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The Role of Attention Control Deficit in ADHD and Relevant Interventions

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ABSTRACT

Attention deficit/hyperactivity disorder (ADHD) is a common neurodevelopmental disorder that can cause several cognition impairments, including inattention and overly active. Based on Dual-Process Theory, scientists suggest that ADHD is associated with poor impulsive inhibition and reward dysfunction. On the other side, the Dual System Theory of Self-Control suggests that the intervention should focus on the cognitive control system and the reward system. Based on two neuropsychological theories, psychologists try to build the interventions through understanding the brain mechanism in children with ADHD. Most of the studies about ADHD focus on working memory, however, attention control deficit also plays a non-negligible role in ADHD problems. Researchers investigated the relationship between inattention and academic performance, and indicated_that attention control training could improve children with ADHD's academic performance. Others explored interventions that could influence underlying neural mechanisms. They analysed changes in neural patterns after attention control training and its relationship with ADHD symptoms. Therefore, they considered mindfulness treatment as the new hope to improve impairment like inhibition problems, especially for pre-schoolers to improve attention control deficits. And for adolescents with ADHD, virtual reality-based interventions provide them with realistic stimuli. Neurofeedback treatment could fulfil flexible adjustment and preference of the individual during the clinical sessions. These attention-related interventions significantly reduce the severity of symptoms. Although existed researchers provide plausible interventions for ADHD patients, the longitudinal study are still needed to reveal the long-term effect of interventions. Also, comparing and combining different methods would be highly valuable for ADHD research. Probably in the future, the psychologist can combine interventions with medical treatment to help individuals with ADHD.

Keywords: *ADHD, Inhibition control, Attention control training, Academic performance, Mindfulness, Attention-related interventions*

1. INTRODUCTION

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder that may cause impairment in school or at home. Patients with ADHD may have trouble keeping focus, experience impulsiveness, and be overly active [1]. ADHD significantly harms the patient's ability to read, do mathematics, and even complete school. Negative outcomes of ADHD include antisocial behavior, criminal behavior, and greater substance abuse that exist in later life. There continues to be a great need for the public to understand ADHD. According to a national 2016 parent survey, there are approximately 6.1 million children have been diagnosed with ADHD [2]. Based on the Diagnostic and Statistical Manual of Mental Disorders (DSM–5), ADHD is associated with five or more symptoms of attention problems [3]. One aspect of attention is attention control, which refers to the ability to regulate our attention to a specific aspect of our world and decide the target of attention [4]. Generally, attention control is the cognition process that directs what to pay attention for. People using this ability every day, to prevent counting how many trees have been pass while driving the car on the highway or spent the whole night focusing on the material of paper of the textbook instead of content. Successful attention

control is critically dependent upon our ability to avoid risk in daily life and is essential for achievement in school and work. In order to complete a task or remember knowledge, we, as normal people, try to create an environment with minimal distraction. Excellent attention control can improve efficacy in life and work. By contrast, having a deficit in attention control will create an extra burden to achieve the goal. This becomes one typical sign of ADHD. ADHD patients have to spend much more time and attention resources to complete a simple task. Studying attention control may develop more effective and adjunctive interventions for ADHD.

There are two theories that explain ADHD: one is ADHD Dual-Process Theory which could be described by neuropsychological processes' dysfunction: impulsive inhibition or reward dysfunction [5]. In this model, deficits in inhibition and consequent dysregulation of nigro-striatal-prefrontal pathways. The other one is Dual Systems Theory according to Self-control. This theory suggested two neural pathways: (1) the reward system preferentially responds to immediately available rewards, including multiple brain regions targeted by the midbrain dopamine system, including the nucleus accumbens, posterior cingulate cortex, and ventromedial prefrontal cortex; and (2) a cognitive control system consisting of DLPFC and the posterior parietal cortex that evaluates the choice to wait for a reward when it is delayed, whether early or late. In addition, ADHD is clearly associated with social cognition impairments involving emotional face and prosody perception. Furthermore, the social cognition impairments are consistent with fronto-striatal dysfunction in ADHD, but other functional networks of brain areas also appear to be implicated [6]. Results from imaging studies have suggested a predominant role of the PFC in ADHD, although it should be noted that other brain structures have also been implicated. Compared with drug therapy, parents of children with ADHD pay more attention to behavioral therapy alone without medication intervention. Previous studies have focused on working memory training. Klingberg and his colleagues developed a computerized cognitive training program that provided the largest evidence base for children with ADHD [7]. The authors designed a program based on working memory training protocol to improve speech processing in children with language learning disabilities. A recent study compared the effects of Cogmed's working memory training program with ADHD to the effects of stimulant drugs on short-term and working memory [8]. The results showed that cognitive training had a broader effect on improving working and short-term memory than did medication.

