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不同認知負荷強度之急性運動介入對注意力缺陷過動症兒童之效益

The Effect of Acute Exercise with Different Cognitive Load in Children with Attention Deficit Hyperactivity Disorder (ADHD)

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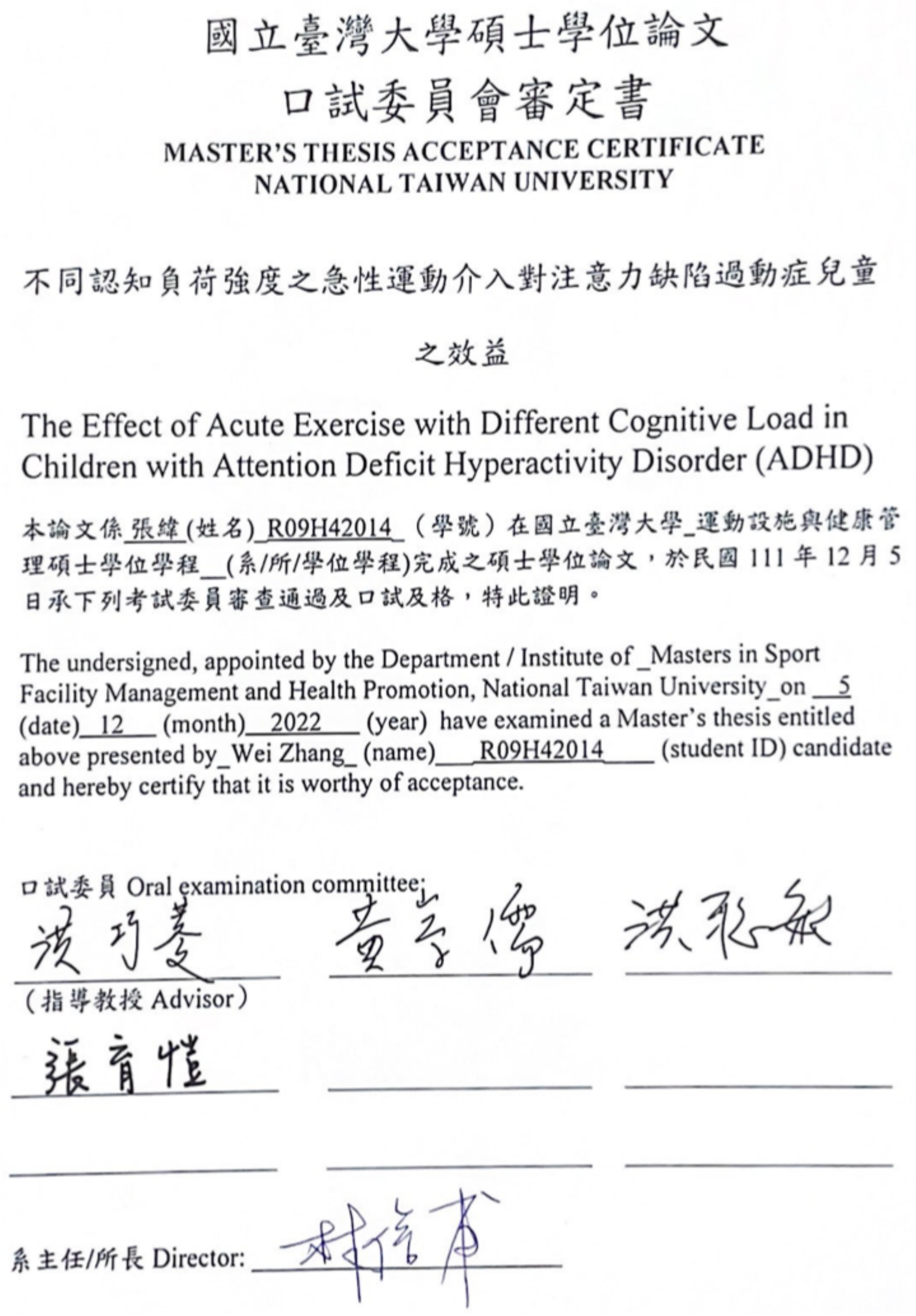

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MASTER'S THESIS ACCEPTANCE CERTIFICATE

NATIONAL TAIWAN UNIVERSITY

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The Effect of Acute Exercise with Different Cognitive Load in Children with Attention Deficit Hyperactivity Disorder (ADHD)

本論文係 張緯 (姓名) R09H42014 （學號）在國立臺灣大學_運動設施與健康管理碩士學位學程__(系/所/學位學程)完成之碩士學位論文，於民國 111 年 12 月 5 日承下列考試委員審查通過及口試及格，特此證明。

The undersigned, appointed by the Department / Institute of _Masters in Sport Facility Management and Health Promotion, National Taiwan University_ on __5 (date)__12___ (month)__2022____ (year) have examined a Master's thesis entitled above presented by_Wei Zhang_ (name)___R09H42014____ (student ID) candidate and hereby certify that it is worthy of acceptance.

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摘要

ADHD 是一種始於童年的神經發育疾患。其三大基礎特徵為注意力不集中、過動、與衝動行為，並可能會影響到認知功能與發展、抑制控制、注意力和工作記憶等執行功能。急性有氧運動也可能有助於促進認知彈性、抑制控制和工作記憶，利用運動或身體活動有助於改善 ADHD 及其併發症的狀況。因此，運動成為 ADHD 潛在的有效輔助介入方法，備受關注。但是，不同類型的運動對改善 ADHD 的效果不盡相同。開放式運動 (open skill exercise, OSE) 比閉鎖式運動 (close skill exercise, CSE) 更有效改善認知功能，可能與 OSE 具有較高的認知負荷強度有關，所以認知負荷可能是改善認知功能的重要因子。因此，本研究**目的**為探討不同認知負荷強度運動對 ADHD 兒童和典型發展 (typically developing , TD) 兒童的認知功能和事件相關電位 (event-related potential, ERP) 的急性效果。**方法**：招募 8 至 12 歲 18 名 TD 和 8 名 ADHD 兒童，分 3 天進行控制、低認知負荷、高認知負荷情境介入。控制階段為看和桌球相關影片 30 分鐘；低認知負荷為進行 30 分鐘中等強度運動的單色桌球介入；高認知負荷為進行 30 分鐘中等強度運動的雙色桌球介入。使用心率儀監測心跳率保持在中等運動強度 (60%-65% 儲備心率) 及檢視擊球準確率。，並於影片或運動介入後進行作業轉換 (task-switching) 認知測試，收集腦波與行為表現數據。**結果**：低與高認知負荷運動情境之運動強度皆為中等運動強度，而擊球準確率達顯著差異。行為表現方面，ADHD 在單一條件顯示低認知負荷情境反應時間最快。ADHD 的準確率在整體轉換效應的混合條件下，高認知負荷情境之準確率顯著高於低認知負荷情境及控制情境。在局部轉換效應中發現，TD 在高認知負荷階段、低認知負荷階段、控制階段之準確率皆顯著高於 ADHD。 ERP 方面，P3 振幅皆無顯著改善。P3 潛伏期則在局部轉換效應顯示低認知負荷情境為最快。**結論**：較高認知負荷的運動介入可能對 ADHD 兒童的認知功能更有促進效果，但對 TD 兒童無顯著差異。

關鍵詞： 認知負荷、急性運動效果、認知功能、注意力缺陷過動症、事件關聯電位、作業轉換

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Abstract

ADHD is a neurodevelopmental disorder that begins in childhood. An essential feature of ADHD is a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development and may affect inhibitory control, attention, and working memory. Past studies have shown that acute exercise has a positive effect on cognitive flexibility, inhibitory control, and working memory, and also showed that exercise or physical activity can improve symptoms of ADHD and its complications. Therefore, exercise has become a potentially effective intervention method for ADHD children that has attracted much attention. However, different types of exercise have varying effects on improving ADHD. Open-skill exercise (OSE) is more effective in improving cognitive function than closed-skill exercise (CSE), which may be related to the higher cognitive load intensity of OSE. Therefore, this study believes that cognitive load is a variable that could improve cognitive function. **Purpose**: "To investigate the acute effects of exercise intervention at different cognitive load intensities on cognitive function and ERP in children with ADHD and typically developing (TD) children.". **Methods**: 18 TD and 8 ADHD children aged 8 to 12 were recruited, and interventions in control, low cognitive load, and high cognitive load sessions were divided into 3 days. In the control session, 30 minutes of watching a video related to table tennis; the low cognitive load was 30 minutes of moderate-intensity exercise intervention of a one-color table tennis ball; the high cognitive load was 30 minutes of moderate-intensity exercise intervention of a two-color table tennis ball. The ball return accuracy of high or low cognitive load exercise intervention was used to calculate whether there was indeed a difference in cognitive load intensity between the two. Heart rate monitoring was used to maintain moderate exercise intensity (60%-65% reserve heart rate) during exercise intervention. Immediately after watching a video or playing table tennis, an

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EEG cap was worn and a task-switching cognitive test was used to collect and record ERP and behavioral data. **Results:** In terms of exercise performance, all subjects performed the same moderate exercise intensity. High and low cognitive load exercise interventions did achieve a significant difference in terms of accuracy. In terms of behavioral performance, the reaction time of ADHD in a pure condition was significantly fastest in low cognitive load session. Accuracy for ADHD was found in the mixed condition in the global switch effect, with the acute effect of the high cognitive load session having a significantly better effect than the low cognitive load session, and also significantly better than the control session. In the local switch effect, it was found that the accuracy of TD was significantly better than that of ADHD in the high, low, and control session. In terms of ERP, there was no significant improvement in P3 amplitude. The P3 latency was the fastest in the low cognitive load session where the local switch effect was significant. **Conclusion**: Exercise intervention with a higher cognitive load might have a positive effect on the improvement of cognitive function in children with ADHD, but no significant difference was reached in TD children.

Keywords: cognitive load, acute exercise intervention, cognitive function, ADHD, ERP, task-switching

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Chapter 1

Introduction

1.1 Background

ADHD is a neurodevelopmental disorder that begins in childhood. The requirement that six (or more) symptoms would be present before age 12 years, which needed to occur and last for at least six months, conveyed the importance of a substantial clinical presentation during childhood. The essential feature of ADHD is persistent inattention and/or hyperactivity-impulsivity that interferes with functioning or development (American Psychiatric Association (APA), 2013). Recently, research on treating ADHD patients focused on other non-drug interventions, exercise, or physical activities that could be used to prevent and improve personalities and complications (Silva et al., 2015). The particular reason for this circumstance was that exercise might be the key to reducing hyperactivity/impulsive behavior, improving attention, memory, motor skills, and social skills (Wigal et al., 2013). Exercise has become a potential and effective intervention method for ADHD children, which has attracted much attention (Neudecker et al., 2019).

Exercise helped reduce the risk of dementia, depression, and stress (Pedersen, 2019). It had a role in maintaining cognitive function and metabolic control and had many benefits for brain health (Pedersen, 2019). Exercise could cause acute changes (usually leading to an increase) in the concentration of several neurochemicals in the brain (Moreau & Conway, 2013). Exercise could also increase the concentration of brain-derived neurotrophic factor (BDNF) in serum, thereby enhanced neuro-proliferation, memory, and learning ability, and improving medial temporal lobe function. Indicating that exercise could induce cognitive function enhancement

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(Griffin É et al., 2011). In addition to BDNF, exercise could also improve these neurochemicals including cortisol, noradrenaline, dopamine, and possibly serotonin (McMorris et al., 2016). When you were exercising, your muscle would secrete myokines and the myokine cathepsin B passes through the blood-brain barrier to enhance brain-derived neurotrophic factor production, it also could enhance neurogenesis, memory, and learn to contribute to the regulation of hippocampal function (Pedersen, 2019). In addition, acute aerobic exercise could increase the secretion of thyroid hormones and improve the cognitive dysfunction of patients with hypothyroidism (Masaki et al., 2019). The 2019 empirical study also clearly showed that acute aerobic exercise might promote cognitive flexibility, inhibitory control, and working memory (Bae & Masaki, 2019). Exercise could increase the arousal level of the prefrontal cortex (PFC), cerebral blood flow, catecholamines, and BDNF concentration, and had potential effects on the frontal cortex and behavior.

The effect of exercise intervention on the improvement of cognitive function had been demonstrated. Past studies had shown that exercise had a positive effect on mental health, cognitive function, and delayed the occurrence of neurodegenerative diseases (Bherer, 2015; Deslandes et al., 2009; Donnelly et al., 2016a). It could also positively affect different aspects of cognitive function, such as spatial learning and memory (Cassilhas et al., 2016), working memory (Bustamante et al., 2016), attention (Hattabi et al., 2019), cognitive flexibility and attention resource allocation ability (Tsai & Wang, 2015), etc. Past studies also found that open skill exercises (OSE), which were led by extraneous events (e.g., volleyball, badminton, tennis) (Singer, 2000) was better than close skill exercises (CSE), which were self-paced in the development (e.g., swimming, jogging, circling) (Singer, 2000) in inhibiting control (Crova et al., 2014), cognitive flexibility (Schmidt et al., 2015), increasing serum BDNF concentration

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(Hung et al., 2018), and the cognitive function of children and the elderly were more effective in improving these aspects (Gu et al., 2019). A comparison of open versus closed movements could be viewed as a practical application of cognitive load intensity in exercise (Gu et al., 2019).

The reason might be that OSE was a reactive exercise (Gabbett et al., 2008). When performing OSE, athletes needed to move in a relatively unpredictable and changeable environment, not only must remain focused on the goal but also necessary to observe the activities and positions of multiple participants (adversaries and teammates) at the same time, made plans and execute actions (Formenti et al., 2019). OSE also had more high cognitive load and social interaction challenges were a kind of exercises intervention that could effectively improve cognitive ability (Crova et al., 2014). And could subdivide such exercise into strategic exercise (such as dancing, and football), and interception exercise (such as taekwondo, and karate) ((Voss et al., 2010). CSE was a movement that was relatively stable and less interactive with the environment, with a clear starting point and end point, and could be further defined as a static exercise (such as running, and swimming) with a highly consistent movement pattern (Coelho et al., 2007; Gabbett et al., 2008; Voss et al., 2010), thus presented a lower cognitive load intensity (Crova et al., 2014). On the other hand, the dual-task motor intervention with additional secondary tasks in the same situation also had a higher cognitive load intensity than a single-task because it needed to process different stimuli and perform task requirements at the same time (Atiomo, 2020; Haji et al., 2015). In addition to the fact that different exercise prescriptions might provide different effects on the benefits of cognitive function, concurrent cognitive tasks and exercise intervention might be one of the more effective ways to enhance cognitive reserve (Herold et al., 2018). Therefore, this study believed that cognitive load was a variable that could improve cognitive function.

OSE could effectively improve cognitive function, possibly because OSE had a higher cognitive load intensity (Crova et al., 2014). Given this, the next step was to discuss whether acute exercise with higher cognitive load intensity was better for improved cognitive function. Twelve experienced football players engaged in three different types of acute interventions lasting 20 minutes. (1) Sat and rested; (2) Moderate-intensity treadmill exercise; (3) Futsal game. Then, participants completed the Stroop color-word conflict task and measured the reaction time (RT) and P3 event-related potential at the same time. The results showed that the reaction time during the Stroop performance was significantly faster after a futsal game and treadmill exercise compared with rest. After Futsal, the P3 range during Stroop's performance was the largest. It could be shown that futsal could improve cognitive function best (Won et al., 2017). Another study for the elderly examined the acute effects of a single OSE and CSE intervention on cognitive function and found that the immediate memory of both exercise groups improved compared with the control group. Only in the OSE group was an improvement in audiovisual perception (O'Brien et al., 2017). The intervention of cognitive tasks and exercise at the same time was the most effective way to enhance cognitive reserve (Herold et al., 2018). And if it could provide novel and fun exercises intervention, it might be an important way to promote cognitive improvement to a greater extent (Schmidt et al., 2020). Taken together, cognitive function and executive function (EF) were impaired in individuals with ADHD. Therefore, this study believed that OSE was an intervention that could provide more cognitive load, and had a better effect on the adjuvant treatment of patients with ADHD. However, it should be noted that if the exercise intensity was too high or exercise time was too long, it might cause excessive secretion of catecholamines, lead to physical and emotional fatigue and led to cognitive impairment (Barnes & Van Dyne, 2009; McMorris et al., 2016). Dehydration caused by long-term exercise might also impair information processing and memory functions (Tomporowski, 2003).

The intensity of cognitive load at different intensities during exercise might also be a key factor in improving cognitive function (Schmidt et al., 2020). The executive function performance of the elderly who had participated in OSE for the long term was better than that of the elderly who had been engaged in CSE and sedentary life for the long term (Dai et al., 2013). Previous findings also supported that OSE was better at improving cognitive function than CSE (Gu et al., 2019). In addition, the dual-task of enhancing cognitive reserve by performing cognitive tasks and motor intervention at the same time might also be an important way to promote the improvement of cognitive function (Herold et al., 2018; Schmidt et al., 2020). Using the dual-task of CogniPlus cognitive and motor training (including walking with attention training, alternating standing and kneeling positions with memory training, walking back and forth with executive function training) was effective for the elderly with mild cognitive impairment (MCI). The improvement effect of cognitive function and attention function was significantly higher than that of cognitive task intervention alone (Hagovská et al., 2017). Additionally, 16 weeks after simultaneous motor interventions and cognitive function training (reaction time, inhibitory control, attention, visuospatial planning and decision making, etc.) using interactive cognitive-motor training (ICMT). The study found significant improvements in attention, processing speed, and visuospatial abilities in healthy elderly participants compared to a no-intervention control group (Schoene et al., 2015).

The event-related potential (ERP) could directly and accurately measure brain activity and timing such as RT and accuracy. It was very suitable for detecting changes in response inhibition, attention, or working memory in patients with ADHD (McLoughlin et al., 2010). ERP studies could also significantly contribute to a better understanding of the pathophysiological background of ADHD (Wangler et al., 2011). Past studies had indicated that the P3 (P3) amplitude of patients with ADHD was significantly lower than that of healthy people (Alexander et al., 2008; Griffiths et al., 2019; Szuromi et al., 2011). And the improvement effect of the P3 amplitude in the group with poor cognitive function is better than that of the group with better cognitive function (Drollette et al., 2014). Therefore, the P3 of ERP component, a possible endophenotype for attention deficit hyperactivity disorder (ADHD), had been widely examined in children (Szuromi et al., 2011). In addition, ADHD was accompanied by cognitive control disorders, such as task-switching defects (Aarts et al., 2015), because task-switching was a cognitive function that might be impaired after brain damage (Pohl et al., 2007). Past studies had also confirmed that when task-switching was used as a cognitive test, there was a potential correlation between task-switching and ERP (N1, P2, P3) (Kieffaber & Hetrick, 2005). Thence, task-switching was also a common cognitive test used in patients with ADHD.

1.2 Purpose

Based on the evidence mentioned above, past studies had examined the effects of acute exercise on EF in children with ADHD had focused on aerobic exercise. Whether the cognitive load of OSE might be a moderator that manifests the effect of acute exercise on EF in children with ADHD remains unknown. To the best of our knowledge, no existing study had specifically explored the effect of different intensities of cognitive load as a variable. Therefore, the purpose of this study was:

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"To examine the acute effects of exercise intervention at different cognitive load intensities on cognitive function and ERP in children with ADHD and typically developing (TD) children."

