time required for stimulus classification [19,20].

One variant of the oddball paradigm, the "three-stimulus" oddball paradigm, presents the participant with an additional infrequent non-target stimulus that is inserted into the sequence of target and standard stimuli. An infrequent non-target also elicits a P300 component. In general, non-target P300 has a more anterior distribution than the parietally distributed target P300, although the properties of the non-target P300 component vary with experimental conditions [6,15–17].

As mentioned above, the P300 component could be elicited by both target and non-target stimuli, and its amplitude reflects the allocation of attentional resources. If the efficient allocation of attentional resources is defined as a maximum allocation for task-relevant information and a minimum allocation for task-irrelevant information, it should be reflected by a larger P300 amplitude for target stimuli and a smaller P300 amplitude for non-target stimuli. One problem arising here is that there are individual differences in the absolute value of the P300 amplitude itself that are due to non-cognitive factors (e.g., anatomical factors, biological factors, and background EEG factors [10,12,26]). This issue would not be a critical problem in a within-participant design or between-groups design comparing

diagnostic and control groups. However, when a correlational approach is employed, this issue would be critical. Therefore, a ratio of non-target P300 to target P300 amplitude would be a better measure to assess the efficiency of attentional resource allocation properly because the individual differences in the absolute value of the P300 amplitude could be canceled out; low ratio indicates the efficient allocation of attentional resource.

Twenty-four healthy young adults (10 men and 14 women, 23 right-handed and 1 ambidextrous) with normal or corrected-to-normal visual acuity and normal color vision served as participants (range = 20–32 years, M = 23.3 years, S.D. = 2.8 years). All participants reported being free of neurological or psychiatric disorders and provided written, informed consent.

Two kinds of Japanese-translated AD/HD symptom scales were used to assess the degree of AD/HD symptoms: the Wender Utah Rating Scale (WURS) [30] and the Current Symptoms Scale [4]. Since Ward et al. [30] reported that 25 WURS items (of the total 61) were particularly good for discriminating between adults with and without AD/HD, the present study used these 25 items (score range: 0–4 each) in WURS. The Current Symptoms Scale contains 18 symptom items (score range: 0–3 each) for AD/HD from DSM-IV in the form of a self-report rating scale. Because both scores showed a similar tendency with respect to the P300 amplitude ratio, the summated score of the WURS and Current Symptoms Scale was used to give individual AD/HD symptom scores (total possible score range: 0–154).

Stimuli were presented on a computer monitor, placed 1 m in front of the participant, in a random series once every 2 s, with a 200 ms duration. In each experimental condition, 300 stimuli were presented, consisting of standard, target, and non-target with probabilities of .70, .15, and .15, respectively. Target stimulus was a circle and standard stimulus was an "X" in both conditions. Two task conditions were defined according to the non-target stimulus type (typical or novel): a triangle for the typical condition and colored non-repetitive novel stimuli for the novel condition. All stimuli were 3.2 cm high × 3.2 cm wide. The participants were instructed to respond to the target stimuli by pushing a button with the right thumb as quickly as possible. Each experimental condition was divided into three experimental blocks and each block lasted about 3.4 min. The order of the two conditions was randomized across participants.

Electroencephalographic (EEG) activity was recorded from 4 midline electrodes at frontal (Fz), central (Cz), parietal (Pz), and occipital (Oz) sites according to the 10–20 System. Both earlobes were used as the reference, and the forehead was used as a ground. Voltage changes caused by eye movements and blinks were monitored with two electrooculogram (EOG) recordings from bipolar electrodes placed at the outer canthi of each eye, and above and below the right eye. Impedance was kept at 10 kΩ or less. The EEG and EOG signals were amplified with a bandpass of 0.05–30 Hz and digitized at 250 Hz. Averaging epochs were 900 ms, beginning 100 ms before stimulus onset. Waveforms were averaged off-line, such that trials with a response error or those in which the EEG or EOG exceeded ±100 μV were rejected automatically.

The P300 component was defined as the largest positive-going peak between 300 and 700 ms after stimulus onset. Peak