ADHD Dual-Process Theory and Dual Systems Theory of Self-Control are two highly plausible theories to explain the brain mechanism in children with ADHD. In clinical practices, abundant researches suggested that working memory training caused significant improvement in treatment for children with ADHD in multidomain. As mentioned above, normal people rely on attention control modifying their attention and focus on specific aspects of events to avoid potential risks and gain academic or career achievements in life. But for ADHD patients, it costs a lot more attention resources to complete equally demanding tasks than normal people. So, studying attention control of ADHD patients is necessary to understand ADHD underlying mechanisms and will possibly bring about effective treatment to deal with attention deficits. However, most researches about ADHD focused on working memory deficits and impulsive control. In comparison, the insufficiency of exploring the role of attention control deficits in ADHD could be easily figured out. Considering the importance of attention deficits and their potential treating value, this paper proposes that attention control should be a key point for future studies of ADHD. This review included previous researches from three perspectives: the relationship between inattention of ADHD patients and their academic performance, the underlying neural mechanisms of attention deficits, and the attention-related interventions for ADHD patients. By reviewing papers from these three views, it is intended to provide possible further directions for researchers studying ADHD.

2. THE IMPACT OF ATTENTION CONTROL DEFICIT ON ACADEMIC ACHIEVEMENT IN ADHD

Even though Methylphenidate (MPH) often ameliorates ADHD behavioral dysfunction according to indirect informant reports and rating scales. The effect of the presence or absence of executive-working memory (EWM) and self-regulation (SR) on drug action is still worth investigating. Hale and his colleagues conducted a study to investigate whether recording "cold" executive working memory (EWM) and "hot" SR neuropsychological disorders in the presence of MPH intervention could affect cognitive and academic responses in children with ADHD [9]. Several neuropsychological instruments were used to assess attention, working memory, executive function, inhibition, and SR through auditory, visual, verbal, and motor domains. Some neuropsychological tests through auditory, visual, verbal, and motor domains such as Stroop Test, Go-No Go Test and so on have been used to measure attention, inhibition, working memory, executive function, and SR.The baseline has also been assessed by two different tests. Children aged 6 to 16 with ADHD inattentive type and combined type hyperactive-impulsive type participated in double-blind placebo-controlled MPH trials with baseline and randomized placebo, low MPH dose, and high MPH dose conditions. EWM/SR measures and behavior ratings/classroom observations were rank ordered separately across conditions, with nonparametric randomization tests conducted to determine individual MPH response. Participants were subsequently grouped according to their

level of cool EWM and hot SR circuit dysfunction. Robust cognitive and behavioral MPH response was achieved for children with significant baseline EWM/SR impairment, yet response was poor for those with adequate EWM/SR baseline performance. Even for strong MPH responders, the best dose for neuropsychological functioning was typically lower than the best dose for behavior. Evidence for this assertion can be seen in the lower correlation between EWM and SR factors and DSM-IV-TR inattention symptoms in this study. Also, the four EWM/SR executive impairment groups differed on DSM-IV-TR hyperactive-impulsive symptoms but did not differ on DSM- IV-TR inattention ones, suggesting that only those with "true" ADHD and hot circuit involvement are more likely to respond to MPH. So, in the case of MPH, SR is still important.