The following questions were raised for this study:

(1) Improvement effect under different cognitive load intensity interventions, was the improvement effect of high cognitive load intervention on behavioral performance (reaction time, accuracy rate) the best?

(2) The improvement effect under different cognitive load intensity interventions, was the improvement effect of high cognitive load intervention on ERP (P3 amplitude, latency) the best?

(3) In terms of improvement in cognitive function, did ADHD children have better outcomes than TD children after the intervention in this study?

1.3 Hypothesis

This study used the ERP and task-switching cognitive tasks as tools to measure the effect of improved cognitive function. Based on previous findings, the hypotheses of this study were:

(1) According to past research on task-switching, after long-term exercise intervention, the impact of high-intensity cognitive load on behavioral performance would lead to higher accuracy and faster reaction time. Therefore, we hypothesized that using a single exercise intervention with different cognitive load intensities could also see the impact of high-intensity cognitive load on behavioral performance, which might bring about the acute effects of higher accuracy and faster reaction time.

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(2) According to previous studies on ERP, the effect of high-intensity cognitive load on ERP was associated with higher P3 amplitude and faster latency after long-term exercise intervention. Therefore, we hypothesized that using a single exercise intervention with different cognitive load intensities, we could also see the acute effect of higher P3 amplitude and faster latency on the effect of high-intensity cognitive load on ERP.

(3) The improvement effect of ADHD children after intervention would be more effective than that of TD children.

Based on the above discussion, this study used table tennis corresponding to the definition of OSE as an exercise intervention to explore the acute improvement effect of different intensities of cognitive load on children with ADHD.

1.4 Significance of the study

Based on the previous findings, this study found that there were still some studies worth continuous attention or that could be tried, and tried to fill in the gaps in current research. Therefore, there were a few points of importance that this research could bring:

(1) Most of the previous studies conducted table tennis training for long-term intervention, and also achieved certain benefits in improving the cognitive function of ADHD children. Therefore, this study wanted to try to understand if the acute effect of one-time table tennis could also bring benefits to the improvement of cognitive function in children with ADHD.

(2) In the past, most studies focused on the experimental design of exercise prescription, and seldom used cognitive load intensity as an independent variable in the study. Previous studies on

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the intensity of cognitive load mainly used different exercise interventions for comparison. Therefore, this study sought to understand whether using the same exercise intervention but with different degrees of cognitive load intensity had a beneficial effect on the improvement of cognitive function.

(3) Wanting to know whether the same cognitive load intensity would have different improvement effects for different ethnic groups.

Chapter 2

Literature review

2.1 ADHD and Exercise Intervention

2.1.1 Neural mechanism and symptoms of ADHD

As a neurobiological condition of childhood, ADHD was often accompanied by defects such as lack of concentration, impulsivity, and hyperactivity (Bokor & Anderson, 2014). It might be caused by the obstruction of children's neurodevelopment (Thapar & Cooper, 2016). The prevalence estimates of ADHD in Taiwan were 4.2%, respectively (Liu et al., 2018). The integrated analysis study also pointed out that the performance of ADHD patients in performing cognitive tasks was worse than that of the general healthy population, and was related to at least seven main functional areas (Mueller et al., 2017), such as temporal information processing (Toplak et al., 2006), sustained attention related to the arousal system (Oken et al., 2006), cognitive flexibility (Kim et al., 2011), RT (Kofler et al., 2013), reaction inhibition (Aron et al., 2014), & working memory (Lara & Wallis, 2015), etc. In addition, children with ADHD were associated with multi-domain disorders, including social, family, emotional, and academic abilities, and existing drug treatments for ADHD cannot improve such defects (Hattabi et al., 2019). It might be because as many as 60% of ADHD children had at least one diagnostic criterion for anxiety, including social phobia (SAD), generalized anxiety disorder (GAD), and separation anxiety disorder (SepAD) (Sciberras et al., 2019). Children with ADHD often suffer from cognitive abilities, motor abilities (Ziereis & Jansen, 2015), and executive function deficits (Benzing & Schmidt, 2019). According to past neurophysiological research on the pathology of

ADHD, the abnormal motivation and emotional control of ADHD patients might be derived from defects in the limbic system, Ventromedial Prefrontal Cortex (vmPFC), and orbitofrontal cortex (OFC) (Rubia, 2018). Additionally, the reason for reducing cognitive functions such as inhibitory control, attention, and working memory in patients with ADHD might be due to the existence of complex damage in the brain. Such as the dorsal and ventral sides of the left and right hemispheres, medial fronto-cingulo-striato-thalamic network, and fronto-parieto-cerebellar network (Rubia, 2018). In terms of neurobiochemistry, studies had pointed out that the DRD4.7 and DRD5 receptors of dopamine in the brains of ADHD patients were associated with ADHD symptoms (Wu et al., 2012).

2.1.2 The effect of acute and moderate-intensity exercise on cognitive function

Past studies had shown that moderate-intensity exercise training was closely related to cognitive function. The definition of moderate exercise intensity is 40-59% heart rate reserve (HRR) or oxygen uptake reserve (VO2R) (Raichlen & Alexander, 2017; Solheim et al., 2014). The high exercise intensity was defined as 60%-80% HRR (Alberts & Rosenfeldt, 2020; Pang et al., 2013). And get 12 to 13 points in the Rating of Perceived Exertion (RPE) score of 6 to 20 points (Garber et al., 2011). Past studies had shown that moderate-intensity exercise training was closely related to cognitive function. The adaptive capacity model (ACM) proposes that the human body's most suitable intensity range for exercise falls in the medium intensity from the perspective of neuromorphology (the cognitive enhancement effect was also the best) (Raichlen & Alexander, 2017). In the 2016 study, elementary school students were randomly assigned to three different moderate-intensity exercise modes: (A) sitting all morning working on simulated school tasks; (B) one 20-minute physical activity bout after 90min; and (C) two 20-minute

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physical activity bouts. It was found that children who did two 20-minute moderate-intensity physical exercises had better selective attention scores than children who did one physical exercise or sat all day (Altenburg et al., 2016). A systematic review of adults over 50 years of age using exercise intervention to improve cognitive function found that no matter what level of cognitive function the participants were at, as long as they had exercise training, they could benefit from their cognitive function. These exercise interventions do not need to limit the types of exercise (such as resistance training, aerobic exercise, yoga, etc.). But what needed to be determined was that the intensity of these exercise interventions must be at least moderate to produce the effect of improving cognitive function (Northey et al., 2018). Another 2019 study wanted to understand the cognitive improvement effects of moderate-intensity acute exercise on sedentary overweight/obese older adults with normal cognitive function. The results of the study found that moderate-intensity exercise could improve the serum BDNF and working memory or executive function of the elderly (Wheeler et al., 2020). In addition to studies on normal cognitive function people, previous studies had also shown that moderate-intensity exercise intervention could also help improve the cognitive function of participants with cognitive and/or neurological disorders. A study on the use of moderate-intensity acute aerobic exercise intervention for children with learning disabilities (LD) found that after the intervention of moderate-intensity acute aerobic exercise, children with LD significantly enhanced the adjustment of mental state and the allocation of attention resources. And it affects the sustained attention and discriminatory functions of children with LD (Huang et al., 2020). To evaluate the effect of moderate-intensity of aerobic exercise on elderly people with mild Alzheimer's disease, a 2015 study recruited fifty volunteers aged 50 years to 80 years with cognitive impairment. The study let the aerobic group be treated with cycling training at 70% of maximal intensity for 40

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minutes per day, 3 days a week for 3 months. The results showed that moderate-intensity of aerobic exercise could improve cognitive function in patients with mild Alzheimer's disease (Yang et al., 2015). The 2017 study wanted to explore the improvement of cognitive control of young people suffering from major depressive disorder (MDD) with moderate-intensity aerobic exercise intervention. Eight weeks after using moderate-intensity aerobic exercise intervention, it was found that the participants successfully improved neural indices of conflict monitoring and reduced depressive symptoms among individuals with MDD (Olson et al., 2017). The study on the cognitive function and health-related quality of life of the elderly with MCI used a 16-week moderate-intensity aerobic step-up exercise program, with three sets of 60-minute training per week. The results found that participants who participated in the moderate-intensity exercise program had significant improvements in cognitive function and health-related quality of life. In addition, it indirectly improves the quality of sleep and improves the symptoms of depression (Song & Yu, 2019). In addition, the use of moderate-intensity aerobic dance training for the elderly with mild cognitive impairment could improve their cognitive functions, especially episodic memory and processing speed (Zhu et al., 2018).

Continue to explore the related studies on the effect of acute exercise on the improvement of cognitive function. In terms of acute effects, performing submaximal aerobic exercise for about 60 minutes could help increase the effectiveness of information processing (Tomporowski, 2003). A single high-intensity interval training (HIIT) could bring about non-invasive and acute improvement performance of executive function (Moreau & Chou, 2019). A review study of children to adolescents (5 to 18 years old) found that the use of HIIT intervention could produce mild to moderate acute improvements in executive function. It showed that participating in HIIT could improve the cognitive function and mental health of children and adolescents. (Leahy et al., 2020). Using acute aerobic exercise intervention could also adjust the mental state, the allocation of attention resources, sustained attention, and produce significant acute improvement effects for children with LD (Huang et al., 2020). From the above studies, it could be known that acute exercise could improve cognitive function. The specific improvement mechanism might be as follows: Acute exercise would activate the arousal mechanism in the reticular-activating system (RAS). Then, many neurotransmitter systems were involved in this activation process, which had several interrelated effects on cognition and emotion. Next, exercise causes the prefrontal cortex to lose higher-order functions due to resource constraints. Lastly, although acute exercise might cause resource limitations in the prefrontal cortex, it didn’t impair the function of the RAS (Dietrich & Audiffren, 2011).

2.1.3 Different exercise intervention types for improvement benefits of ADHD

In ADHD adolescents, exercise might play a major role in the development of cognition, memory, selective attention, and exercise response time (Kadri et al., 2019a). It might be because the impact of non-fine acute gross physical activity on cognitive function mainly focuses on attention or executive function (Mavilidi et al., 2018). Attention and executive function deficits were common symptoms in patients with ADHD (Bokor & Anderson, 2014; Mueller et al., 2017).

Some benefits could be found in the use of CSE as a study to improve the cognitive function of patients with ADHD. After 10 weeks of intermittent exercise training for ADHD children, it was found that overactivity and visuospatial working memory were significantly improved (Bustamante et al., 2016). ADHD adults trained with moderate-intensity cycling for 30 minutes, although there was no significant improvement in acute task performance, it was found in MRI imaging that moderate-intensity cycling helped to activate brain areas related to inhibition (Such as parietal, temporal, and occipital areas) (Mehren et al., 2019). 12 consecutive weeks of swimming training could have a positive impact on the cognitive functions of ADHD children, such as selective attention, inhibition, and accuracy (Hattabi et al., 2019).

Previous studies on the use of OSE for exercise intervention to improve cognitive function in patients with ADHD were as follows. For example, equine-assisted activities and therapy (EAA/T) which was a therapeutic activity related to horses, the purpose was to promote people's physical and mental health, and it also was regarded as a clinically effective exercise intervention that could improve the scores of ADHD children's hyperactivity scale and social behavior problem scales (Jang et al., 2015). The 2017 study used the simulated developmental horse-riding program (SDHRP) as an exercise intervention. The study wanted to understand the exercise ability and physical fitness of ADHD children and hoped to improve the exercise and physical fitness of ADHD children. After 12 weeks of training, it was found that the athletic ability, cardiovascular adaptability and flexibility of ADHD children had been significantly improved (Pan et al., 2017).

A multi-exercises consisting of running, skipping rope, basketball, etc. were used as an intervention. After six weeks of training, it was found that after exercise intervention in children with ADHD, their Korean ADHD Rating Scale (K-ARS) scores and persistent errors were significantly reduced (Choi et al., 2015). Another study of multi-exercises intervention allows children with ADHD to participate in exercise training consisting of tennis, rock climbing, beach volleyball, swimming, and other exercises. Research results showed that the score performance of working memory, Digit Span Forward, and Number-Letter Sequence had improved significantly (Ziereis & Jansen, 2015). Racket exercise (such as table tennis) was also a kind of exercise intervention that could improve the executive function of ADHD children, and could also simultaneously improve the motor skills, muscle strength, and agility of ADHD children (Pan et al., 2016). Using a multi-exercises intervention consisting of ball exercises (such as basketball, billiards, and football) to explore the benefits of improving the cognitive function of ADHD children. The results also showed that choosing an exercise program with a certain duration, frequency and intensity could improve ADHD children's behavioral inhibition control, RT, and executive function (Memarmoghaddam et al., 2016). After eight weeks of intervention, it could improve the total switching cost of ADHD children (Benzing et al., 2018), inhibition, and RT (Benzing & Schmidt, 2019). The 2019 study found that after 12 weeks of table tennis intervention for children with ADHD, both Stroop color and word test (SCWT) and Wisconsin card sorting test (WCST) scores improved significantly (Pan et al., 2019). A study on adolescents with ADHD using Taekwondo as an exercise intervention found that after 18 weeks of Taekwondo training, the benefits of attention inhibition control and continuous and selective visual attention increased (Kadri et al., 2019b).

Different from traditional exercise interventions, the infrared thermal imaging dynamic game captured by the Xbox Kinect infrared thermal imaging camera was a new type of game exercise intervention for ADHD children (Benzing & Schmidt, 2017). A total of 6 weeks of interventional research using virtual reality running training found that the incidence of social problems in children with ADHD (such as reducing the difficulty of making new friends or maintaining relationships with friends) in the follow-up reports of parents had significantly improved. And in the cognitive function test, it was found that executive function, memory, and pace frequency also showed significant improvement effects (Shema-Shiratzky et al., 2019). A study on preschool children with ADHD found that using ‘Enhancing Neurobehavioral Gains with the Aid of Games and Exercise, (ENGAGE)’ which was accompanied by important other people (parents) and uses games for exercises training, could significantly improve the occurrence of several related problems such as overactivity, aggression, and attention (Healey & Halperin, 2015).

2.1.4 Event-related potential and cognitive test

The studies scope of electroencephalography (EEG) and ERP covers cognitive function, executive function, memory, language, emotion, and movement, and it was often used to detect neurological diseases related to cognitive function, such as ADHD, autism, childhood-onset schizophrenia, Tourette syndrome, specific language disorder, and developmental dyslexia, anxiety, obsessive-compulsive disorder, and depression (Banaschewski & Brandeis, 2007). In previous studies, ERP was a good and effective method for measuring cognitive function, whether in children (Cao et al., 2013) or adults (Kim et al., 2014) with ADHD. A systematic review and meta-analysis article in 2020 also clarified that the use of ERP could effectively compare the differences in the performance of people with ADHD compared with non-ADHD (Kaiser et al., 2020). The P300 (P3) component was an ERP commonly used to detect ADHD, and it was widely used in the test of children with ADHD. Recently, studies on the use of P3 to detect adults with ADHD had also begun to be integrated (Szuromi et al., 2011). Because P3 could reflect the cognitive functions closely related to ADHD, such as executive and attention functions, including updating working memory, event classification, attention resource allocation, and attention redirection (Donchin & Coles, 1988). The reason for the above might be that P3 was particularly sensitive to changes in the nerve potential of the brain areas related to

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attention resources, such as the frontal lobe and temporal lobe (Polich, 2007). According to the above research results, it could be understood that the change in P3 amplitude was an important indicator of the effect of improving cognitive function in patients with ADHD. And a study in 2020 also found that in experiments using EEG to quantify cognitive load, sitting, standing, and running interventions could successfully trigger P3, and each task only takes 5 minutes to successfully collect data (Swerdloff & Hargrove, 2020). Provide a reliable basis for the measurement of acute effects. Low-intensity acute aerobic exercise could help to shorten the P3 latency in healthy men, and moderate-intensity acute aerobic exercise could also help to increase the P3 amplitude and shorten the P3 latency (Kamijo et al., 2007). And the improvement effect of the P3 amplitude in the group with poor cognitive function is better than that of the group with better cognitive function (Drollette et al., 2014).

Here were some examples of common cognitive tests that use ERP. The SCWT, which could reflect different interferences on the activation of brain regions (Liotti et al., 2000) and could be used to evaluate the distribution of attention resources (Potter et al., 2002), and WCST, which could be used to evaluate metrics for abstract reasoning tasks (Barceló et al., 1997) and could be used to assess the function and activation of the frontal lobe (Barceló et al., 2000).

Task-switching was defined as changing between two separate tasks (sometimes rapidly), and multitasking behavior was defined as the simultaneous performance of two discrete tasks (Salvucci et al., 2009). But multitasking was not possible except when behaviors become completely automatic (Skaugset et al., 2016). When working on a task-switching, the performance during the task-switching might be reduced due to an increase in extraneous load (Anderson, 1987; Muhmenthaler & Meier, 2019). Therefore, this study also used task-switching

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techniques to increase the total cognitive load of exercise intervention when necessary. A study in 2019 found that task-switching was related to a common core brain area network, such as the intraparietal sulcus (IPS), left dorsal premotor cortex (dPMC), and right anterior insula. Conversely, task-switching was activated more consistently in four clusters (left inferior frontal junction, posterior IPS, and precuneus as well as the front medial cortex (Worringer et al., 2019). A study compared the cognitive function of healthy older adults and older adults with amnestic MCI (aMCI) showed that using task-switching could accurately detect changes in accuracy rates (ARs), RTs, global switching cost, and ERP P3 amplitude (Tsai et al., 2016). Another study on children from 4 to 13 years old and young adults also showed that using task-switching and functional Magnetic Resonance Imaging (fMRI) could measure children's cognitive flexibility, inhibition, accuracy, and global switching cost (Davidson et al., 2006). This meant that task-switching could not only correspond to the complex damage in the brain of patients with ADHD but also could measure important indicators of the improvement of cognitive function in patients with ADHD (changes in the amplitude of P3 and N1, etc.). Because of this, this study used task-switching as a cognitive test to detect the effect of cognitive function improvement.

2.2 Cognitive function and cognitive load intensity of exercise

2.2.1 Cognitive load overview

Cognitive Load Theory (CLT), first described by John Sweller in 1988 (Sweller, 1988), represented an important cognitive learning theory. CLT integrated three key components of the cognitive architecture: the memory system (sensory, working, and long-term memory), the learning process, and the type of cognitive load imposed on working memory (WM) (Young et al., 2014). This study used the effect of an acute intervention, so this study focused on the cognitive load of WM. CLT assumed that the working memory of the human cognitive system was limited, and the storage of new information during learning could only accommodate five to nine information elements, and only two to four elements during active processing at the same time (Miller, 1956; van Merriënboer & Sweller, 2010; Young et al., 2014). In addition, CLT also identified three types of cognitive load that affect WM: intrinsic load, extraneous load, and germane load (Atiomo, 2020). Intrinsic cognitive load was related to the complexity of the tasks performed and the professional knowledge of learners. Extraneous cognitive load refers to extraneous factors that do not directly contribute to the task performed. Germane cognitive load was the influence of patterns gained from past learning on new information (Atiomo, 2020; van Merriënboer & Sweller, 2010; Young et al., 2014). Reducing extraneous cognitive load, optimizing germane load, and managing intrinsic cognitive load could reduce the intensity of cognitive load (Atiomo, 2020). Conversely, adding secondary tasks to the main tasks could lead to a significant increase in cognitive load intensity (Haji et al., 2015). Therefore, how to manipulate cognitive load would be the focus of this study.

