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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 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.

Key words:

Introduction

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 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 (2003) 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 [33]. Since most previous studies have been based on a between-groups design (e.g., AD/HD vs. normal control, or low vs. 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, 16, 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.

Methods

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, *SD* = 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. (1993) [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 x 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 latencies for target and non-target were measured from the time of stimulus onset. Peak amplitudes for target and non-target

were measured relative to the prestimulus baseline at the Pz (target) and Cz (non-target) peak latency points. The non-target (Cz)/target (Pz) P300 amplitude ratio was calculated individually, and a correlation analysis was used to investigate the relationship between the degree of AD/HD symptoms and the non-target/target P300 amplitude ratio.

Results

Table 1 shows the mean reaction time, hit rate, and false positive rate. Behavioral performance was similar between the two conditions, and one-way ANOVAs revealed no significant differences.

Fig. 1 shows the grand averaged ERPs from the four midline electrodes for the standard, target, and non-target stimuli in each condition. Targets elicited a Pz maximum P300 component and non-targets elicited a Cz maximum P300 component. The amplitude data from the Pz (target) and Cz (non-target) electrodes were assessed with a two-factor (2 conditions x 2 stimulus categories) ANOVA. This analysis revealed the main effect of stimulus category, which indicates that the P300 amplitude for target was greater than that for non-target, $F (1, 23) = 89.9$, $p < .001$. No significant main effect of condition or its interaction was observed. The same analysis for the latency found neither main effects nor interaction.

Fig. 2 shows scattergrams and Pearson's r correlation coefficients to illustrate

the relationship between the degree of AD/HD symptoms and the non-target/target P300 amplitude ratio. This correlation analysis revealed a strong positive correlation between the AD/HD symptom score and the non-target/target P300 amplitude ratio in the typical condition, r (22) = .80, p = .001, while only a weakly positive correlation was observed in the novel condition, r (22) = .24, p >.2. There were weak or no correlations between the degree of AD/HD symptoms and the absolute values of the P300 amplitude (typical condition: target r (22) = -.41, non-target r (22) = .09; novel condition: target r (22) = -.25, non-target r (22) = -.05). In addition, there were no significant correlations between the AD/HD symptom score and the P300 latency or behavioral performance.

Discussion

In both conditions, target and non-target stimuli elicited P300s that had similar latencies. The amplitudes for the target were larger than those for the non-target stimuli. These results are consistent with previous reports using a three-stimulus oddball paradigm [24].

The non-target/target P300 amplitude ratio reflects the efficiency of attentional resource allocation, and effective allocation is reflected by a reduction in this ratio. The present study found that the AD/HD symptom score in healthy adults is strongly and positively correlated with the non-target/target P300 amplitude ratio in the

typical condition. This finding suggests that individuals with a higher degree of AD/HD symptoms tend to allocate their attentional resource ineffectively, at least when a non-target stimulus has attributes similar to those of a target stimulus. In contrast, there was only a weak positive correlation in the novel condition. These results suggest that the commonality of task-relevant and task-irrelevant information, rather than the stimulus novelty of task-irrelevant information, enhances the association between the severity of AD/HD symptoms and the efficiency of attentional resource allocation. Therefore, it is reasonable to conclude that the commonality of task-relevant and task-irrelevant information induces the inefficient allocation of attentional resources in AD/HD.

In the present study, the AD/HD symptoms are rated in a non-patient sample, resulting in a wide range of symptom scores (score range in the present study was 20-115 within the possible range of 0-154), which makes correlation analysis useful. The AD/HD symptom score in AD/HD patients would be similar or higher than the high scores in the present study. Thus, similar association of AD/HD symptoms with the efficiency of attentional resource allocation would be expected in AD/HD patients, although further research is required.

The present study showed the electrophysiological differences in the absence of performance differences. One possibility is that the absolute value of the reaction time, as well as the P300 amplitude, is ineffective, in particular with non-patient

sample and correlational approach. Furthermore, a similar result pattern has also been found even in the diagnosed AD/HD patient studies (e.g., [13]), which indicates that the electrophysiological marker could be a more sensitive measure in some cases.

This is the first report that demonstrates the strong correlation between the degree of AD/HD symptoms in non-diagnosed adults and their neural activities regarding the attentional resource allocation. This finding provides important evidence for the cognitive mechanism of AD/HD which has been discussed in many neuroscience studies [e.g., 5, 7]. Furthermore, it is reasonable to suppose that the three-stimulus oddball paradigm using typical stimuli can be used to assess the attentional function of children and adults with AD/HD and candidates for AD/HD.

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Table 1.   Mean Reaction Times and Performance Rates for Each Task Condition

	Typical	Novel
Reaction time (ms)	410	410
SD	67	72
Hit rate (%)	99.0	99.5
SD	1.7	1.1
False positive (%)		
Standard	0.1	0.1
SD	0.2	0.2
Non-target	0.3	0.3
SD	0.8	0.8

Figure Captions

Fig. 1.   Grand averaged ERPs for each condition from four midline electrode sites (N

= 24).