Attention control is a part of SR. For adolescents with ADHD, the influence of inattention and working memory levels on academic performance is a problem worthy of discussion. A study investigated the role of inattention and working memory in predicting academic achievement of ADHD adolescent [10]. The Strengths and Difficulties Questionnaire is a standardized measure of social, emotional, and behavioral functioning, including reports from teachers, parents and adolescents [11]. For the present study, only the hyperactivity subscale was used. The teacher form of the Strengths and Weaknesses of ADHD- symptoms and Normal Behavior Scale was used to assess classroom inattentiveness. The experiment used Digit Span and Letter-Number Sequencing tests to measure auditory- verbal working memory. Spatial Span and Finger Windows tests were used to assess visual-spatial working memory. Another standardized test of Achievement was used to measure academic achievement. Path analysis was used to examine whether auditory-verbal and visual-spatial working memory would mediate the relationships between classroom inattention symptoms and achievement outcomes. Results provided support for the mediational model. Behavioral inattention significantly predicted both auditory-verbal and visual-spatial working memory performance. Auditory-verbal working memory was strongly associated with adolescents' achievement in reading and mathematics, while visual-spatial working memory was only associated with achievement in mathematics. Working memory mediated the pathway from inattention symptoms to reading, but did not mediate the pathway from inattention to math. This result suggests that attention control has a direct impact on academic performance and is not always associated with working memory.

Attention contains three different components, and the relationships between these components and academic achievement are worth exploring. A standardized test was used to assess a multidimensional model of attention, consisting of sustained attention (i.e., involving maintaining attention over an extended period), selective attention (i.e., involving attending to relevant stimuli while ignoring irrelevant stimuli), and attentional control/switching (i.e., referring to as involving executive functioning skills and changing attentional focus flexibly and adaptively as well as the ability to inhibit automatic, irrelevant responses and initiate more relevant alternative responses) [12]. Preston and his colleagues measured parent-reported inattention [13]. Intellectual functioning also has been assessed. Academic achievement was assessed by a standardized achievement scale. The experiment results show that attentional control/switching accounted for a significant amount of variance in all academic areas (reading, math, and spelling), even after accounting for verbal IQ and parent-reported inattention. Sustained attention predicted variance only in math, while selective attention did not account for variance in any achievement domain [13]. Therefore, attention control is the most important.

3. THE NEURAL MECHANISM UNDERLYING ATTENTION CONTROL DEFICIT

ADHD is a neurodevelopmental disorder that may cause impairment in school or at home by harming the patient's ability to control the inhibition. Inhibitory control describes the process to suppress the response to irrelevant stimuli. Researchers have been interested in how and why children with ADHD experience such difficulties, so they decide to study the relationship between the level of ADHD symptoms and impairments of brain regions through monitoring the BOLD response. Hwang *et al*. used the go/no go task with functional MRI to test the participants [14]. The go/no go test was designed to test dysfunctional recruitment of regions implicated in inhibition control and sustained attention [15]. On the other hand, the sustain attention involves several brain regions, including the superior frontal cortex (self-awareness), interior frontal cortex (responding to the distractor stimuli), parieto-temporal cortices (analyzing the spatial coordination of body parts.), insula (responding to the target stimuli), anterior cingulate cortex (controlling the inhibition), and caudate (goal-directed action). Inhibition control allows people not to respond to certain stimuli. Some brain regions, for example, the caudate and inferior frontal gyrus, are involved in the process of inhibition control and sustain attention. Other brain regions, anterior insula cortex (i.e., relate to emotional feelings), and pre-supplementary motor area (exerting control over voluntary actions) are related to the executive function of inhibition control. Among all participants, 59% of them were diagnosed with ADHD. Hwang and his colleagues collected participants' data including IQ scores, ADHD symptom level, and medical history. Participants did much worse in the no-go trail, which testing the inhibition control. In the no-go trial, the researcher has observed the abnormal reaction in the left anterior insular cortex. As the result, ADHD

symptom severity was significant and negative related to the BOLD response that in the left anterior insular cortex. Moreover, the anterior insular cortex is the core region to implicate the response inhibition. Thus, it may be concluded that, inhibition control and sustain attention are two abilities that lie under attention theory but work separately with symptoms of ADHD. Compared to sustain attention, the inhibition control is more relative to the severity of the ADHD.