2.2.2 Measures of cognitive load intensity

When people were learning new things, they could feel the increase in cognitive load intensity (especially related to working memory) (Young et al., 2014). Because the extraneous load increased, the additional burden also increased (Anderson, 1987). The high cognitive load intensity was mainly because learners had to deal with multiple elements at the same time, and these tasks with high element interaction and incomprehensibility would produce a high cognitive load (van Merriënboer & Sweller, 2010). For example, the extraneous cognitive load also increased when performing dual-tasks at the same time, which increased interference (Lavie

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et al., 2004). Recognizing spoken words in sentences under adverse listening conditions (Hunter & Pisoni, 2018). Using non-native language to understand new knowledge (Sweller et al., 2019). The cognitive load intensity was different when walking and sitting still (Swerdloff & Hargrove, 2020). In the 2015 study, medical students who had no experience in surgical knotting were allowed to perform simple and complex knotting tasks. Students who were engaged in complex knotting assignments in the main task needed to wear gloves used a thinner thread and completed the knotting assignment in a deeper area. In addition, in the secondary task, there would be a vibration device that stimulates the students' thighs from time to time, and the students needed to feel the stimulation and press the button for recording. Using a subjective rating of mental effort (SRME) and simple reaction time (SRT) to assess cognitive load for secondary tasks. The results of the study found that the SRME of students engaged in complex tasks increased significantly, indicating a high cognitive load intensity. It also meant that the performance of secondary tasks and SRME were very sensitive to changes in intrinsic load (Haji et al., 2015). Another study of young people and old people found that under the same cognitive load intensity, the old people had poor performance in speech motor (MacPherson, 2019).

There were four common measurement methods for cognitive load, namely (1) using the Subjective Workload Assessment Technique (SWAT) (Reid & Nygren, 1988) and the NASA-task load index (NASA-task load index, NASA- TLX) (Hart & Staveland, 1988) questionnaire, which measured the cognitive load experienced during a specific task (Gopher & Braune, 1984). (2) Objectively measured changes in performance and grades (Yerkes & Dodson, 1908). (3) Behavioral measures of gaps in task processing (Lim et al., 2015; Magnusdóttir et al., 2017). (4) Detection of physiological changes associated with cognitive statuses, such as electrodermal

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activity (Sevcenko et al., 2021) and heart rate variability (HRV) (Thayer et al., 2009) physiological indicators.

The increase or decrease of cognitive load intensity interacted with sympathetic nerves, and skin electrical activity could be used as an indicator to monitor sympathetic nerve activity (Ströfer et al., 2015). When engaging in higher cognitive load activities, the response of electrodermal activity was also increased (Ellermeier et al., 2020). HRV was the heart rate change through the mutual regulation of parasympathetic and sympathetic nerves in the autonomic nervous system (Bricout et al., 2010). A higher HRV indicated that the autonomic nervous system was able to respond accordingly to environmental demands (Thayer et al., 2009), indicating its adaptive function (Porges, 1995). Therefore, there might be an important relationship between electrodermal activity and HRV on cognitive load and cognitive performance (Thayer et al., 2009; Wilson, 2002). Although there were many methods of measuring cognitive load, it was still impossible to use a single assessment method to confirm all aspects of cognitive load, so it was better to use multiple assessment methods (Sevcenko et al., 2021).

2.2.3 Practical application of cognitive load in exercise

Generally speaking, the cognitive load was defined in the exercise as the intrinsic load caused by individual physiological and psychological reactions, and the extraneous load imposed on athletes during training or competition to generate extraneous physical stimuli (Soligard et al., 2016). Adding secondary tasks to the primary task resulted in a significant increase in cognitive load intensity simply (Haji et al., 2015). Conversely, if the extraneous cognitive load could be reduced or the germane cognitive load could be increased, the intensity of the cognitive load

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could be effectively reduced (Atiomo, 2020). Thus, cognitive load in exercise could be seen as available mental resources for task solving (Fuster et al., 2021). According to the viewpoint proposed by the adaptive capacity model (ACM), the increase in cognitive load intensity during exercise could help strengthen cognitive and executive functions (Raichlen & Alexander, 2017). Its mechanism might be because exercise with higher cognitive load intensity had a better effect on increasing the concentration of brain-derived neurotrophic factor (BDNF) and neuron activity index N-acetylaspartic acid (NAA) (Anderson-Hanley et al., 2012; Lövdén et al., 2011). And reduced the proportion of hippocampal volume decrease with age (Lövdén et al., 2012)

2.2.4 Improvement effect of exercise intervention with different cognitive load intensities

The use of different intensities of cognitive load with exercise for intervention could also see the difference in the effect of improving cognitive function. A study of young participants (13-14 years old) who used different cognitive load intensities and dual-tasks found that the dual-task group was more effective than the single-task group in improving youth motor skills and working memory. In addition, the difficult dual-task group had the best effect on improving motor skills. (Bustillo-Casero et al., 2020). Furthermore, adding cognitive load to the training of transfer tasks could help to improve the dexterity of the hands (Sankaranarayanan et al., 2020). The basic motor skills of ADHD were worse than those of healthy peers (Pan et al., 2017). Therefore, the intervention of cognitive load might help to improve the basic motor skills of ADHD. Dual-task intervention with cognitive load was not only beneficial to healthy people. In the study of the elderly with mild cognitive impairment (MCI), it was also shown that the group that combined cognitive tasks and physical activity intervention had significantly higher effects on cognitive function and attention function than the group that simply engaged in the classical

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cognitive training program (Hagovská et al., 2017). The elderly with a sedentary lifestyle were randomly assigned to three different cognitive load intensities and exercise patterns. The first group was the high cognitive load exercises group, which engaged in dancing exercises. The second group was a low cognitive load exercise group, using a treadmill to walk slowly. The third group was the control group. The exercise group performed moderate-intensity aerobic exercise for 50 minutes/time, 3 times/week for 4 months. The final result found that the high cognitive load exercise group had the best effect on improving the overall cognitive function of the elderly (Chao et al., 2020). Participants aged 4-5 were randomly assigned to four different cognitive load intensities and exercise patterns. Exercises and Cognition Group 1: Use pedal less bicycles and complete designated tasks. Exercises and Cognition Group 2: Use running and complete designated tasks. Cognitive group: acting (related to bicycles). Control group: drawing (related to bicycle). In the end, it was found that the exercise and the cognitive group performed better in self-adjustment and cognitive control than the other two groups (Ureña et al., 2020).

In addition to improving executive function, the motion sensing game could also make participants have a positive attitude toward related interventions (Kayama et al., 2014; Maillot et al., 2012; Schättin et al., 2016; Schoene et al., 2015). Compared with running intervention with low cognitive load, dance intervention with high cognitive load had a better effect on improving executive functions such as working memory, attention, and inhibitory control. It also showed positive effects in the prefrontal cortex, superior frontal gyrus, and anterior cingulate cortex (Chao et al., 2020; Eggenberger et al., 2015; Eggenberger et al., 2016). In terms of comprehensive exercise, the improvement effect of different evaluation items might be the most diverse due to the large number of exercises involved (Falbo et al., 2016; Morita et al., 2018; Nishiguchi et al., 2015; Yokoyama et al., 2015). On the other hand, using cognitive training

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coupled with balance training had been shown to improve motor control (Bustillo-Casero et al., 2020). The use of taekwondo intervention had been shown to improve attention and reaction time in ADHD ((Kadri et al., 2019a). The use of football intervention could also be found to shorten the reaction time of SCWT and had a significant effect on improving the P3 stimulation of SCWT (Won et al., 2017). Finally, in addition to the improvements from long-term exercise interventions, the benefits of using acute exercise interventions resulted in significant improvements in cognitive function, motor control, self-regulation, and overall SCWT performance (Bustillo-Casero et al., 2020; Ureña et al., 2020; Won et al., 2017).

However, not all exercise interventions with high cognitive load havd better effects on improving cognitive function than those with low cognitive load. A study had shown that exercise intervention with high and low cognitive load might have the same effect on improving cognitive function, but there were differences in specific executive functions. For example, exercise intervention with high cognitive load had a better effect on improving cognitive flexibility. However, exercise intervention with the low cognitive load had a better effect on improving working memory (Tsai et al., 2017). Another study found that the intervention of cognitive load and physical activity at the same time had a weaker effect on improving the attention of healthy children than that of single-exercise intervention or cognitive training (Gallotta et al., 2015).

It could be known from the above studies that increasing the extraneous load could effectively improve the intensity of cognitive load. Most exercise interventions with higher cognitive load were more effective in improving cognitive function and executive function than those with low cognitive load. However, exercise interventions with different cognitive load

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intensities had different effects on improving cognitive function, executive function, and physical ability. On the other hand, having sufficient cognitive resources (proficiency, automation, expertise, etc.) to maintain a low intrinsic load and reduce excessive extraneous load could reduce the overall cognitive load intensity. Since this study hopes to recruit participants with more than one year of experience in table tennis (which means they had a sufficiently low intrinsic load), the intensity of cognitive load manipulated in this study would focus on the amount of extraneous load.

Chapter 3

Methods

3.1 Participants

Participants in this study must be (1) children with ADHD with a diagnosis certificate. (2) TD children. (3) Conforming to the following characteristics: (1) No history of cardiovascular disease, diabetes, or previous injury. (2) No hearing or vision problems, and normal or corrected vision. (3) Participate in table tennis training for at least one year. (4) Must be between 8 and 12 years old.

In this study, based on the study of Yamazaki et al (2018), used G-power software to calculate the number of samples required for the experiment. The study for using the study above as the basis of calculation was as follows: (1) Used of within-group variance design. (2) Divided into three different exercise intensity interventions. (3) Used acute effects. (4) Measured cognitive function. Based on the effect size of .25 (Yamazaki et al., 2018), a power of .80, and an alpha of .05. It was concluded that the total sample size of participants requires 28 people. The estimated attrition rate for the retest was 20%, so it was estimated that the total sample size of participants needed to recruit 32 participants. Therefore, this study would recruit 16 ADHD participants and 16 TD participants, a total of 32.

This study originally expected to recruit 16 ADHD children and 16 TD children as participants. However, due to the impact of the COVID-19 epidemic, the experiment was forced to be suspended for several months. Therefore, as of the start of the paper, only eight ADHD

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children were recruited to complete three experiments. However, TD Children recruited 18 participants to complete the three experiments, exceeding the originally expected 16 participants.

3.2 Procedure

A total of three tests would be conducted in this experiment. During the first visit, explained the entire experimental procedure to the participants and their legal guardians. The participant's legal guardian would complete the health history, demographic questionnaire, ADHD-T, CBCL, and informed consent form. Participants would be required to complete the Test of Nonverbal Intelligence-Fourth Edition (TONI-4) to test intelligence quotient (IQ). Lastly, the height and weight of the participants would be measured and the body mass index (BMI) would be calculated.

After completing the above items during the first visit, the first test would be conducted. We used a counterbalance subject design to make sure that there would be no learning effect and affect the experimental results.

On one day, participants would watch a 20 minutes video of table tennis. Afterward, a cognitive test of task-switching would be performed to record the baseline of cognitive function performance. (Before the formal experiment, the participants would equip with electrode caps and accepted the task guidance. The pure and mixed conditions would be tested until the participants reach the standard of 80% accuracy.).

On the other day, the participant would use the HR monitor to record the participant's resting HR after sitting quietly for three minutes. Then enter the movement intervention phase. Participants would experience 5 minutes of warm-up activities, 20 minutes of moderate exercise intensity (60-65% HRR; HRR would pre-determine using the formula: (maximal heart rate – resting HR) x % intensity + resting HR) table tennis intervention, and 5 minutes of relaxation activities. Lastly, a cognitive test of task-switching would be conducted to record the performance of a cognitive function.

On another day, the participant would use the HR monitor to record the participant's resting HR after sitting quietly for three minutes. Then enter the movement intervention phase. Participants would experience 5 minutes of warm-up activities, 20 minutes of moderate exercise intensity (60-65% HRR; HRR would pre-determine using the formula: (maximal heart rate – resting HR) x % intensity + resting HR) table tennis intervention, and 5 minutes of relaxation activities. Lastly, a cognitive test of task-switching would be conducted to record the performance of a cognitive function.

The difference was that participants would engage in table tennis with low cognitive load intensity for 20 minutes on one day, while participants would engage in table tennis with high cognitive load intensity for 20 minutes on the other day (see Figure 1).

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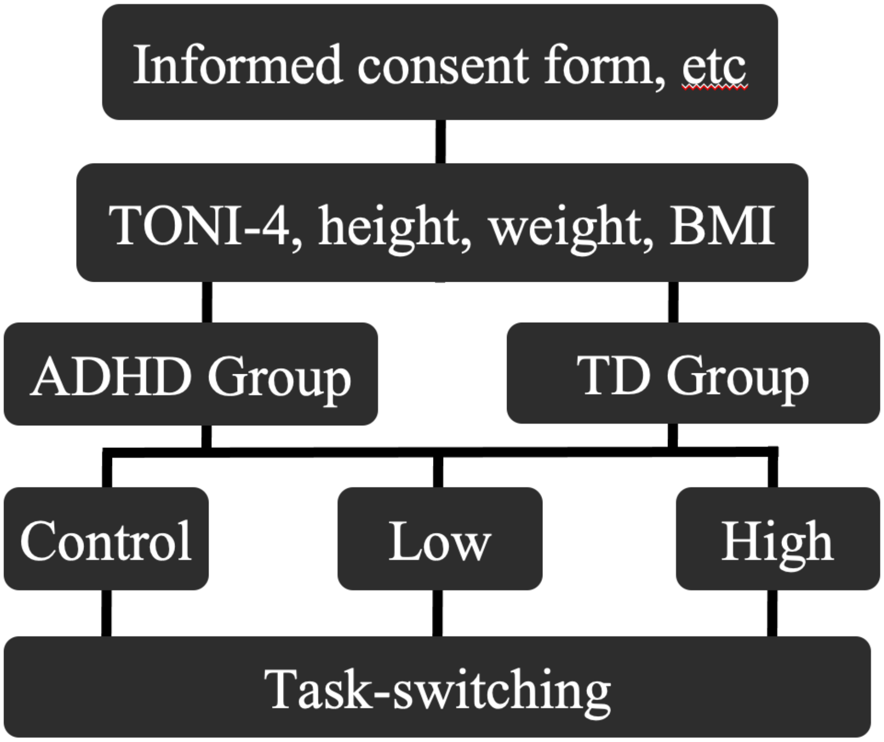

Figure 1. Procedure

Participants would be required to (1) sleep at least 7 hours a day before the test; (2) avoid caffeine; (3) avoid strenuous exercise; (4) ask participants to eat the same breakfast in the morning of each test; (5) forbidden to use any kind of drugs during and between trials.

3.3 Heart rate monitoring and hitting accuracy

This study used the method of recording heart rate to maintain the moderate exercise intensity of each participant in the range of 60%-65% of the reserve heart rate. And to ensure that the intensity during the exercise had reached the exercise intensity that was believed to help improve cognitive function in previous studies (Northey et al., 2018; Raichlen & Alexander, 2017; Solheim et al., 2014). The heart rate was recorded with a heart rate belt to maintain moderate exercise intensity during exercise. The heart rate setting range was 60-65% HRR. First, measured your resting heart rate after sitting quietly for three minutes. Then, calculated the maximum heart rate with the formula "208 - 0.7 x age". Lastly, HRR was calculated by the formula "(maximum heart rate – resting heart rate) x 60-65% + resting heart rate". Recorded the heart rate every 30 seconds during the exercise, and calculated the average heart rate (bpm) during the exercise. To ensure that we could always be at a moderate exercise intensity during exercise, we would monitor changes in heart rate and adjust the intensity, frequency, and strength of the ball machine when serving. Therefore, the exercise intensity of this study was individually designed to ensure that each participant could maintain their moderate exercise intensity (60-65% HRR).

In this study, to calculate whether there were indeed differences in different cognitive load intensities, a cellphone was used to shoot videos to record the hitting accuracy. Recorded whether the ball returned to the correct position during the movement. Watched the video afterward and used the counter to count the total number of serves, and the number of correct return shots (or the number of missed shots), to obtain each person's hitting accuracy at high cognitive load and low cognitive load. This was consistent with the method we used to measure the difference between high and low cognitive load intensity (Lim et al., 2015; Magnusdóttir et al., 2017).

3.4 Table tennis intervention and cognitive load intensity design

The experimental design of this study was modified from the previous experimental procedures (Pan et al., 2017; Pan et al., 2019). Participants would be required to participate in

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two exercise plans and cognitive tests. The sessions included a warm-up (5 min), table tennis training with different cognitive load intensities (20 min), and a cool-down (5 min) (see Table 1).

Table 1. Physical activity training program protocol.

Activity	Length (min)	Content	Goal
Warm-up	5 min	Jogging, skipping rope, muscle stretching	Warm-up and stretching.
Table tennis training with different cognitive load intensities	20 min	Low cognitive load intensity or high cognitive load intensity.	Use different cognitive load intensities for exercise intervention, and explore the effect of different cognitive load intensities on cognitive function in subsequent cognitive tests.
Cool-down	5 min	Slow walking, stretching exercises	Relax the muscles and restore the body from exercise to normal.

Simple tasks or tasks that were familiar and could be automated require a low degree of cognitive load (Paas, 1992), and adding secondary tasks to the main task could cause significant changes in the intensity of cognitive load (Haji et al., 2015). Integrating cognitive tasks into physical activities could enhance children's cognitive learning better than performing physical activities that were not related to cognitive tasks (Toumpaniari et al., 2015). Therefore, this study believed that using table tennis as an exercise intervention and adding secondary tasks of different difficulty to the main task could increase the cognitive load of different intensities. For

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the main session of the program (20 minutes), it was modified from previous research (Pan et al., 2017; Pan et al., 2019) to divide table tennis training into low and high two different levels of cognitive load. (1) The exercise intervention with low-intensity cognitive load was as follows: the automatic ball-shooting machine projects an orange ball from a random direction and a fixed height. Competitors needed to return the long ball to the left backcourt. (2) The exercise intervention with high-intensity cognitive load was as follows: the automatic ball-pitching machine projects two different-colored balls from random directions and fixed heights. If it was a white ball, the competitor needed to return the long ball to the right backcourt. If it was an orange ball. Competitors needed to return the long ball to the left backcourt. All participants used a forehand when returning the ball, and moved their footsteps to hit the ball by the direction of the ball machine.