Fig. 2.   Correlations between the AD/HD symptom score and the non-target/target

P300 amplitude ratio in each condition. A correlation analysis excluding

outlier data (AD/HD symptom score = 115) also showed a similar result

pattern; r (21) = .64, p < .001 and r (21) = .19, p > .3 for the typical and novel
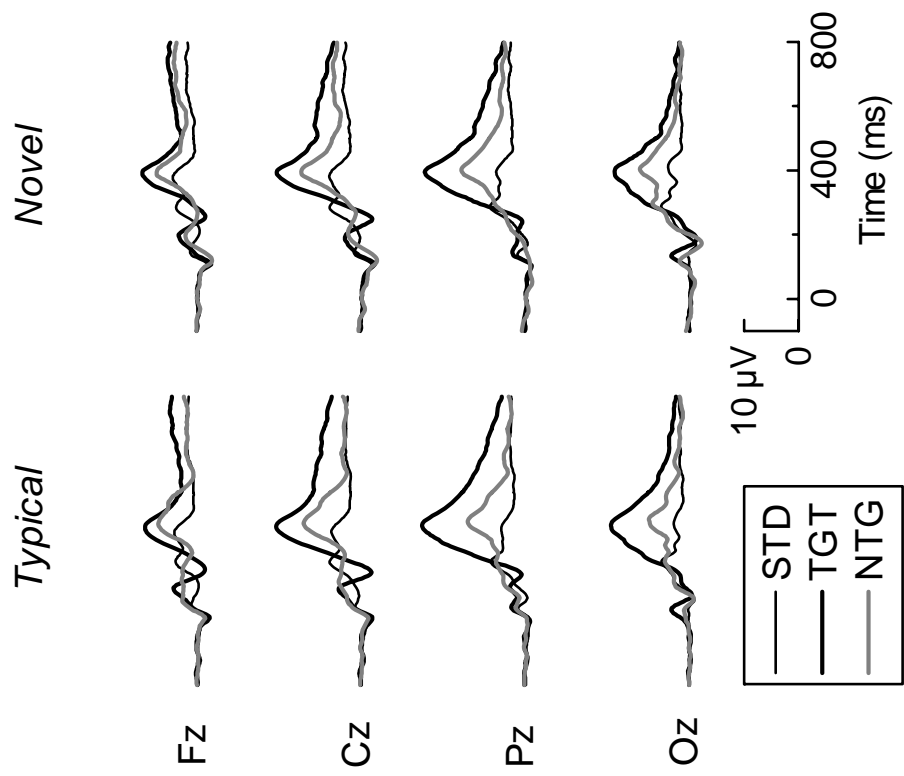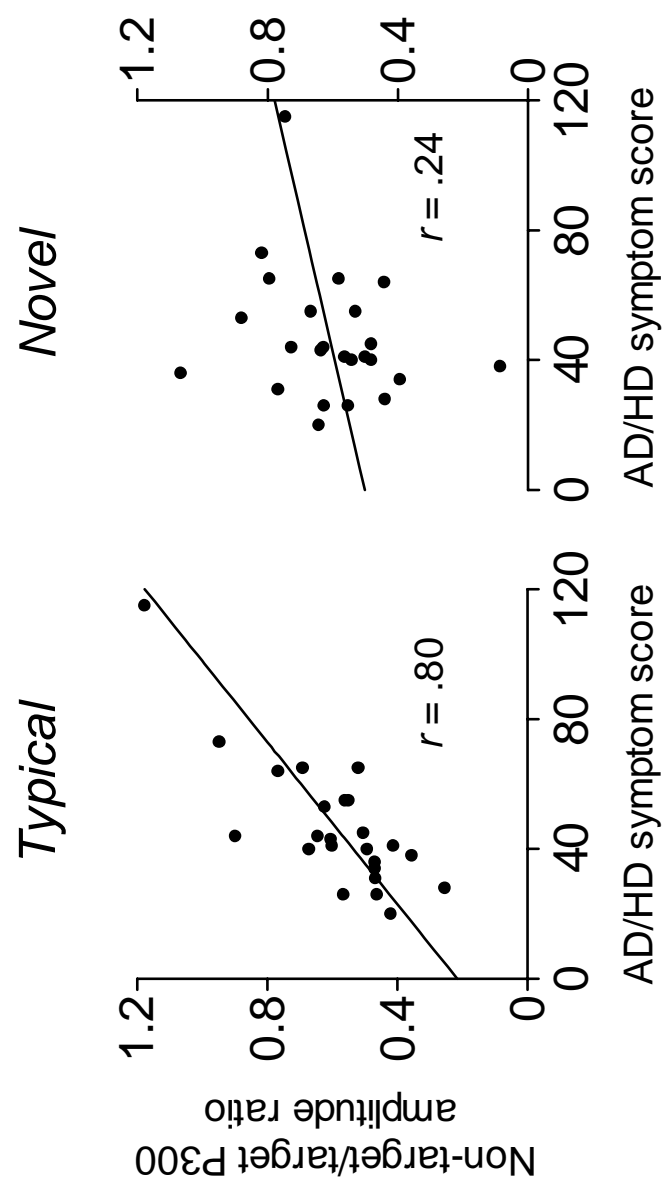
conditions, respectively.

Figure 1.

Figure 2.