Indeed, attention control can be separate from sustained attention in brain regions. Additionally, one variable called error processing can influence symptoms of ADHD. Error processing is the fundamental cognitive function that heavily relates to attention control. After realizing we made a mistake during a test, we normally pay more attention to the next question. People with decent error processing can focus more after they made mistakes. Scientists tend to believe that the error processing on patients with ADHD is quite distinguished from us. Van Meel *et al*. conducted a study in the area of ADHD with error-related negativity (ERN) [16]. While scientists using electroencephalography (EEG) to measure event-related potential (ERP), they observed a sharp negative deflection (P300) that appeared 80 ms after the participants made a mistake in choice tasks. The ERN soon becomes a well-established measurement of error processing. The target of the study is to understand whether deficient error processing could trigger ADHD children's poor adaptive control. They also added the time pressure as the independent variable and used ERN to measure the error detection in their experiment. It showed that science may blame the brain's error checking system for causing implement adequate cognitive control in ADHD children in speeded choice reaction task. After making a mistake, an ERP occurs in healthy children, thus they can realize and remember what happened. In the experiment, ERN amplitudes followin g error commission were significantly diminished in youth with ADHD. Brown and Braver have revealed the origin of ERN: the anterior cingulate cortex receives the alert of error and engage in the control progress, which is the same area in charge with inhibition control [17]. Base on the weaker ERP on ADHD children, it can be concluded that error processing deficit underlies the failure to implement adequate attention control.

The study mentioned above suggests that patients with ADHD don't pay more attention after the error, others argue maybe their alert system experience problems even before the task begin. According to the alerting theory of Strum and Willmes, attention comprises alertness and sustained attention. The alertness can be further subdivided into two domains, intrinsic alertness, and phasic alertness. Intrinsic alertness refers to the internal control of arousal in the absence of an external stimulus. Phasic alertness is defined as the ability to increase readiness after receiving an external cue in short term. Science usually uses intrinsic alertness times minus phasic alertness times to measure the alerting effect in reaction time study [18]. Cao *et al*. investigated the ability to alert deficit in children with ADHD. Cao made great progress base on Konrad and his colleagues, they found out ADHD children have less neural activity in the right anterior cingulate gyrus and higher activity in the brainstem for the alerting effect. Cao *et al*. wanted to use fMRI to reveal the difference of alerting effect in normal and ADHD. In the experiment, the participant completed cued target task while receiving an fMRI scan. Researchers surprisingly found out that children with ADHD show completely different activation from normal children when testing alerting effect. Bilateral middle frontal gyrus, right superior frontal gyrus, bilateral precuneus, bilateral insular, right middle temporal gyrus, left superior temporal gyrus, and left middle occipital gyrus were activated for the normal children [19]. The ADHD group, however, activated posterior brain areas and right cerebellum. The result also links the severity of ADHD symptoms to the signal changes in the right precuneus. For intrinsic alertness, a negative correlation exists between activation in the right precuneus and scores of inattention symptoms. Overall, children with ADHD have less activation in the frontal, parietal, and striatum regions. The experiments suggested that shortages in the attentional alerting functions in children with ADHD are related to certain brain regions. The abnormal activities in frontal and parietal regions expand the attention control theory.