3.5 Task-switching

Cognitive performance was assessed using the task-switching paradigm modified by Hung et al. (2016), presented on a computer monitor controlled via Neuroscan Stim software (ver. 2.0; Neuro Inc., El Paso, TX, USA). There were six blocks in total, of which the first and second rounds were pure condition, and the third to sixth rounds were mixed condition. Each block had 64 trials, for a total of 384 trials. The task-switching test would perform three different cognitive tests: (1) Used pure condition task-switching cognitive test. The first test was called "bigger or smaller”: In this test, any number from one to nine except five would appear in a square box drawn by a solid line. If the number appeared one to four, it was judged to be smaller than five. At this time, you needed to use your left thumb to press the "number four" button which was “left” button on the keyboard. If the number appeared six to nine, it was judged to be bigger than five. At this time, you needed to use your right thumb to press the "number six" button which

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was “right” button on the keyboard. (2) Used pure condition task-switching cognitive tests. The second test was called “odd or even”: In this test, any number from one to nine except five would appear in a square frame drawn by a dotted line. If the number appeared one, three, seven, or nine, it was judged to be an odd number. At this time, you needed to press the "number four" button which was “left” button on the keyboard with your left thumb. If the number appeared two, four, six, or eight, it was judged to be an even number. At this time, you needed to use your right thumb to press the "number six" button which was “right” button on the keyboard. (3) Use the mixed condition task-switching cognitive test. This test was a combination of the first two tests, which also meant that the difficulty of this test would be higher. In this test, any number from one to nine except five would appear in a square frame drawn by a solid or dotted line. If this box was drawn by a solid line, you needed to use the game rules of task 1. Conversely, if the box was drawn by a dotted line, you needed to use the game rules of task 2 (see Figure 2).

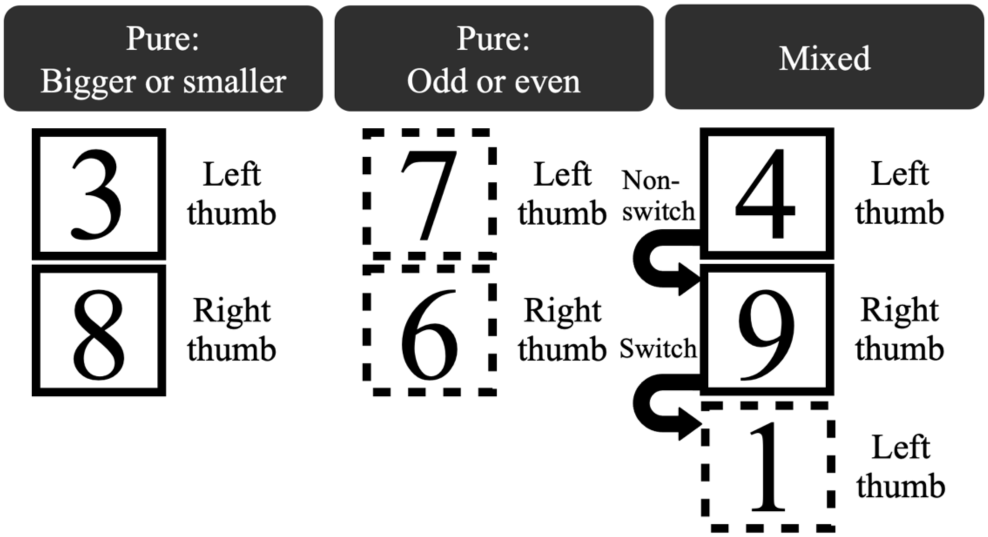

Figure 2. The rules of task-switching

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All stimuli were presented as single numbers in black. 400 milliseconds after the target appeared, followed by a 2500 millisecond answer time. After a preparation time of 500 milliseconds, a new cycle was started (see Figure 3).

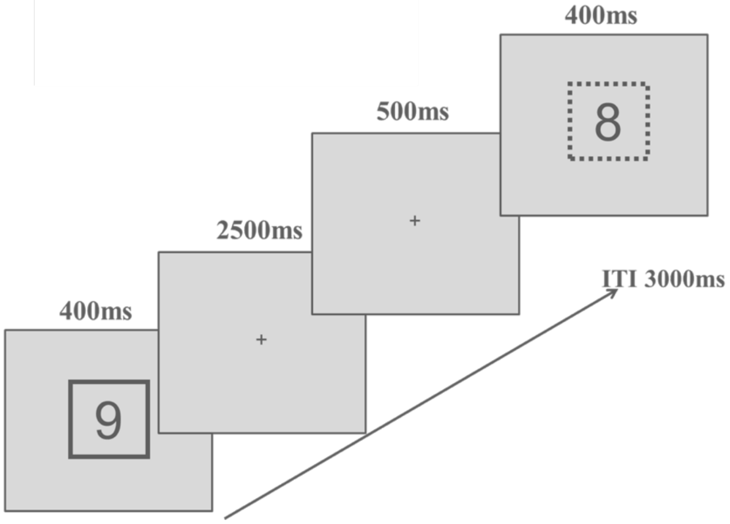

Figure 3. The procedure of task-switching

3.6 ERP recording and analysis

The event-related potential was measured using an electrode cap, a 32-channel shock cap, and the international standard-setting of 10-20; each electrode reference point was the average value of the post-auricular mastoid electrode in both ears; the impedance was kept below 10 kΩ. Used Neuroscan SynAmps2 amplifier to apply 60 Hz notch filter to record brain waves. Since the parietal lobe (Pz) position record could best record the change of P3 amplitude (van Dinteren et al., 2014), this study only analyzed the ERP data of the Pz position record (Hung et al., 2016). The offline data reduction included merging with the behavioral data. The ERP data would be corrected for ocular artifacts. Epochs would be defined as 100ms pre-stimulus to 900ms post-

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stimulus, and baseline corrections would be performed using the 100-ms pre-stimulus interval. A low-pass filter with a 30 Hz cutoff (12db/octave) would be employed to further attenuate noise. ERP trials with amplitudes outside the range of ±100 μV would be excluded from further analysis. The correct trials were separately averaged. To examine ERP components, P3 mean amplitudes would be calculated for 300-700ms time intervals within a 50-ms interval surrounding the largest positive going peak (Elke & Wiebe, 2017; Hermens et al., 2005; Hung et al., 2016). Peak latencies would be measured within the latency window.

3.7 Statistical analysis

Statistical analyses were performed using the IBM SPSS Statistics software system, with an alpha of .05 set as significant criteria. To first test the homogeneity between groups, independent-sample t-tests were subjected to all descriptive and fitness measures (age, height, weight, BMI, and IQ scores).

To examine the effects of cognitive load intensity on the exercise of different levels, 2 (Group: ADHD, TD) x 2 (Session: high cognitive load intensity, low cognitive load intensity) repeated-measured analyses of variance (RM ANOVAs) were subjected to mean accuracy. Another separate 2 (Group: ADHD, TD) x 2 (Session: high cognitive load intensity, low cognitive load intensity) RM ANOVAs were subjected to mean HR.

For behavioral indices, 2 (Group) × 3 (Session: Control, Low cognitive load intensity, High cognitive load intensity) × 2 (Condition: Pure, Mixed or Non-switch, switch) RM ANOVAs were subjected to mean accuracy and mean RT. Secondary 2 (Group) x 2 (Session) RM ANOVA would be performed on SI in accuracy or RT if a significant congruency effect was found.

For neuroelectric indices, 2 (Group) x 3 (Session) x 2 (Condition) RM ANOVAs were performed on P3. Recordings of P3 were averaged across electrodes on the centroparietal point (Pz).

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Chapter 4

Results

4.1 Demographic analysis

This study originally expected to recruit 16 ADHD children and 16 TD children as participants. However, due to the impact of the COVID-19 epidemic, the experiment was forced to be suspended for several months. Therefore, as of the start of the paper, only eight ADHD children were recruited to complete three experiments. However, TD Children recruited 18 participants to complete the three experiments, exceeding the originally expected 16 participants.

There were no significant differences between the groups in age (p > .05), Body weight (p > .05), Height (p > .05), BMI (p > .05), and IQ (p > .05), suggesting and equivalence between the two groups. The demographic characteristics of participants in both groups were summarized in Table 2.

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Table 2. Participant demographic characteristics for study

	ADHD (*N* = 8)	TD (*N* = 18)	*P*
	M (SD)	**M (SD)**	
Gender (M:F)	8:00	13:05	
Age (years; *M* (*SD*))	9.56±0.90	9.94±0.56	.065
Body weight (kg; *M* (*SD*))	37.04±5.95	35.72±4.81	.371
Height (cm; *M* (*SD*))	141.00±8.33	143.21±5.42	.744
Body mass index (kg/m2; *M* (*SD*))	18.56±3.15	17.50±1.74	.068
Test of Non-verbal Intelligence (score)	106.75±14.79	109.00±13.78	.949

4.2 Exercise intervention performance

There were no significant differences between the groups in heart rate (ADHD: Low: 136.88 bpm, High: 134.13 bpm, p > .05; TD: Low: 146.72 bpm, High: 140.50 bpm, p > .05), suggesting equivalence between the two groups. It also meant that all of them had carried out the same exercise intensity training, and there’s no difference in the time after the exercise and before the start of the test. The demographic characteristics of participants in both groups were summarized in Figure 4.

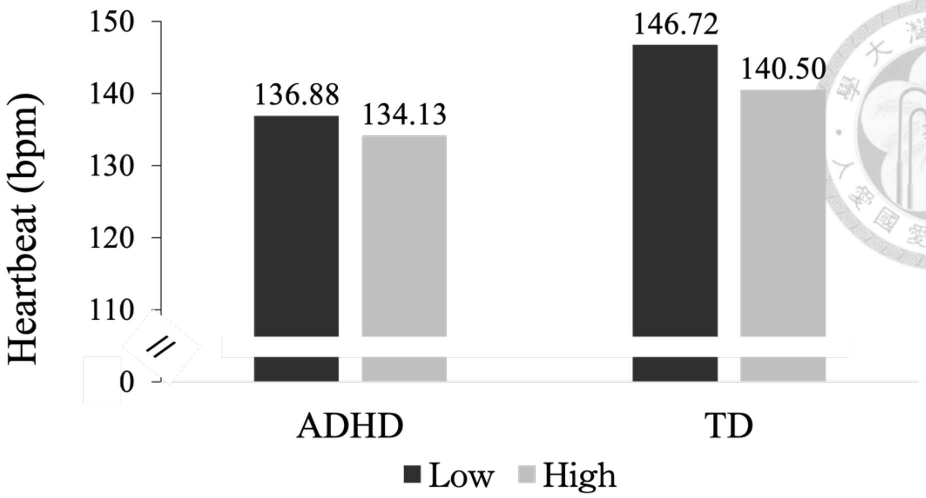

Figure 4. Means for the exercise intervention performance

There was a significant difference in the accuracy of the high cognitive load intensity table tennis intervention and the low cognitive load intensity table tennis intervention (ADHD: Low: 49.98%, High: 40.27%, p < .01; TD: Low: 84.48%, High: 74.82%, p < .01). The accuracy rate of low cognitive load intensity table tennis intervention was significantly higher than that of high cognitive load intensity table tennis intervention. It showed that there was a significant difference in cognitive load intensity between table tennis intervention with high cognitive load intensity and low cognitive load intensity table tennis intervention. On the other hand, the accuracy rate of the TD group was significantly better than that of the ADHD group (ADHD: 45.13%; TD: 79.65%, p < .01). The within-subject effect among the ADHD group and TD group also reached a significant difference, which meant that the cognitive load intensity of high cognitive load intervention was indeed higher than that of low cognitive load intervention (see Figure 5).

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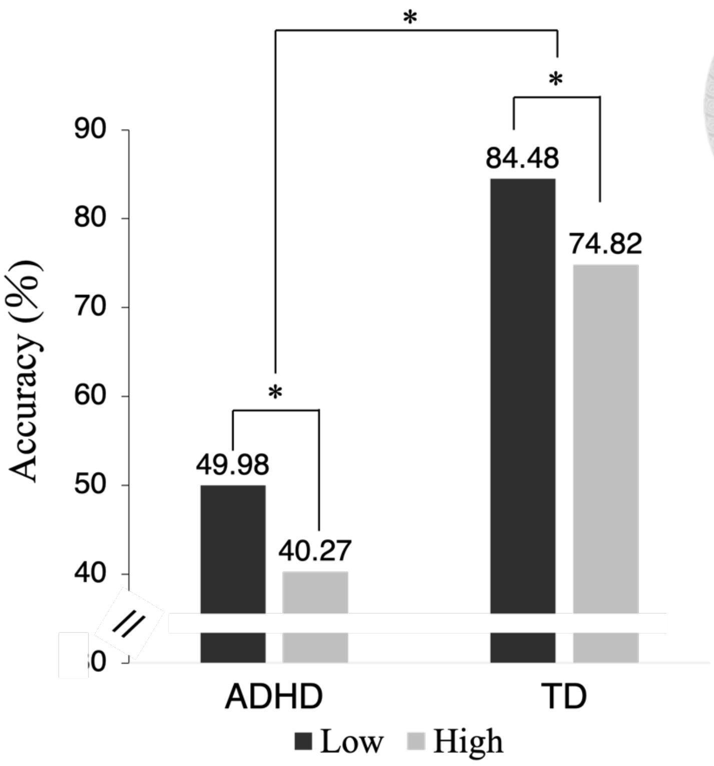

Figure 5. Accuracy for the exercise intervention performance

4.3 Task performance

4.3.1 Reaction time

Table 3 presented the detailed behavioral data (reaction time) of the global switch effect and local switch effect for the task-switching indices for each group.

Table 3. Means, and standard deviations (SD) of reaction time for the task-switching

	ADHD (*N* = 8)			**TD (*N* = 18)**		
	M (SD)			M (SD)		
Global switch RT (ms)	Control	Low	High	Control	Low	High
Pure trials	947.69	874.22	1058.63	813.62	747.91	804.13
	±81.09	±81.71	±89.39	±54.06	±54.47	±59.59
Mixed trials	1299.35	1294.89	1226.46	1188.86	1145.22	1117.49
	±132.25	±118.13	±111.83	±88.17	±78.75	±74.55
Local switch RT (ms)	Control	Low	High	Control	Low	High
Non-switch trials	1252.79	1278.08	1220.10	1173.40	1135.43	1117.86
	±125.42	±121.27	±112.89	±83.61	±80.84	±75.26
Switch trials	1345.91	1311.71	1232.82	1204.33	1155.01	1117.13
	±140.69	±117.42	±113.12	±93.79	±78.28	±75.41

4.3.1.1 Global switch effect

After analyzed of RT revealed the main effect of Group, we found three-way ANOVA revealed the main effect of group, session, and condition (p > .05), which did not reach significant differences. These main effects were reached significant by a Condition and Session (p < .05). A main effect of Condition was also yielded (p < .05). Table 4 summarizes the results of ANOVA on RT in the global switch effect.

Table 4. ANOVA results on RT in the global switch effect

	df	**F**	***P***
CON	1	131.64	<.001*
CON * SESSION	2	5.59	.007*

The decomposition of the Condition and Session simple main effect showed that low cognitive load session had shorter RT compared with high cognitive load session and control session in the pure condition (Control: 854.87ms; Low: 786.77ms; High: 882.44ms, p < .05). The mixed condition did not reach significance (Control: 1222.86ms; Low: 1191.28ms; High: 1151.02ms, p < .05). All participants responded faster in the pure condition compared to the mixed condition (Pure: 874.37ms; Mixed: 1212.05ms, p < .01) (see Figure 6).

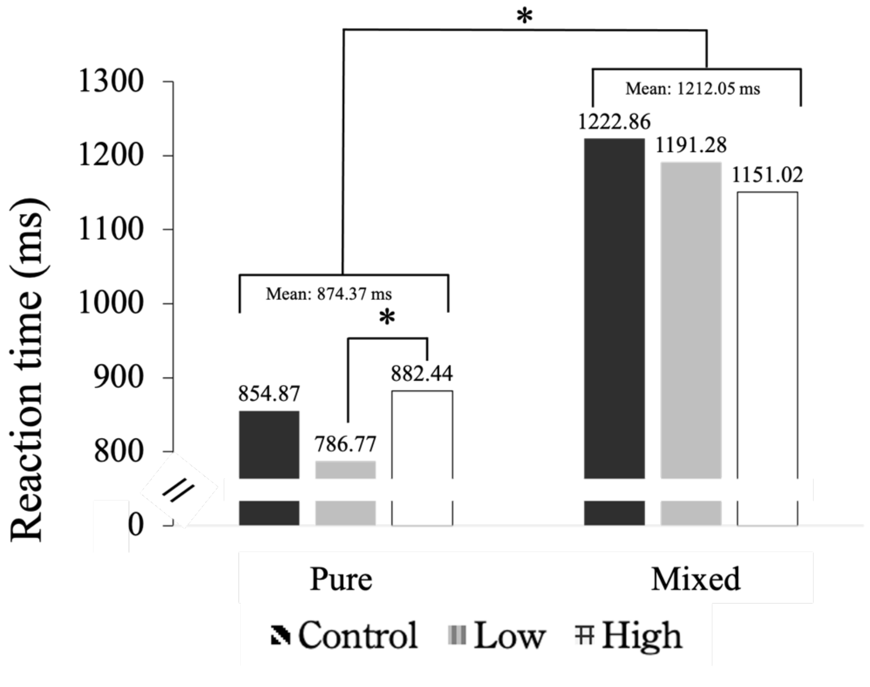

Figure 6. Three sessions in the pure condition and the mixed condition

The decomposition of the Condition and Session simple main effect also showed that pure condition had faster RT compared with the mixed condition in all three Sessions (Pure: Control: 854.87ms, Low: 786.77ms, High: 882.44ms, p < .001; Mixed: Control: 1222.86ms, Low: 1191.28ms, High: 1151.02ms, p < .001).

Lastly, since the three sessions of the pure conditions were significant, we saw whether each group had a significant achievement in the three sessions of the pure conditions. Used to test the improvement effect within the two groups. The results showed that only ADHD achieved a significant (Control: 947.69ms, Low: 874.22ms, High: 1058.63ms, p < .05) in the three sessions of the pure condition, and the reaction time was the fastest in the session with low cognitive load. TD did not reach significance (Control: 813.62ms, Low: 747.91ms, High: 804.13ms, p > .05).

4.3.1.2 Local switch effect

After analyzed of RT revealed the main effectof Group, we found three-way ANOVA revealed the main effectof group, session, and condition (p > .05), which didn't reach significant differences. These main effects didn’t reach significance by a Group and Session (p > .05), a Group and Condition (p > .05), and a Condition and Session (p > .05). The main effect of the Condition (p < .05) was also yielded.

4.3.2 Response accuracy

Table 5 presented the detailed behavioral data (response accuracy) of the global switch effect and local switch effect for the task-switching indices for each group.