The newly developed intervention, mindfulness treatment, could influence the severity of ADHD. Mindfulness treatment concentrates on breath control training. The process of controlling breathing is highly related to attention control, consequently, mindfulness training should be able to impact neural mechanisms about attention. Medication is not the only way to treat ADHD, Sibalis *et al*. provided new hope for youth patients. In the experiments, ADHD patients were divided into two groups. The experimental group of participants received the mindfulness treatment based on activity. Mindfulness interventions are a group treatment program [20]. The target of the program is to help children with ADHD improve their attention and inhibition. The program combines mindfulness mediation instruction and practice with yoga. The intervention lasts 20 weeks and cognitive behavioral therapy and martial arts. The participants complete a single-point focus rest task and two active attention tasks before and after the treatment. During the task, the EEG was recorded to measure the impact of treatment. The scientists provided a significant improvement in children with ADHD after the interaction by time by task. After receiving mindfulness treatment, participa nts' attention allocation increases in go trials. On both Go and No-Go tasks, children with ADHD's theta/beta ratio significantly decrease after the intervention. By contrast, the control group's theta/beta

ratio has no difference in the Go trial and significantly increases in the No-Go trial. Moreover, when testing inhibition in the No-Go trials, participants with mindfulness treatment show more active thought and concentration to inhibit their behavior. Thus, it can be concluded that the mindfulness treatments are a potential intervention for children with ADHD since they can influence their brain regions that relate to attention control.

4. INTERVENTIONS FOR ATTENTION CONTROL DEFICIT IN ADHD

As the impact of attention deficits in ADHD patients on academic performance and underlying neural mechanism of attention deficits were reviewed above, we discussed the articles about interventions for attention control deficits in ADHD in the following part. Mindfulness training is a recently noticed training method for ADHD, the effect of which is not yet well clarified. Also, Johnston stated that excessive synapses found in early childhood are pruned until about 16-year-old and stronger adaptive plasticity of brains in the first decade of life [21]. So, it's important whether early mindfulness interventions in preschoolers for improving attention deficits could be more effective due to their relatively stronger brain plasticity. Yoga is a sport combines physical exercise and mindfulness training, which includes body poses, breathing, and meditation to improve self-regulating skill for body and mind. According to Cohen and colleagues, yoga had a mild effect on preschool children with ADHD symptoms [22]. Preschoolers in the study were randomly assigned into group 1 (immediately exposed to yoga) and group 2 (in the waiting list). Thus, group 2 acted as a control group at time 1 when group 1 completed yoga for a period while group 2 was not yet exposed. The result showed that at time 1, group 1 had significantly shorter reaction time for correct answers on the Go/No-Go subtest and fewer omission errors on the Distractibility subtest in attention measurement. Mindfulness training is an effective complementary treatment for preschoolers with ADHD.

Referring to Romer and colleagues, functional imbalances could be found between better developed limbic regions and less developed prefrontal cortex with weak control in adolescence. In this case, adolescents are more sensation-seeking and they need interventions that are realistic to daily life to explore and gain experiences [23]. The VR-based interventions, rather than limited screen distractors in laboratory training for ADHD patients, could provide various training which is more similar to real circumstances in life. These suggest that studying the VR-based interventions treating adolescents with ADHD should be highly effective. Romero-Ayuso and colleagues estimated the effect of virtual-reality based interventions (VR-based interventions, Virtual Reality, i.e., embodied technology which offers immersive presence and allows interactions) for children and adolescents with ADHD by a systematic review and meta-analysis including four studies [24]. In experimental groups, subjects who received VR-based interventions were asked to do tasks. One of the experiments asked children to figure out letters while suppressing various distractors (e.g., dropped pencils, the sound of footsteps, intercom notifications, etc.) And in another experimental condition, participants were asked to focus on virtual dinosaurs and then answered some questions about the information presented relating to the dinosaurs. Among these studies, especially according to Cho and colleagues, treatment in their study focused on sustained, selective, divided and alternating attention, with tasks that subjects were asked to stop an event at the signal (e.g., a flag) [25]. The result showed that subjects' perceptual sensitivity in the VR-based intervention group significantly dropped more than the non-VR group, and only in the VR group, the response bias was found to decrease. In general, VR-based interventions can improve the inattention symptoms in adolescent ADHD patients and help them inhibit distractors better.