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Table 5. Means, and SD of response accuracy for the task-switching

	ADHD (*N* = 8)			**TD (*N* = 18)**		
	M (SD)			M (SD)		
Global switch accuracy (%)	Control	Low	High	Control	Low	High
Pure trials	91.63±1.05	90.63±1.10	91.13±1.20	96.11±0.70	96.67±0.73	97.50±0.80
Mixed trials	76.50±1.92	80.00±1.88	86.75±1.83	91.61±1.28	92.94±1.25	93.50±1.22
Local switch accuracy (%)	Control	Low	High	Control	Low	High
Non-switch trials	79.25±2.12	80.50±2.52	87.38±1.71	91.39±1.41	91.67±1.68	92.67±1.14
Switch trials	73.75±2.60	79.88±1.60	85.75±2.27	91.78±1.74	94.06±1.07	94.11±1.52

4.3.2.1 Global switch effect

After analyzed of accuracy revealed the main effect of Group, we found three-way ANOVA revealed the main effect of group, session, and condition ($p < .05$), which reached significant differences. These main effects were reached significantly by a Condition and Session ($p < .05$), and a Group and Condition ($p < .05$). Main effect of Condition ($p < .05$), and Session ($p < .05$) was also yielded. Table 6 summarizes the results of ANOVA on accuracy in the global switch effect.

Table 6. ANOVA results of the global switch effect

	df	F	*P*
CON	1	120.77	<.001*
Session	2	6.44	.003*
CON * Group	1	22.95	<.001*
CON * Session	2	9.37	<.001*
CON * Session * Group	2	8.52	<.001*

The decomposition of the Group, Condition, and Session interaction showed significance, we perform the following test to confirm the simple interaction.

(1) When performed Group, and Session interaction effects on Condition (Pure, Mixed), used Two-way RM ANOVA (Mixed: $p < .01$).

(2) When performed Group, and Condition interaction effects on Session (Control, Low, High), used Two-way RM ANOVA (Control: $p < .001$; Low: $p < .01$).

(3) When performed Condition, and Session interaction effects on Group (ADHD, TD), used Two-way paired-sample ANOVA (ADHD: $p < .001$; TD: $p < .001$).

The decomposition of the Group and Session simple main effect showed that the high cognitive load session had the highest accuracy compared with the low cognitive load session and control session of both groups, in the mixed condition (ADHD's Control: 76.5%, Low: 80.00%, High: 86.75%, $p < .05$; TD's Control: 91.67%, Low: 92.95%, High: 93.43%, $p > .05$)

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Figure 7 showed that ADHD group in the mixed condition, the accuracy of the high cognitive session was significantly better than that of the low cognitive session, and it was also significantly better than that of the control session (Control: 76.50%, Low: 80.00%, High: 86.75%, p < .05). In the TD group, there was no significant difference in accuracy between different sessions no matter what the condition was.

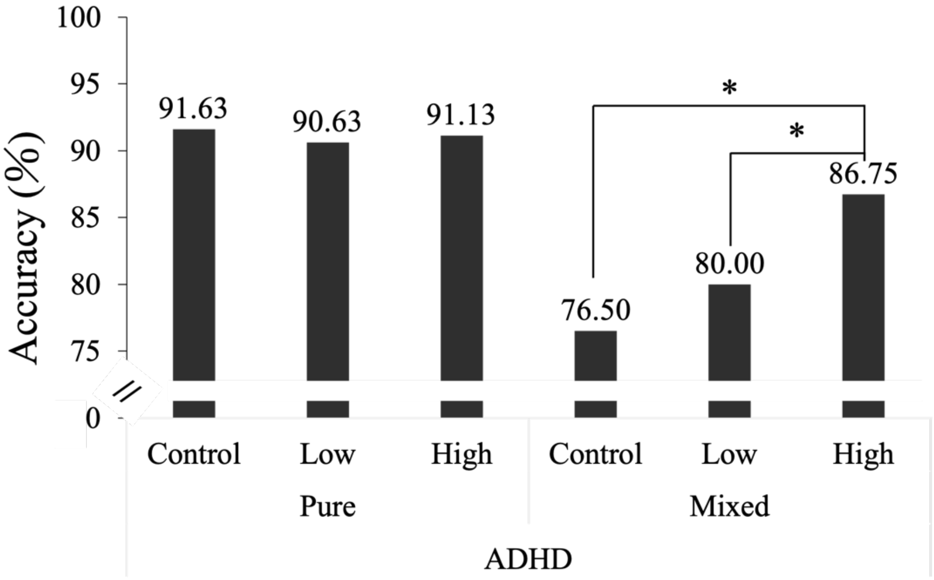

Figure 7. Two-way RM ANOVA for Group, and Condition interaction effect on Session

The decomposition of the Group and Session simple main effect showed that TD always had higher accuracy than ADHD in three of all sessions, in mixed condition (Control: ADHD: 76.50%, TD: 91.67%, p < .001; Low: ADHD: 80.00%, TD: 92.95%, p < .001; High: ADHD: 86.75%, TD: 93.43%, p < .001).

Figure 8 showed that the ADHD group was in the control session, and the low cognitive session, the accuracy of the pure condition was significantly better than that of the mixed condition (Control: Pure: 91.63%, Mixed: 76.50%, p < .05; Low: Pure: 90.63%, Mixed: 80.00%, p < .05).

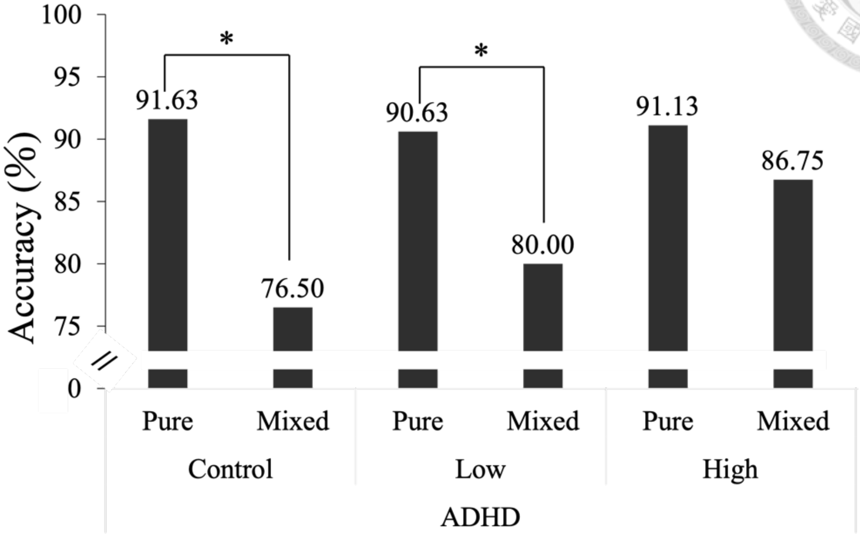

Figure 8. Two-way RM ANOVA for Session interaction effect on Condition of ADHD

The decomposition of the Group and Condition simple main effect showed that the accuracy of ADHD (Pure: 91.12%; Mixed: 81.08%, p < .05) and TD (Pure: 96.63%; Mixed: 92.68%, p < .05) both showed that the pure condition was significantly better than the mixed condition.

The decomposition of the Group and Condition simple main effect showed that TD (Pure: 96.63%; Mixed: 92.68%, p < .05) was significantly better than ADHD (Pure: 91.12%; Mixed: 81.08%, p < .05) in both pure and mixed condition.

The decomposition of the Condition and Session simple main effect showed the three sessions in the mixed condition had reached significant (Control: 87.00%, Low: 88.96%, High: 91.38%, p < .05). And the accuracy was highest in high cognitive load sessions. The three

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sessions of the pure condition did not reach significance (Control: 94.62%, Low: 94.71%, High: 95.47%, p > .05) (see Figure 9).

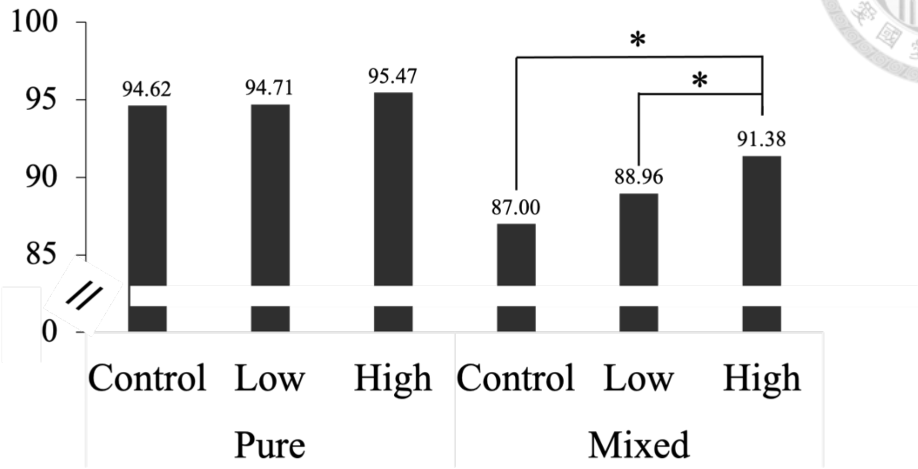

Figure 9. Three sessions in the pure condition and the mixed condition

The decomposition of the Condition and Session simple main effect showed regardless of the type of session, the accuracy of the pure condition was significantly better than that of the mixed condition (Control: Pure: 94.62%, Mixed: 87.00%, p < .001; Low: Pure: 94.71%, Mixed: 88.96%, p < .001; High: Pure: 95.47%, Mixed: 91.38%, p < .001).

Figure 10 showed that in the mixed condition, the accuracy of the high cognitive session, low cognitive session, and control session were all significantly better in the TD group than in the ADHD group.

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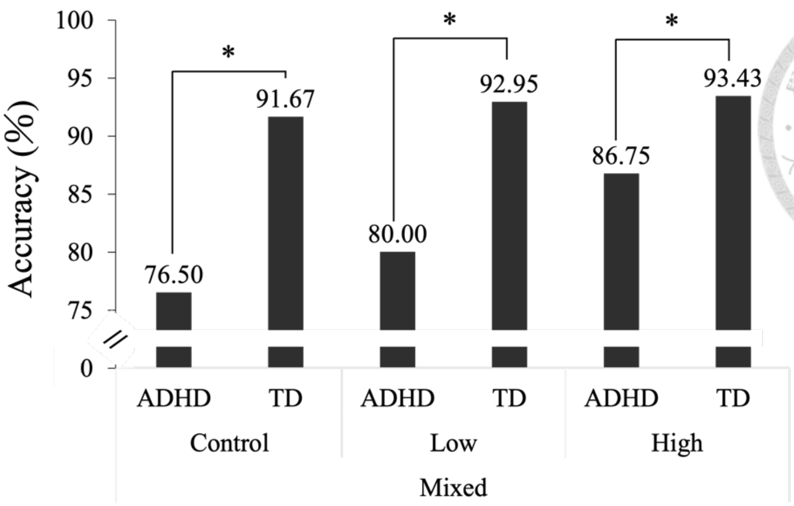

Figure 10. Two-way RM ANOVA for Session interaction effect on Group in mixed session

4.3.2.2 Local switch effect

After analyzed of accuracy revealed the main effect of Group, we found three-way ANOVA revealed the main effect of group, session, and condition (p > .05), which didn't reach significanct differences. These main effects reached significance by a Group and Session (p < .05), and a Group and Condition (p < .05). Main effect of Session (p < .05) was also yielded. Table 7 summarizes the results of ANOVA on accuracy in the local switch effect.

Table 7. ANOVA results of the local switch effect

	df	**F**	***P***
Session	2	9.901	<.001*
CON * Group	1	6.939	.015*
Session * Group	2	5.119	.010*

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The decomposition of the Group and Condition simple main effect showed there was no significant difference in the accuracy of ADHD (Non-switch: 82.12%, Switch: 82.04%, $p > .05$) and TD (Non-switch: 92.01%, Switch: 93.36%, $p > .05$) between the non-switch condition and the switch condition.

The decomposition of the Group and Condition simple main effect showed there the accuracy of TD was significantly better than that of ADHD under both Non-switch (ADHD: 82.38%; TD: 92.01%, $p < .001$) and switch (ADHD: 79.79%; TD: 93.36%, $p < .001$) condition.

The decomposition of the Group and Session simple main effect showed that when the ADHD (Control: 76.50%, Low: 82.44%, High: 85.31%, $p > .05$), and TD (Control: 91.67%, Low: 92.95%, High: 93.43%, $p > .05$) were separated to see whether the Session reached a significant difference, none of them were found to be significant.

The decomposition of the Group and Session simple main effect showed that TD was significantly more accurate than ADHD in the control session (ADHD: 76.50%, TD: 91.67%, $p < .001$), low cognitive load session (ADHD: 80.19%, TD: 92.95%, $p < .001$), and high cognitive load session (ADHD: 86.56%, TD: 93.43%, $p < .01$).

Figure 11 showed that in the local switch effect, the within-group effects of the TD group and ADHD group on the accuracy of the high cognitive session, low cognitive session, and control session were not significant. Compared to the effect between groups, the accuracy of the TD group in the high cognitive session, low cognitive session, and control session were all significantly better than the ADHD group.

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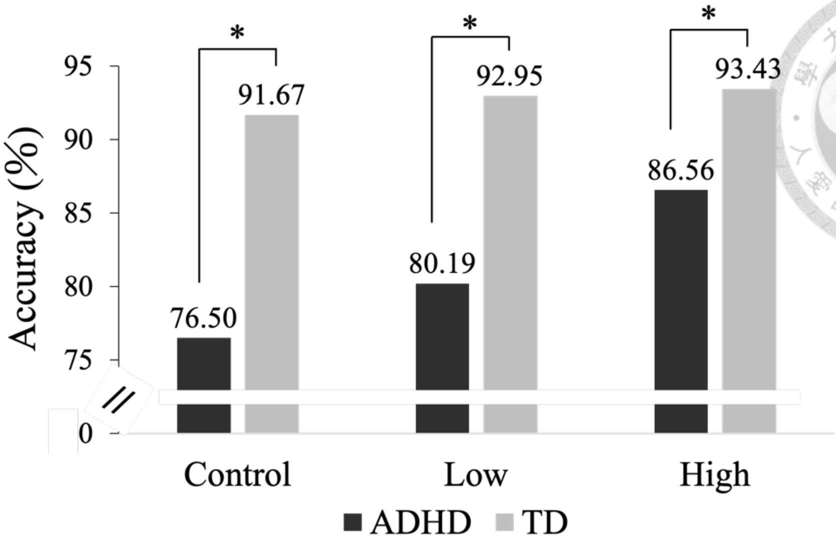

Figure 11. Group and Session simple main effect of accuracy in the local switch effect

4.4 ERP data

4.4.1 P3 amplitude

Table 8 presented the ERP data (P3 amplitude) of the global switch effect and local switch effect for the task-switching indices for each group.

Table 8. Means, and SD of P3 amplitude for the ERP

	ADHD (*N* = 8)			**TD (*N* = 18)**		
	M (SD)			M (SD)		
Global switch P3 amplitude (μV)	Control	Low	High	Control	Low	High
Pure trials	8.37±3.89	7.03±2.64	7.19±4.50	8.36±2.46	8.38±2.89	7.45±2.32
Mixed trials	8.41±4.03	7.05±2.65	7.35±4.37	8.18±2.60	8.11±2.98	7.63±2.22
Local switch P3 amplitude (μV)	Control	Low	High	Control	Low	High
Non-switch trials	8.58±3.77	7.15±2.27	7.52±4.89	8.46±2.61	8.56±2.97	7.77±2.68
Switch trials	9.30±4.11	7.59±2.91	7.55±3.76	8.33±2.51	8.03±3.13	7.64±2.14

4.4.1.1 Global switch effect

After analyzed of P3 amplitude revealed the main effect of Group, we found three-way ANOVA revealed the main effect of group, session, and condition (p > .05), which didn’t reach significant differences. These main effects didn’t reach significance by a Condition and Session (p > .05), a Group and Condition (p > .05), and a Group and Session (p > .05). Main effect of Condition (p > .05), and Session (p > .05) didn’t reach significance differences.

4.4.1.2 Local switch effect

After analyzed of P3 amplitude revealed the main effect of Group, we found three-way ANOVA revealed the main effect of group, session, and condition (p > .05), which didn’t reach significant differences. These main effects didn’t reach significance by a Condition and Session (p > .05), a Group and Condition (p > .05), and a Group and Session (p > .05). Main effect of Condition (p > .05), and Session (p > .05) didn’t reach significance differences.

4.4.2 P3 latency

Table 9 presented the ERP data (P3 latency) of the global switch effect and local switch effect for the task-switching indices for each group.

Table 9. Means, and SD of P3 latency for the ERP

	ADHD (*N* = 8)			**TD (*N* = 18)**		
	M (SD)			M (SD)		
Global switch P3 latency (ms)	Control	Low	High	Control	Low	High
Pure trials	538.50 ±107.74	454.00 ±132.20	453.75 ±126.32	468.06 ±104.64	480.06 ±119.16	464.44 ±118.30
Mixed trials	503.13 ±119.11	440.38 ±122.92	498.88 ±149.18	473.78 ±115.79	470.00 ±125.55	448.56 ±118.90
Local switch P3 latency (ms)	Control	Low	High	Control	Low	High
Non-switch trials	530.13 ±133.24	416.38 ±100.71	483.13 ±130.27	479.50 ±118.19	497.11 ±115.35	494.89 ±106.11
Switch trials	493.63 ±151.25	417.75 ±122.47	565.13 ±117.81	486.56 ±105.87	474.22 ±114.62	428.78 ±122.06

4.4.2.1 Global switch effect

After analyzed of P3 latency revealed the main effect of Group, we found three-way ANOVA revealed the main effect of group, session, and condition ($p > .05$), which didn't reach significant differences. These main effects didn't reach significance by a Condition and Session ($p > .05$), a Group and Condition ($p > .05$), and a Group and Session ($p > .05$). Main effect of Condition ($p > .05$), and Session ($p > .05$) didn't reach significance differences.

4.4.1.2 Local switch effect

After analyzed of accuracy revealed the main effect of Group, we found three-way ANOVA revealed the main effect of group, session, and condition ($p < .05$), which reached significant differences. These main effects reached significance by a Group and Session ($p < .05$). Main effect of Session ($p < .05$) was also yielded. Table 10 summarizes the results of ANOVA on accuracy in the local switch effect.

Table 10. ANOVA results of the local switch effect

	df	**F**	***P***
Session	2	4.577	.015*
Session * Group	2	8.193	.001*
CON * Session * Group	2	4.720	.013*

The decomposition of the Group, Condition, and Session interaction showed significance, we perform the following test to confirm the simple interaction.

(1) When performed Group, and Session interaction effects on Condition (Pure, Mixed), used Two-way RM ANOVA (Non-switch: $p < .05$; Switch: $p < .001$).

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(2) When performed Group, and Condition interaction effects on Session (Control, Low, High), used Two-way RM ANOVA (High: $p < .05$).

(3) When performed Condition, and Session interaction effects on Group (ADHD, TD), used Two-way paired-sample ANOVA.

The decomposition of the Group and Session simple main effect showed that in the non-switch condition, the low cognitive load session had the highest accuracy compared with the high cognitive load session and control session of ADHD (Control: 530.13ms, Low: 416.38ms, High: 483.13ms, $p < .05$), low cognitive session was the fastest (faster than control session significantly). TD (Control: 479.50ms, Low: 497.11ms, High: 494.89ms, $p > .05$) didn't reach significance differences.