The interventions mentioned above ask patients to receive guidance or follow the standardized program from the outer world. Nevertheless, it's common for individuals to have various preferences which cannot be fulfilled by the outer world. Neurofeedback as an intervention could satisfy personalized needs of patients. The neurofeedback needs a brain-computer interface (BCI) and requires a software system and processing pipeline to realize. Some features of brain activity were selected and calculated into pre-selected brain parameters, which are transferred into signals given back to the user in real time. Using the feedback, the participants can self-regulate their brain activity to change the underlying cognition and behavior. The review by Enriquez-Geppert and colleagues explored the theory and evidence for the effectiveness of neurofeedback working as an intervention for ADHD [26]. They reviewed 3 standard protocols of neurofeedback. Theta/beta ratio (TBR) neurofeedback monitored the theta and beta power of central and frontal brain locations. Researches suggested that 30-40 sessions of TBR neurofeedback trials were effective to reduce inattention and hypersensitivity in ADHD patients and associate with their post-intervention academic performance. And the sensori-motor rhythm (SMR) neurofeedback focused mainly on the central right hemispheric brain region as the functional association was made between sensori-motor rhythm and behavioral inhibition. Studies revealed that SMR neurofeedback reduces inattention and hypersensitivity/implosion in ADHD children to the same degree as TBR treatment and with a similar session number. Lastly, the slow cortical potential (SCP) neurofeedback depends on a learned SR of cortical activation and inhibition which are respectively correlated with electrical negativation and positivation of

slow cortical electrical deflections. The phasic tuning mechanism in attention control can explain the phasic shifts from electrical positivity to negativity, which is suggested by the improved reaction time, stimulus detection and short-term memory during the negative phase. For ADHD, SCP therapeutic emphasis is on increasing firing probabilities of cortical regions. And a recent meta-analysis concluded that the neurofeedback is more effective than semi-active control treatment groups and similarly effective as active-treatment groups including MPH when treating ADHD [27]. This meta-analysis also confirmed that effects of neurofeedback increased with time while medication effects decreased with time concurrently. In conclusion, the neurofeedback as a treatment enables participants to know about their attention control, benefit from self-intervene and be free of outer constrains (e.g., standardized protocols, therapists, clinical rooms). Also, the neurofeedback helps clarify the corresponding relationships between activities taking place in different brain areas and attention control.

5. LIMITATION AND FUTURE DIRECTION

There are some limitations that cannot be ignored in this review article as follows: Firstly, most researches in this article study the correlation relationships between variables. Secondly, existed researches mainly focus on cross-sectional comparison for concurrent effects and lack of longitudinal comparison results. Lastly, papers reviewed above about interventions merely explore the single effects of interventions related to attention control and working memory for ADHD patients apart.

Based on these, this paper proposes several future research directions for researchers. After the correlations found between variables being reported, casual relationships between those variables are remained to be further examined by manipulated experiments. Also, empirical evidence is insufficient for longitudinal comparison, so conducting follow-up studies for long-term effects of attention-related interventions could be a meaningful direction. Finally, researchers could consider how to combine both attention control and working memory training in an intervention protocol and its clinical effect.

6. CONCLUSION

Experiments show that even though in the case of MPH, SR is still important. The attention control ability of adolescent with ADHD has a direct impact on their academic performance. A study of attention components shows that Attentional Control/Switching has a wider influence on academic achievement than Sustained Attention and Selective Attention. The brain's caudate gyrus, inferior frontal gyrus, anterior insula cortex, and anterior auxiliary motor areas are associated with inhibitory control. The lack of attention alerting in children with ADHD is associated with abnormal activity in the frontal parietal lobe. Interventions such as mindfulness, neurofeedback, virtual reality (VR) and other methods can help ADHD patients improve their attention control. Most of the current studies are cross-sectional studies and correlation studies. Most of the current studies are cross-sectional and correlation studies that measure the relationship between working memory, attentional control and academic performance of ADHD patients. In the future, more causal studies and longitudinal follow-up studies can be conducted, and the combined effect of working memory and attention control in ADHD patients can also be focused on.

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