The decomposition of the Group and Session simple main effect showed that in the switch condition, the low cognitive load session had the highest accuracy compared with the high cognitive load session and control session of ADHD (Control: 493.63ms, Low: 417.75ms, High: 565.13ms, $p < .05$), the low cognitive session was the fastest (faster than high cognitive session significantly). TD (Control: 486.56ms, Low: 474.22ms, High: 428.78ms, $p > .05$) didn't reach significance differences.

Figure 12 showed that ADHD group in the non-switch condition, latency in to the low cognitive session was significantly faster than latency in to the control session. ADHD group in the switch condition, the latency to the low cognitive session was significantly faster than the latency to the high cognitive session. There were no significant differences within the TD group.

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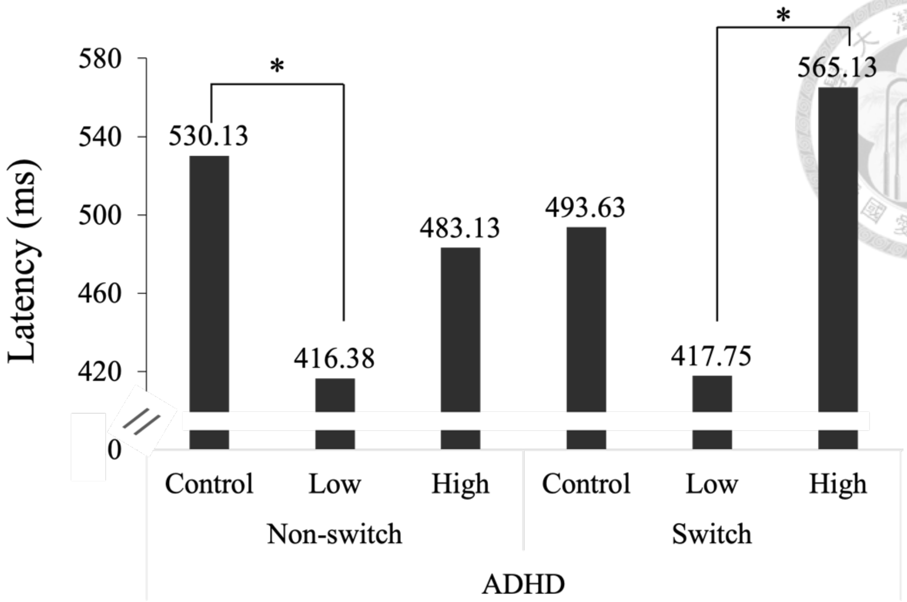

Figure 12. The local switch effect of P3 latency

The decomposition of the Group and Session simple main effect showed that latency between ADHD (Control: 503.13ms, Low: 416.38ms, High: 483.13ms) and TD (Control: 479.50ms, Low: 479.11ms, High: 494.89ms) was not significantly different in non-switch condition (p > .05).

The decomposition of the Group and Session simple main effect showed that latency between ADHD and TD was not significantly different in Control (ADHD: 493.63ms, TD: 486.56, p > .05) and Low (ADHD: 417.75ms, TD: 474.22, p > .05) in switch condition. However, ADHD and TD were significantly different in High (ADHD: 565.13ms, TD: 428.78, p < .05) in switch condition.

The decomposition of the Group and Condition simple main effect showed that latency of ADHD (Non-switch: 483.13ms; Switch: 565.13ms, p > .05) and TD (Non-switch: 494.89ms;

Switch: 428.78ms, p > .05) both showed that there had no significant differences between non-switch condition and switch condition in high session.

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Chapter 5

Discussion

5.1 Exercise intervention performance

This study used the method of recording heart rate to maintain the moderate exercise intensity of each participant in the range of 60%-65% of the reserve heart rate. And to ensure that the intensity during the exercise had reached the exercise intensity that was believed to help improve cognitive function in previous studies (Northey et al., 2018; Raichlen & Alexander, 2017; Solheim et al., 2014). The two groups performed exercise intervention under two different sessions, and neither the group difference nor the session difference produced a significant difference. Representative participants all played table tennis at the same exercise intensity. Therefore, the generation of other confounding variables could be minimized. On the other hand, there were no significant differences in all aspects between the time after finishing the table tennis training and before starting the cognitive test. This ensures that their acute effects were similar (Bae & Masaki, 2019; Huang et al., 2020; Hung et al., 2018). Different from the situation where neither of the above two had reached a significant level, under the table tennis training with different cognitive load intensities, the accuracy had reached a significant difference. This was consistent with the method we used to measure the difference between high and low cognitive load intensity (Lim et al., 2015; Magnusdóttir et al., 2017). And according to the results, it could be found that the accuracy rate of the exercise intervention design with the high cognitive load was indeed lower than that of the exercise intervention design with the low cognitive load. That was to say, this study had a prescription based on previous research and

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modified into a feasible exercise intervention design for this experiment (Pan et al., 2017; Pan et al., 2019; Pan et al., 2017).

The TD group showed no significant difference in the three sessions. Could the possible reason be that the TD group had a lower intrinsic or extrinsic cognitive load, resulting in a lower intensity of the overall cognitive load? The results of this study showed that the reaction time of the TD group was significantly faster than that of the ADHD group, the accuracy was significantly higher than that of the ADHD group, and the hitting accuracy of table tennis was also significantly higher than that of the ADHD group. Because reducing any one cognitive load can effectively reduce the overall cognitive load intensity (Atiomo, 2020). Therefore, this phenomenon might be understood as easier when performing a task-switching test (extrinsic cognitive load) or better due to their skills (intrinsic cognitive load) when playing table tennis. Therefore, compared with the ADHD group, the TD group engaged in tests and interventions with lower cognitive load intensity, resulting in a lower improvement effect than the ADHD group.

5.2 Task performance

5.2.1 Reaction time

In global switch, this study found that the reaction time of the mixed condition was significantly longer than that of the pure condition. The degree of difficulty representing mixed conditions was relatively high and had a high cognitive load intensity, causing adding secondary tasks to the main tasks could lead to a significant increase in cognitive load intensity (Haji et al., 2015), and needing more time to think and answer questions. However, no significant differences

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were produced between the three sessions, but there was a trend for reaction times to be shortest after performing a low cognitive load. Nevertheless, this result differed from our hypothesis. Previous studies used exercise interventions with different cognitive load intensities to improve reaction time, most of which were long-term interventions (Chuang et al., 2015; Kadri et al., 2019a; Tsai et al., 2017). Perhaps the acute effects of exercise interventions on reaction times were as effective, or even more beneficial, with low cognitive load exercise interventions than with high cognitive load exercise interventions (Won et al., 2017). Therefore, this study further analyzed the data. Unfortunately, significant differences were only found for the different conditions, ie the pure condition had a significantly shorter reaction time than the mixed condition. And the reaction time under non-switch condition was also significantly faster than that under switch condition. In the pure condition, within-subject differences in the ADHD group could be found for significantly faster reaction time after the low cognitive load intervention than after the high cognitive load intervention and were also the fastest of the three sessions. There were no such significant differences in the within-subject differences in the TD group.

Although this was not consistent with the results of previous studies (Benzing & Schmidt, 2019; Schoene et al., 2015; Tsai et al., 2016), it could still be found to be consistent with the hypothesis that children with ADHD had better improvement compared with TD children (Choi et al., 2015; Memarmoghaddam et al., 2016). It was worth mentioning that the acute effects of the high cognitive load phase tended to exhibit the fastest reaction times under mixed conditions. Although the result had not yet reached significance in this study, it would still be a positive research result. It could be seen that in more complex mixed conditions, intervention with high cognitive load might be most effective (Eggenberger et al., 2016; Maillot et al., 2012). On the other hand, although only the low cognitive load intervention in the pure condition worked best,

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it was still seen that the behavioral performance of ADHD using the exercise intervention was significantly better than the control condition (Benzing et al., 2018; Benzing & Schmidt, 2019; Kadri et al., 2019a; Memarmoghaddam et al., 2016).

5.2.2 Response accuracy

In the global switch effect, the results showed that the acute effect of the high cognitive load session had a significantly better effect on the accuracy than the low cognitive load session and the control session. In previous studies, it could be found that exercise intervention could improve the accuracy and performance of children with ADHD in various tests, such as SCWT (Hiyamizu et al., 2012; Kadri et al., 2019a), WCST (Pan et al., 2019), Number Sequencing Test (Ziereis & Jansen, 2015), etc. The results of this study were also the same as those found in previous studies, indicating that in the mixed conditions, the accuracy of ADHD after high cognitive load session intervention was significantly higher than that of low cognitive load session and control session. There was no significant difference in TD. Our hypothesis was verified again: (1) According to past research on task-switching, after long-term exercise intervention, the impact of high-intensity cognitive load on behavioral performance would lead to higher accuracy. Therefore, we hypothesized that using a single exercise intervention with Different cognitive load intensities could also see the impact of high-intensity cognitive load on behavioral performance, which might bring about the acute effects of higher accuracy. And (3) The improvement effect of ADHD children after intervention would be more effective than that of TD children. Improvement in behavioral performance was greatest under conditions of high cognitive load. Exercise intervention could improve accuracy, while the acute intervention with high cognitive load was more conducive to improving accuracy.

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Among the local switching effects, in terms of accuracy, the acute effect of the high cognitive load stage was significantly greater than the other two, and the acute effect of the low cognitive load stage was also significantly greater than that of the control stage. In line with our hypothesis, that is, under the condition of high cognitive load, the improvement effect of the behavioral performance was the best, and it was most helpful to improve the accuracy rate. In addition, in terms of reaction time, it could also be seen that the improvement effect after high cognitive load intervention was significantly faster than in the other two situations, so it was also in line with the hypothesis of this study.

Overall, the accuracy rate was in line with the assumptions for both global and local switching effects, and in the local switching effect, it could be seen that both low and high cognitive load significantly improve the control situation. Reaction times in the global switching effect were seen to be the fastest in the high cognitive load group in the mixed condition and the low cognitive load group in the pure condition. However, the local switching effect could be seen to be the fastest in the high cognitive load group.

While the ADHD group significantly improved accuracy, the TD group did not. Past research had found that children who were regularly physically active perform significantly better academically (on standardized achievement tests in reading, math, and science) and in cognitive function than children who engaged in lower levels of physical activity (Asigbee et al., 2018; Donnelly et al., 2016b; Harveson et al., 2019). Aerobic exercise might be more effective (Bartee et al., 2018). All the participants recruited in this study had regular exercise training for more than one year, and they were aerobic exercise such as table tennis. Since the ADHD group itself had a poorer cognitive function, there still was room for a more substantial upside (Aarts et

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al., 2015; Benzing & Schmidt, 2019; Griffiths et al., 2019; Rubia, 2018). However, after the intervention of exercise with different cognitive load intensities, there was no significant difference in the TD group might be due to the ceiling effect (Mehren et al., 2019). It might be one of the reasons why the results of this study produced no significant improvement in the TD group.

5.3 ERP data

5.3.1 P3 amplitude

In global switch, this study found that the P3 amplitude in the control session was the highest. And there was a trend that high cognitive load sessions were lower than low load cognitive, and also were lower than control sessions. This was not consistent with our hypothesis, and even the opposite. It should be noted that if the exercise intensity was too large or the exercise time was too long, it might cause excessive secretion of catecholamines, lead to physical and mental fatigue, and lead to cognitive impairment (Barnes & Van Dyne, 2009; McMorris et al., 2016). Dehydration from prolonged exercise might also impair information processing and memory function (Tomporowski, 2003). The possible reasons why the experimental results were not as expected, according to previous studies, might have the following points: Studies used acute exercise interventions with different cognitive loads had found that high cognitive load exercise interventions were helpful for the increase of P3 amplitude. However, the study was targeted at young healthy adult players rather than children and thus might have had a different effect (Won et al., 2017). In addition, other studies were long-term interventions, and the participants were elderly (Chuang et al., 2015; Tsai et al., 2016), so it might be possible to try to use exercise interventions with different cognitive load intensities

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for long-term studies in the future to understand its improvement effect on children with ADHD. On the other hand, under recruitment of the number of participants might also be one of the reasons.

Present results of this study related to P3 focus only on the Pz point. However, there was no significant difference in the amplitude of P3 regardless of the difference between the ADHD group and the TD group or the difference within each group. However, recent research focused not only on the Pz point but more on the region of interest (ROI). For example, focused on the midline region of the brain (Elke & Wiebe, 2017; Hung et al., 2016; Janssen et al., 2018), the parietal region (Griffiths et al., 2019), etc. Therefore, in the future, if the analysis target is a region rather than a single point, there may be opportunities to discover more different results. We will also use the regional analysis composed of multiple points in the follow-up research, hoping to understand more different results, and make more explanations and contributions to this experiment.

5.3.2 P3 latency

In terms of ERP, it was not as expected, and there was no significant difference in the effect of P3 latency of the three stages in the global switch effect. One of the surprising points was that the trend of P3 latency appears to be highest in the low cognitive load session. Although not significantly higher than the other two scenarios, this trend was still inconsistent with our hypothesis. The range of P3 amplitude acquisition this time was determined according to previous research (Elke & Wiebe, 2017; Hermens et al., 2005; Hung et al., 2016; Wangler et al., 2011), and its value was the average value of 25ms before and after the maximum value of 300-

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700ms. It might be caused by the relationship of the acquisition range, and follow-up studies might consider subsequent analysis to redefine the capture range.

However, in the local switch effect, latency was significantly fastest in the low cognitive load session for ADHD, but not for TD among the three sessions. Since reaction times were also significantly fastest in the low cognitive load sessions with ADHD, there might be an association between the two. At least it could be found that low cognitive load intervention could help reduce the length of the latency, and the improvement effect of ADHD children was better than that of TD children.

5.4 Limitations

Due to the impact of the Covid-19 epidemic, the number of participants who completed the experiment in this study was not as expected. Although the experimental results also showed a lot of phenomena we want to clarify if we could recruit the anticipated number of participants. Could we get better results? This was one of the current limitations of this study. In terms of table tennis skills, the personal experience and ability of the participants were also essential. Due to our results, we could see that the hitting accuracy of the TD group was significantly better than that of the ADHD group in both high cognitive load and low cognitive load. Even if there was a significant difference between high cognitive load and low cognitive load in terms of hitting accuracy, it meant that there was indeed a significant difference in the intensity of cognitive load. But was it possible that the final improvement in the ADHD group was significantly better than the TD group because of the ceiling effect? And there was almost no significant improvement in the effect within the TD group. The large gap between the participants in table tennis ability might also be one of the current limitations of this study.

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Lastly, the exercise intervention used in this study was table tennis which was conducted by participants with table tennis-related skills. Therefore, whether the results of this experiment could be analogized to other types of exercise was also an issue worth exploring.

5.5 Conclusion

In conclusion, it could be found that the acute effect of exercise intervention could help improve reaction time. Reaction times with the low cognitive load intensity were significantly fastest in ADHD. On the other hand, the acute effects of motion interventions help improve accuracy. And the acute effect of co-intervention with high cognitive load was the most effective for improving the accuracy rate, which was consistent with the hypothesis at the beginning of this study. The accuracy improvement effect of ADHD children with high cognitive load was better than that of TD children. The effect of low cognitive load on the reaction time of children with ADHD was better than that of children with TD. However, neither the amplitude nor the latency of P3 was significantly improved. Only P3 latency exhibited the fastest latency after intervention with low cognitive load. Because this study used an intervention of the same exercise but different cognitive load intensities, it focused more on cognitive load than previous studies that focused on exercise prescription. Therefore, we hoped to gain a more comprehensive understanding of the effects of different cognitive load interventions on cognitive function and ADHD children. In future applications, the same exercise but different schedules can be designed to match the level of participants and improve cognitive function.

Overall, exercise intervention with a higher cognitive load may be more effective in promoting the cognitive function of children with ADHD, but no significant difference was reached in TD children.

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References

Aarts, E., van Holstein, M., Hoogman, M., Onnink, M., Kan, C., Franke, B., Buitelaar, J., & Cools, R. (2015). Reward modulation of cognitive function in adult attention-deficit/hyperactivity disorder: A pilot study on the role of striatal dopamine. *Behavioural Pharmacology*, *26*(1-2), 227-240. https://doi.org/10.1097/fbp.0000000000000116

Alberts, J. L., & Rosenfeldt, A. B. (2020). The universal prescription for Parkinson's disease: Exercise. *Journal of Parkinson's Disease*, *10*(1), 21-27. https://doi.org/10.3233/jpd-202100

Alexander, D. M., Hermens, D. F., Keage, H. A., Clark, C. R., Williams, L. M., Kohn, M. R., Clarke, S. D., Lamb, C., & Gordon, E. (2008). Event-related wave activity in the EEG provides new marker of ADHD. *Clinical Neurophysiology*, *119*(1), 163-179. https://doi.org/10.1016/j.clinph.2007.09.119

Altenburg, T. M., Chinapaw, M. J., & Singh, A. S. (2016). Effects of one versus two bouts of moderate intensity physical activity on selective attention during a school morning in Dutch primary schoolchildren: A randomized controlled trial. *Journal of Science and Medicine in Sport*, *19*(10), 820-824. https://doi.org/10.1016/j.jsams.2015.12.003

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.). Arlington, VA: American Psychiatric Publishing

Anderson, J. R. (1987). Skill acquisition: Compilation of weak-method problem situations. *Psychological Review*, *94*(2), 192-210. https://doi.org/10.1037/0033-295X.94.2.192

Anderson-Hanley, C., Arciero, P. J., Brickman, A. M., Nimon, J. P., Okuma, N., Westen, S. C., Merz, M. E., Pence, B. D., Woods, J. A., Kramer, A. F., & Zimmerman, E. A. (2012). Exergaming and older adult cognition: A cluster randomized clinical trial. *American*

Journal of Preventive Medicine, *42*(2), 109-119. https://doi.org/10.1016/j.amepre.2011.10.016

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2014). Inhibition and the right inferior frontal cortex: One decade on. *Trends in Cognitive Sciences*, *18*(4), 177-185. https://doi.org/10.1016/j.tics.2013.12.003

Asigbee, F. M., Whitney, S. D., & Peterson, C. E. (2018). The link between nutrition and physical activity in increasing academic achievement. *Journal of School Health*, *88*(6), 407-415. https://doi.org/10.1111/josh.12625

Atiomo, W. (2020). Cognitive load theory and differential attainment. *BMJ Journals*, *368*, 965. https://doi.org/10.1136/bmj.m965

Bae, S., & Masaki, H. (2019). Effects of acute aerobic exercise on cognitive flexibility required during task-switching paradigm. *Frontiers in human neuroscience*, *13*, 260-269. https://doi.org/10.3389/fnhum.2019.00260

Banaschewski, T., & Brandeis, D. (2007). Annotation: What electrical brain activity tells us about brain function that other techniques cannot tell us - a child psychiatric perspective. *Journal of Child Psychology and Psychiatry*, *48*(5), 415-435. https://doi.org/10.1111/j.1469-7610.2006.01681.x

Barceló, F., Muñoz-Céspedes, J. M., Pozo, M. A., & Rubia, F. J. (2000). Attentional set shifting modulates the target P3b response in the Wisconsin card sorting test. *Neuropsychologia*, *38*(10), 1342-1355. https://doi.org/10.1016/s0028-3932(00)00046-4

Barceló, F., Sanz, M., Molina, V., & Rubia, F. J. (1997). The wisconsin card sorting test and the assessment of frontal function: A validation study with event-related potentials. *Neuropsychologia*, *35*(4), 399-408. https://doi.org/10.1016/s0028-3932(96)00096-6

Barnes, C., & Van Dyne, L. (2009). I'm tired': Differential effects of physical and emotional fatigue on workload management strategies. *Human Relations*, *62*, 59-92. https://doi.org/10.1177/0018726708099518

Bartee, R. T., Heelan, K. A., & Dority, B. L. (2018). Longitudinal evaluation of aerobic fitness and academic achievement among schoolchildren. *Journal of School Health*, *88*(9), 644-650. https://doi.org/10.1111/josh.12666

Benzing, V., Chang, Y.-K., & Schmidt, M. (2018). Acute physical activity enhances executive functions in children with ADHD. *Scientific Reports*, *8*(1), 12382. https://doi.org/10.1038/s41598-018-30067-8

Benzing, V., & Schmidt, M. (2017). Cognitively and physically demanding exergaming to improve executive functions of children with attention deficit hyperactivity disorder: A randomised clinical trial. *BMC Pediatrics*, *17*(1), 8. https://doi.org/10.1186/s12887-016-0757-9

Benzing, V., & Schmidt, M. (2019). The effect of exergaming on executive functions in children with ADHD: A randomized clinical trial. *Scandinavian Journal of Medicine and Science in Sports*, *29*(8), 1243-1253. https://doi.org/10.1111/sms.13446

Bherer, L. (2015). Cognitive plasticity in older adults: Effects of cognitive training and physical exercise. *Annals of the New York Academy of Sciences*, *1337*, 1-6. https://doi.org/10.1111/nyas.12682

Bokor, G., & Anderson, P. D. (2014). Attention-Deficit/Hyperactivity Disorder. *Journal of Pharmacy Practice*, *27*(4), 336-349. https://doi.org/10.1177/0897190014543628

doi:10.6342/NTU202210188

Bricout, V. A., Dechenaud, S., & Favre-Juvin, A. (2010). Analyses of heart rate variability in young soccer players: The effects of sport activity. *Autonomic Neuroscience*, *154*(1-2), 112-116. https://doi.org/10.1016/j.autneu.2009.12.001

Bustamante, E. E., Davis, C. L., Frazier, S. L., Rusch, D., Fogg, L. F., Atkins, M. S., & Marquez, D. X. (2016). Randomized controlled trial of exercise for ADHD and disruptive behavior disorders. *Medicine and Science in Sports and Exercise*, *48*(7), 1397-1407. https://doi.org/10.1249/mss.0000000000000891

Bustillo-Casero, P., Cebrian-Bou, S., Cruz-Montecinos, C., Pardo, A., & García-Massó, X. (2020). Effects of a dual-task intervention in postural control and cognitive performance in adolescents. *Journal of Motor Behavior*, *52*(2), 187-195. https://doi.org/10.1080/00222895.2019.1600467

Cao, J., Wang, S., Ren, Y., Zhang, Y., Cai, J., Tu, W., Shen, H., Dong, X., & Xia, Y. (2013). Interference control in 6-11 year-old children with and without ADHD: Behavioral and ERP study. *International Journal of Developmental Neuroscience*, *31*(5), 342-349. https://doi.org/10.1016/j.ijdevneu.2013.04.005

Cassilhas, R. C., Tufik, S., & de Mello, M. T. (2016). Physical exercise, neuroplasticity, spatial learning and memory. *Cellular and Molecular Life Sciences*, *73*(5), 975-983. https://doi.org/10.1007/s00018-015-2102-0

Chao, Y.-P., Wu, C. W., Lin, L.-J., Lai, C.-H., Wu, H.-Y., Hsu, A.-L., & Chen, C.-N. (2020). Cognitive load of exercise influences cognition and neuroplasticity of healthy elderly: An exploratory investigation. *Journal of Medical and Biological Engineering*, *40*(3), 391-399. https://doi.org/10.1007/s40846-020-00522-x

Choi, J. W., Han, D. H., Kang, K. D., Jung, H. Y., & Renshaw, P. F. (2015). Aerobic exercise and attention deficit hyperactivity disorder: Brain research. *Medicine and Science in Sports and Exercise*, *47*(1), 33-39. https://doi.org/10.1249/mss.0000000000000373

Chuang, L. Y., Hung, H. Y., Huang, C. J., Chang, Y. K., & Hung, T. M. (2015). A 3-month intervention of dance dance revolution improves interference control in elderly females: A preliminary investigation. *Experimental Brain Research*, *233*(4), 1181-1188. https://doi.org/10.1007/s00221-015-4196-x

Coelho, R. W., De Campos, W., Da Silva, S. G., Okazaki, F. H., & Keller, B. (2007). Imagery intervention in open and closed tennis motor skill performance. *Perceptual and Motor Skills*, *105*(2), 458-468. https://doi.org/10.2466/pms.105.2.458-468

Crova, C., Struzzolino, I., Marchetti, R., Masci, I., Vannozzi, G., Forte, R., & Pesce, C. (2014). Cognitively challenging physical activity benefits executive function in overweight children. *Journal of Sports Sciences*, *32*(3), 201-211. https://doi.org/10.1080/02640414.2013.828849

Dai, C. T., Chang, Y. K., Huang, C. J., & Hung, T. M. (2013). Exercise mode and executive function in older adults: An ERP study of task-switching. *Brain and Cognition*, *83*(2), 153-162. https://doi.org/10.1016/j.bandc.2013.07.007

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia*, *44*(11), 2037-2078. https://doi.org/10.1016/j.neuropsychologia.2006.02.006

Deslandes, A., Moraes, H., Ferreira, C., Veiga, H., Silveira, H., Mouta, R., Pompeu, F. A. M. S., Coutinho, E. S. F., & Laks, J. (2009). Exercise and mental health: Many reasons to move. *Neuropsychobiology*, *59*(4), 191-198. https://doi.org/10.1159/000223730

Dietrich, A., & Audiffren, M. (2011). The reticular-activating hypofrontality (RAH) model of acute exercise. *Neuroscience and Biobehavioral Reviews*, *35*(6), 1305-1325. https://doi.org/10.1016/j.neubiorev.2011.02.001

Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences*, *11*(3), 357-374. https://doi.org/10.1017/S0140525X00058027

Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., Lambourne, K., & Szabo-Reed, A. N. (2016a). Physical activity, fitness, cognitive function, and academic achievement in children: A systematic review. *Medicine and Science in Sports and Exercise*, *48*(6), 1197-1222. https://doi.org/10.1249/mss.0000000000000901

Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., Lambourne, K., & Szabo-Reed, A. N. (2016b). Physical activity, fitness, cognitive function, and academic achievement in children: A systematic review. *Medicine and Science in Sports and Exercise*, *48*(6), 1197-1222. https://doi.org/10.1249/mss.0000000000000901

Drollette, E. S., Scudder, M. R., Raine, L. B., Moore, R. D., Saliba, B. J., Pontifex, M. B., & Hillman, C. H. (2014). Acute exercise facilitates brain function and cognition in children who need it most: an ERP study of individual differences in inhibitory control capacity. *Developmental Cognitive Neuroscience*, *7*, 53-64. https://doi.org/10.1016/j.dcn.2013.11.001

Eggenberger, P., Schumacher, V., Angst, M., Theill, N., & de Bruin, E. D. (2015). Does multicomponent physical exercise with simultaneous cognitive training boost cognitive performance in older adults? A 6-month randomized controlled trial with a 1-year follow-up. *Clinical Interventions in Aging*, *10*, 1335-1349. https://doi.org/10.2147/cia.S87732

Eggenberger, P., Wolf, M., Schumann, M., & de Bruin, E. D. (2016). Exergame and balance training modulate prefrontal brain activity during walking and enhance executive function in older adults. *Frontiers in Aging Neuroscience*, *8*, 66. https://doi.org/10.3389/fnagi.2016.00066

Elke, S., & Wiebe, S. A. (2017). Proactive control in early and middle childhood: An ERP study. *Developmental Cognitive Neuroscience*, *26*, 28-38. https://doi.org/10.1016/j.dcn.2017.04.005

Ellermeier, W., Kattner, F., Klippenstein, E., Kreis, M., & Marquis-Favre, C. (2020). Short-term noise annoyance and electrodermal response as a function of sound-pressure level, cognitive task load, and noise sensitivity. *Noise Health*, *22*(105), 46-55. https://doi.org/10.4103/nah.NAH_47_19

Falbo, S., Condello, G., Capranica, L., Forte, R., & Pesce, C. (2016). Effects of physical-cognitive dual task training on executive function and gait performance in older adults: A randomized controlled trial. *BioMed Research International*, *2016*, 5812092. https://doi.org/10.1155/2016/5812092

Formenti, D., Duca, M., Trecroci, A., Ansaldi, L., Bonfanti, L., Alberti, G., & Iodice, P. (2019). Perceptual vision training in non-sport-specific context: Effect on performance skills and cognition in young females. *Scientific Reports*, *9*(1), 18671. https://doi.org/10.1038/s41598-019-55252-1

doi:10.6342/NTU202210188

Fuster, J., Caparrós, T., & Capdevila, L. (2021). Evaluation of cognitive load in team sports: Literature review. *PeerJ*, *9*, 12045-12045. https://doi.org/10.7717/peerj.12045

Gabbett, T. J., Sheppard, J. M., Pritchard-Peschek, K. R., Leveritt, M. D., & Aldred, M. J. (2008). Influence of closed skill and open skill warm-ups on the performance of speed, change of direction speed, vertical jump, and reactive agility in team sport athletes. *The Journal of Strength and Conditioning Research*, *22*(5), 1413-1415. https://doi.org/10.1519/JSC.0b013e3181739ecd

Gallotta, M. C., Emerenziani, G. P., Franciosi, E., Meucci, M., Guidetti, L., & Baldari, C. (2015). Acute physical activity and delayed attention in primary school students. *Scandinavian Journal of Medicine and Science in Sports*, *25*(3), 331-338. https://doi.org/10.1111/sms.12310

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., Nieman, D. C., & Swain, D. P. (2011). American college of sports medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Medicine and Science in Sports and Exercise*, *43*(7), 1334-1359. https://doi.org/10.1249/MSS.0b013e318213fefb

Gopher, D., & Braune, R. (1984). On the psychophysics of workload: Why bother with subjective measures? *Human Factors*, *26*(5), 519-532.

Griffin É, W., Mullally, S., Foley, C., Warmington, S. A., O'Mara, S. M., & Kelly, A. M. (2011). Aerobic exercise improves hippocampal function and increases BDNF in the serum of young adult males. *Physiology and Behavior*, *104*(5), 934-941. https://doi.org/10.1016/j.physbeh.2011.06.005

doi:10.6342/NTU202210188

Griffiths, K. R., Jurigova, B. G., Leikauf, J. E., Palmer, D., Clarke, S. D., Tsang, T. W., Teber, E. T., Kohn, M. R., & Williams, L. M. (2019). A signature of attention-elicited electrocortical activity distinguishes response from non-response to the non-stimulant atomoxetine in children and adolescents with ADHD. *Journal of Attention Disorders*, *23*(7), 744-753. https://doi.org/10.1177/1087054717733044

Gu, Q., Zou, L., Loprinzi, P. D., Quan, M., & Huang, T. (2019). Effects of open versus closed skill exercise on cognitive function: A systematic review. *Frontiers in Psychology*, *10*, 1707. https://doi.org/10.3389/fpsyg.2019.01707

Hagovská, M., Dzvoník, O., & Olekszyová, Z. (2017). Comparison of two cognitive training programs with effects on functional activities and quality of life. *Research in Gerontological Nursing*, *10*(4), 172-180. https://doi.org/10.3928/19404921-20170524-01

Haji, F. A., Rojas, D., Childs, R., de Ribaupierre, S., & Dubrowski, A. (2015). Measuring cognitive load: Performance, mental effort and simulation task complexity. *Medical education*, *49*(8), 815-827. https://doi.org/10.1111/medu.12773

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (task load index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Advances in Psychology* (Vol. 52, pp. 139-183). North-Holland. https://doi.org/10.1016/S0166-4115(08)62386-9

Harveson, A. T., Hannon, J. C., Brusseau, T. A., Podlog, L., Papadopoulos, C., Hall, M. S., & Celeste, E. (2019). Acute exercise and academic achievement in middle school students. *International Journal of Environmental Research and Public Health*, *16*(19). https://doi.org/10.3390/ijerph16193527

Hattabi, S., Bouallegue, M., Ben Yahya, H., & Bouden, A. (2019). Rehabilitation of ADHD children by sport intervention: A tunisian experience. *La tunisie Medicale*, *97*(7), 874-881.

Healey, D. M., & Halperin, J. M. (2015). Enhancing neurobehavioral gains with the aid of games and exercise (ENGAGE): Initial open trial of a novel early intervention fostering the development of preschoolers' self-regulation. *Child Neuropsychology*, *21*(4), 465-480. https://doi.org/10.1080/09297049.2014.906567

Hermens, D. F., Williams, L. M., Clarke, S., Kohn, M., Cooper, N., & Gordon, E. (2005). Responses to methylphenidate in adolescent AD/HD: Evidence from concurrently recorded autonomic (EDA) and central (EEG and ERP) measures. *International Journal of Psychophysiology*, *58*(1), 21-33. https://doi.org/10.1016/j.ijpsycho.2005.03.006

Herold, F., Hamacher, D., Schega, L., & Müller, N. G. (2018). Thinking while moving or moving while thinking - concepts of motor-cognitive training for cognitive performance enhancement. *Frontiers in Aging Neuroscience*, *10*, 228. https://doi.org/10.3389/fnagi.2018.00228

Hiyamizu, M., Morioka, S., Shomoto, K., & Shimada, T. (2012). Effects of dual task balance training on dual task performance in elderly people: A randomized controlled trial. *Clinical Rehabilitation*, *26*(1), 58-67. https://doi.org/10.1177/0269215510394222

Huang, C. J., Tu, H. Y., Hsueh, M. C., Chiu, Y. H., Huang, M. Y., & Chou, C. C. (2020). Effects of acute aerobic exercise on executive function in children with and without learning disability: A randomized controlled trial. *Adapted Physical Activity Quarterly*, *37*(4), 404-422. https://doi.org/10.1123/apaq.2019-0108

Hung, C. L., Huang, C. J., Tsai, Y. J., Chang, Y. K., & Hung, T. M. (2016). Neuroelectric and behavioral effects of acute exercise on task switching in children with attention-deficit/hyperactivity disorder. *Frontiers in Psychology*, *7*, 1589. https://doi.org/10.3389/fpsyg.2016.01589

Hung, C. L., Tseng, J. W., Chao, H. H., Hung, T. M., & Wang, H. S. (2018). Effect of acute exercise mode on serum brain-derived neurotrophic factor (BDNF) and task switching performance. *Journal of Clinical Medicine*, *7*(10), 301. https://doi.org/10.3390/jcm7100301

Hunter, C. R., & Pisoni, D. B. (2018). Extrinsic cognitive load impairs spoken word recognition in high- and low-predictability sentences. *Ear and Hearing*, *39*(2), 378-389. https://doi.org/10.1097/aud.0000000000000493

Jang, B., Song, J., Kim, J., Kim, S., Lee, J., Shin, H. Y., Kwon, J. Y., Kim, Y. H., & Joung, Y. S. (2015). Equine-assisted activities and therapy for treating children with attention-deficit/hyperactivity disorder. *Journal of Alternative and Complementary Medicine*, *21*(9), 546-553. https://doi.org/10.1089/acm.2015.0067

Janssen, T. W. P., Heslenfeld, D. J., van Mourik, R., Geladé, K., Maras, A., & Oosterlaan, J. (2018). Alterations in the ventral attention network during the stop-signal task in children with ADHD: An event-related potential source imaging study. *Journal of Attention Disorders*, *22*(7), 639-650. https://doi.org/10.1177/1087054715580847

Kadri, A., Slimani, M., Bragazzi, N. L., Tod, D., & Azaiez, F. (2019a). Effect of taekwondo practice on cognitive function in adolescents with attention deficit hyperactivity disorder. *International Journal of Environmental Research and Public Health*, *16*(2). https://doi.org/10.3390/ijerph16020204

Kadri, A., Slimani, M., Bragazzi, N. L., Tod, D., & Azaiez, F. (2019b). Effect of Taekwondo Practice on Cognitive Function in Adolescents with Attention Deficit Hyperactivity Disorder. *International Journal of Environmental Research and Public Health*, *16*(2), 204-214. https://doi.org/10.3390/ijerph16020204

Kaiser, A., Aggensteiner, P. M., Baumeister, S., Holz, N. E., Banaschewski, T., & Brandeis, D. (2020). Earlier versus later cognitive event-related potentials (ERPs) in attention-deficit/hyperactivity disorder (ADHD): A meta-analysis. *Neuroscience and Biobehavioral Reviews*, *112*, 117-134. https://doi.org/10.1016/j.neubiorev.2020.01.019

Kamijo, K., Nishihira, Y., Higashiura, T., & Kuroiwa, K. (2007). The interactive effect of exercise intensity and task difficulty on human cognitive processing. *International Journal of Psychophysiology*, *65*(2), 114-121. https://doi.org/10.1016/j.ijpsycho.2007.04.001

Kayama, H., Okamoto, K., Nishiguchi, S., Yamada, M., Kuroda, T., & Aoyama, T. (2014). Effect of a kinect-based exercise game on improving executive cognitive performance in community-dwelling elderly: Case control study. *Journal of Medical Internet Research*, *16*(2), 61. https://doi.org/10.2196/jmir.3108

Kieffaber, P. D., & Hetrick, W. P. (2005). Event-related potential correlates of task switching and switch costs. *Psychophysiology*, *42*(1), 56-71. https://doi.org/10.1111/j.1469-8986.2005.00262.x

Kim, C., Johnson, N. F., Cilles, S. E., & Gold, B. T. (2011). Common and distinct mechanisms of cognitive flexibility in prefrontal cortex. *Journal of Neuroscience*, *31*(13), 4771-4779. https://doi.org/10.1523/jneurosci.5923-10.2011

Kim, S., Liu, Z., Glizer, D., Tannock, R., & Woltering, S. (2014). Adult ADHD and working memory: Neural evidence of impaired encoding. *Clinical Neurophysiology*, *125*(8), 1596-1603. https://doi.org/10.1016/j.clinph.2013.12.094

Kofler, M. J., Rapport, M. D., Sarver, D. E., Raiker, J. S., Orban, S. A., Friedman, L. M., & Kolomeyer, E. G. (2013). Reaction time variability in ADHD: A meta-analytic review of 319 studies. *Clinical Psychology Review*, *33*(6), 795-811. https://doi.org/10.1016/j.cpr.2013.06.001

Lara, A. H., & Wallis, J. D. (2015). The role of prefrontal cortex in working memory: A mini review. *Frontiers in Systems Neuroscience*, *9*, 173. https://doi.org/10.3389/fnsys.2015.00173

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General*, *133*(3), 339-354. https://doi.org/10.1037/0096-3445.133.3.339

Leahy, A. A., Mavilidi, M. F., Smith, J. J., Hillman, C. H., Eather, N., Barker, D., & Lubans, D. R. (2020). Review of high-intensity interval training for cognitive and mental health in youth. *Medicine and Science in Sports and Exercise*, *52*(10), 2224-2234. https://doi.org/10.1249/mss.0000000000002359

Lim, Y. M., Ayesh, A., & Stacey, M. (2015). Using mouse and keyboard dynamics to detect cognitive stress during mental arithmetic. *Studies in Computational Intelligence*, *591*, 335-350. https://doi.org/10.1007/978-3-319-14654-6_21

Liotti, M., Woldorff, M. G., Perez, R., & Mayberg, H. S. (2000). An ERP study of the temporal course of the Stroop color-word interference effect. *Neuropsychologia*, *38*(5), 701-711. https://doi.org/10.1016/s0028-3932(99)00106-2

Liu, A., Xu, Y., Yan, Q., & Tong, L. (2018). The prevalence of attention deficit/hyperactivity disorder among chinese children and adolescents. *Scientific Reports*, *8*(1), 11169. https://doi.org/10.1038/s41598-018-29488-2

Lövdén, M., Schaefer, S., Noack, H., Bodammer, N. C., Kühn, S., Heinze, H. J., Düzel, E., Bäckman, L., & Lindenberger, U. (2012). Spatial navigation training protects the hippocampus against age-related changes during early and late adulthood. *Neurobiology of Aging*, *33*(3), 620.629-620.622. https://doi.org/10.1016/j.neurobiolaging.2011.02.013

Lövdén, M., Schaefer, S., Noack, H., Kanowski, M., Kaufmann, J., Tempelmann, C., Bodammer, N. C., Kühn, S., Heinze, H. J., Lindenberger, U., Düzel, E., & Bäckman, L. (2011). Performance-related increases in hippocampal N-acetylaspartate (NAA) induced by spatial navigation training are restricted to BDNF Val homozygotes. *Cerebral Cortex*, *21*(6), 1435-1442. https://doi.org/10.1093/cercor/bhq230

MacPherson, M. K. (2019). Cognitive load affects speech motor performance differently in older and younger adults. *Journal of Speech, Language, and Hearing Research*, *62*(5), 1258-1277. https://doi.org/10.1044/2018_jslhr-s-17-0222

Magnusdóttir, E., Borsky, M., Meier, M., Johannsdottir, K., & Guðnason, J. (2017). Monitoring cognitive workload using vocal tract and voice source features. *Periodica Polytechnica Electrical Engineering and Computer Science*, *61*. https://doi.org/10.3311/PPee.10414

Maillot, P., Perrot, A., & Hartley, A. (2012). Effects of interactive physical-activity video-game training on physical and cognitive function in older adults. *Psychology and Aging*, *27*(3), 589-600. https://doi.org/10.1037/a0026268

Masaki, M., Koide, K., Goda, A., Miyazaki, A., Masuyama, T., & Koshiba, M. (2019). Effect of acute aerobic exercise on arterial stiffness and thyroid-stimulating hormone in subclinical hypothyroidism. *Heart and Vessels*, *34*(8), 1309-1316. https://doi.org/10.1007/s00380-019-01355-8

Mavilidi, M. F., Ruiter, M., Schmidt, M., Okely, A. D., Loyens, S., Chandler, P., & Paas, F. (2018). A narrative review of school-based physical activity for enhancing cognition and learning: The importance of relevancy and integration. *Frontiers in Psychology*, *9*, 2079. https://doi.org/10.3389/fpsyg.2018.02079

McLoughlin, G., Albrecht, B., Banaschewski, T., Rothenberger, A., Brandeis, D., Asherson, P., & Kuntsi, J. (2010). Electrophysiological evidence for abnormal preparatory states and inhibitory processing in adult ADHD. *Behavioral and Brain Functions*, *6*, 66. https://doi.org/10.1186/1744-9081-6-66

McMorris, T., Turner, A., Hale, B. J., & Sproule, J. (2016). Chapter 4 - Beyond the catecholamines hypothesis for an acute exercise–cognition interaction: A neurochemical perspective. In T. McMorris (Ed.), *Exercise-Cognition Interaction* (pp. 65-103). Academic Press. https://doi.org/10.1016/B978-0-12-800778-5.00004-9

Mehren, A., Özyurt, J., Thiel, C. M., Brandes, M., Lam, A. P., & Philipsen, A. (2019). Effects of acute aerobic exercise on response inhibition in adult patients with ADHD. *Scientific Reports*, *9*(1), 19884. https://doi.org/10.1038/s41598-019-56332-y

Memarmoghaddam, M., Torbati, H. T., Sohrabi, M., Mashhadi, A., & Kashi, A. (2016). Effects of a selected exercise programon executive function of children with attention deficit hyperactivity disorder. *Journal of Medicine and Life*, *9*(4), 373-379.

Miller, G. A. (1956). The magical number seven plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*(2), 81-97.

Moreau, D., & Chou, E. (2019). The acute effect of high-intensity exercise on executive function: A meta-analysis. *Perspectives on Psychological Science*, *14*(5), 734-764. https://doi.org/10.1177/1745691619850568

Moreau, D., & Conway, A. R. A. (2013). Cognitive enhancement: A comparative review of computerized and athletic training programs. *International Review of Sport and Exercise Psychology*, *6*(1), 155-183. https://doi.org/10.1080/1750984X.2012.758763

Morita, E., Yokoyama, H., Imai, D., Takeda, R., Ota, A., Kawai, E., Suzuki, Y., & Okazaki, K. (2018). Effects of 2-year cognitive motor dual-task training on cognitive function and motor ability in healthy elderly people: A pilot study. *Brain Sciences*, *8*(5), 86. https://doi.org/10.3390/brainsci8050086

Mueller, A., Hong, D. S., Shepard, S., & Moore, T. (2017). Linking ADHD to the neural circuitry of attention. *Trends in Cognitive Sciences*, *21*(6), 474-488. https://doi.org/10.1016/j.tics.2017.03.009

Muhmenthaler, M. C., & Meier, B. (2019). Task switching hurts memory encoding. *Journal of Experimental Psychology: General*, *66*(1), 58-67. https://doi.org/10.1027/1618-3169/a000431

Neudecker, C., Mewes, N., Reimers, A. K., & Woll, A. (2019). Exercise interventions in children and adolescents with ADHD: A systematic review. *Journal of Attention Disorders*, *23*(4), 307-324. https://doi.org/10.1177/1087054715584053

Nishiguchi, S., Yamada, M., Tanigawa, T., Sekiyama, K., Kawagoe, T., Suzuki, M., Yoshikawa, S., Abe, N., Otsuka, Y., Nakai, R., Aoyama, T., & Tsuboyama, T. (2015). A 12-week physical and cognitive exercise program can improve cognitive function and neural efficiency in community-dwelling older adults: A randomized controlled trial. *Journal of the American Geriatrics Society*, *63*(7), 1355-1363. https://doi.org/10.1111/jgs.13481

Northey, J. M., Cherbuin, N., Pumpa, K. L., Smee, D. J., & Rattray, B. (2018). Exercise interventions for cognitive function in adults older than 50: A systematic review with meta-analysis. *British Journal of Sports Medicine*, *52*(3), 154-160. https://doi.org/10.1136/bjsports-2016-096587

O'Brien, J., Ottoboni, G., Tessari, A., & Setti, A. (2017). One bout of open skill exercise improves cross-modal perception and immediate memory in healthy older adults who habitually exercise. *PLoS One*, *12*(6), 0178739. https://doi.org/10.1371/journal.pone.0178739

Oken, B. S., Salinsky, M. C., & Elsas, S. M. (2006). Vigilance, alertness, or sustained attention: Physiological basis and measurement. *Clinical Neurophysiology*, *117*(9), 1885-1901. https://doi.org/10.1016/j.clinph.2006.01.017

Olson, R. L., Brush, C. J., Ehmann, P. J., & Alderman, B. L. (2017). A randomized trial of aerobic exercise on cognitive control in major depression. *Clinical Neurophysiology*, *128*(6), 903-913. https://doi.org/10.1016/j.clinph.2017.01.023

Paas, F. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology*, *84*, 429-434. https://doi.org/10.1037/0022-0663.84.4.429

Pan, C.-Y., Chu, C.-H., Tsai, C.-L., Sung, M.-C., Huang, C.-Y., & Ma, W.-Y. (2017). The impacts of physical activity intervention on physical and cognitive outcomes in children with autism spectrum disorder. *Autism*, *21*(2), 190-202. https://doi.org/10.1177/1362361316633562

Pan, C.-Y., Tsai, C.-L., Chu, C.-H., Sung, M.-C., Huang, C.-Y., & Ma, W.-Y. (2019). Effects of physical exercise intervention on motor skills and executive functions in children with ADHD: A pilot study. *Journal of Attention Disorders*, *23*(4), 384-397. https://doi.org/10.1177/1087054715569282

Pan, C. Y., Chang, Y. K., Tsai, C. L., Chu, C. H., Cheng, Y. W., & Sung, M. C. (2017). Effects of physical activity intervention on motor proficiency and physical fitness in children with ADHD: An exploratory study. *Journal of Attention Disorders*, *21*(9), 783-795. https://doi.org/10.1177/1087054714533192

Pan, C. Y., Chu, C. H., Tsai, C. L., Lo, S. Y., Cheng, Y. W., & Liu, Y. J. (2016). A racket-sport intervention improves behavioral and cognitive performance in children with attention-deficit/hyperactivity disorder. *Research in Developmental Disabilities*, *57*, 1-10. https://doi.org/10.1016/j.ridd.2016.06.009

Pan, C. Y., Tsai, C. L., Chu, C. H., Sung, M. C., Huang, C. Y., & Ma, W. Y. (2019). Effects of physical exercise intervention on motor skills and executive functions in children with ADHD: A pilot study. *Journal of Attention Disorders*, *23*(4), 384-397. https://doi.org/10.1177/1087054715569282

Pang, M. Y., Charlesworth, S. A., Lau, R. W., & Chung, R. C. (2013). Using aerobic exercise to improve health outcomes and quality of life in stroke: Evidence-based exercise prescription recommendations. *Cerebrovascular Diseases*, *35*(1), 7-22. https://doi.org/10.1159/000346075

Pedersen, B. K. (2019). Physical activity and muscle-brain crosstalk. *Nature Reviews Endocrinology*, *15*(7), 383-392. https://doi.org/10.1038/s41574-019-0174-x

Pohl, P. S., McDowd, J. M., Filion, D., Richards, L. G., Stiers, W., & Kluding, P. (2007). Task switching after stroke. *Physical Therapy*, *87*(1), 66-73. https://doi.org/10.2522/ptj.20060093

Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118*(10), 2128-2148. https://doi.org/10.1016/j.clinph.2007.04.019

Porges, S. W. (1995). Orienting in a defensive world: Mammalian modifications of our evolutionary heritage. A Polyvagal Theory. *Psychophysiology*, *32*(4), 301-318. https://doi.org/10.1111/j.1469-8986.1995.tb01213.x

Potter, D. D., Jory, S. H., Bassett, M. R., Barrett, K., & Mychalkiw, W. (2002). Effect of mild head injury on event-related potential correlates of Stroop task performance. *Journal of the International Neuropsychological Society*, *8*(6), 828-837. https://doi.org/10.1017/s1355617702860118

Raichlen, D. A., & Alexander, G. E. (2017). Adaptive capacity: An evolutionary neuroscience model linking exercise, cognition, and brain health. *Trends in Neurosciences*, *40*(7), 408-421. https://doi.org/10.1016/j.tins.2017.05.001

Reid, G. B., & Nygren, T. E. (1988). The subjective workload assessment technique: A scaling procedure for measuring mental workload. In P. A. Hancock & N. Meshkati (Eds.), *Advances in Psychology* (Vol. 52, pp. 185-218). North-Holland. https://doi.org/10.1016/S0166-4115(08)62387-0

Rubia, K. (2018). Cognitive neuroscience of attention deficit hyperactivity disorder (ADHD) and its clinical translation. *Frontiers in human neuroscience*, *12*, 100. https://doi.org/10.3389/fnhum.2018.00100

Salvucci, D. D., Taatgen, N., & Borst, J. (2009). Toward a unified theory of the multitasking continuum: From concurrent performance to task switching, interruption, and resumption. CHI,

Sankaranarayanan, G., Odlozil, C. A., Wells, K. O., Leeds, S. G., Chauhan, S., Fleshman, J. W., Jones, D. B., & De, S. (2020). Training with cognitive load improves performance under similar conditions in a real surgical task. *The American Journal of Surgery*, *220*(3), 620-629. https://doi.org/10.1016/j.amjsurg.2020.02.002

Schättin, A., Arner, R., Gennaro, F., & de Bruin, E. D. (2016). Adaptations of prefrontal brain activity, executive functions, and gait in healthy elderly following exergame and balance training: A randomized-controlled study. *Frontiers in Aging Neuroscience*, *8*, 278. https://doi.org/10.3389/fnagi.2016.00278

Schmidt, M., Jäger, K., Egger, F., Roebers, C. M., & Conzelmann, A. (2015). Cognitively engaging chronic physical activity, but not aerobic exercise, affects executive functions in primary school children: A group-randomized controlled trial. *Journal of Sport and Exercise Psychology*, *37*(6), 575-591. https://doi.org/10.1123/jsep.2015-0069

Schmidt, M., Mavilidi, M. F., Singh, A., & Englert, C. (2020). Combining physical and cognitive training to improve kindergarten children's executive functions: A cluster randomized controlled trial. *Contemporary Educational Psychology*, *63*, 101908. https://doi.org/10.1016/j.cedpsych.2020.101908

Schoene, D., Valenzuela, T., Toson, B., Delbaere, K., Severino, C., Garcia, J., Davies, T. A., Russell, F., Smith, S. T., & Lord, S. R. (2015). Interactive cognitive-motor step training improves cognitive risk factors of falling in older adults - a randomized controlled trial. *PLoS One*, *10*(12), 0145161. https://doi.org/10.1371/journal.pone.0145161

Sciberras, E., Efron, D., Patel, P., Mulraney, M., Lee, K. J., Mihalopoulos, C., Engel, L., Rapee, R. M., Anderson, V., Nicholson, J. M., Schembri, R., & Hiscock, H. (2019). Does the treatment of anxiety in children with attention-deficit/hyperactivity disorder (ADHD) using cognitive behavioral therapy improve child and family outcomes? Protocol for a randomized controlled trial. *BMC Psychiatry*, *19*(1), 359. https://doi.org/10.1186/s12888-019-2276-3

Sevcenko, N., Ninaus, M., Wortha, F., Moeller, K., & Gerjets, P. (2021). Measuring cognitive load using in-game metrics of a serious simulation game [Original Research]. *Frontiers in Psychology*, *12*(906). https://doi.org/10.3389/fpsyg.2021.572437

Shema-Shiratzky, S., Brozgol, M., Cornejo-Thumm, P., Geva-Dayan, K., Rotstein, M., Leitner, Y., Hausdorff, J. M., & Mirelman, A. (2019). Virtual reality training to enhance behavior and cognitive function among children with attention-deficit/hyperactivity disorder: Brief report. *Developmental Neurorehabilitation*, *22*(6), 431-436. https://doi.org/10.1080/17518423.2018.1476602

Silva, A. P., Prado, S. O., Scardovelli, T. A., Boschi, S. R., Campos, L. C., & Frère, A. F. (2015). Measurement of the effect of physical exercise on the concentration of individuals with ADHD. *PLoS One*, *10*(3), 0122119. https://doi.org/10.1371/journal.pone.0122119

Singer, R. N. (2000). Performance and human factors: Considerations about cognition and attention for self-paced and externally-paced events. *Ergonomics*, *43*(10), 1661-1680. https://doi.org/10.1080/001401300750004078

Skaugset, L. M., Farrell, S., Carney, M., Wolff, M., Santen, S. A., Perry, M., & Cico, S. J. (2016). Can you multitask? Evidence and limitations of task switching and multitasking in emergency medicine. *Annals of Emergency Medicine*, *68*(2), 189-195. https://doi.org/10.1016/j.annemergmed.2015.10.003

Solheim, T. J., Keller, B. G., & Fountaine, C. J. (2014). VO(2) reserve vs. heart rate reserve during moderate intensity treadmill exercise. *International journal of exercise science*, *7*(4), 311-317. https://pubmed.ncbi.nlm.nih.gov/27182409

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4831852/

Soligard, T., Schwellnus, M., Alonso, J. M., Bahr, R., Clarsen, B., Dijkstra, H. P., Gabbett, T., Gleeson, M., Hägglund, M., Hutchinson, M. R., Janse van Rensburg, C., Khan, K. M., Meeusen, R., Orchard, J. W., Pluim, B. M., Raftery, M., Budgett, R., & Engebretsen, L. (2016). How much is too much? (Part 1) International olympic committee consensus statement on load in sport and risk of injury. *British Journal of Sports Medicine*, *50*(17), 1030-1041. https://doi.org/10.1136/bjsports-2016-096581

Song, D., & Yu, D. S. F. (2019). Effects of a moderate-intensity aerobic exercise programme on the cognitive function and quality of life of community-dwelling elderly people with mild cognitive impairment: A randomised controlled trial. *International Journal of Nursing Studies*, *93*, 97-105. https://doi.org/10.1016/j.ijnurstu.2019.02.019

Ströfer, S., Noordzij, M. L., Ufkes, E. G., & Giebels, E. (2015). Deceptive intentions: Can cues to deception be measured before a lie Is even stated? *PLoS One*, *10*(5), 0125237. https://doi.org/10.1371/journal.pone.0125237

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257-285. https://doi.org/10.1016/0364-0213(88)90023-7

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review*, *31*(2), 261-292. https://doi.org/10.1007/s10648-019-09465-5

Swerdloff, M. M., & Hargrove, L. J. (2020). Quantifying cognitive load using EEG during ambulation and postural tasks. *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, *2020*, 2849-2852. https://doi.org/10.1109/embc44109.2020.9176264

Szuromi, B., Czobor, P., Komlósi, S., & Bitter, I. (2011). P300 deficits in adults with attention deficit hyperactivity disorder: A meta-analysis. *Psychological Medicine*, *41*(7), 1529-1538. https://doi.org/10.1017/s0033291710001996

Thapar, A., & Cooper, M. (2016). Attention deficit hyperactivity disorder. *The Lancet*, *387*(10024), 1240-1250. https://doi.org/10.1016/s0140-6736(15)00238-x

Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. H. (2009). Heart rate variability, prefrontal neural function, and cognitive performance: The neurovisceral integration perspective on self-regulation, adaptation, and health. *Annals of Behavioral Medicine*, *37*(2), 141-153. https://doi.org/10.1007/s12160-009-9101-z

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica*, *112*(3), 297-324. https://doi.org/10.1016/s0001-6918(02)00134-8

Toplak, M. E., Dockstader, C., & Tannock, R. (2006). Temporal information processing in ADHD: Findings to date and new methods. *Journal of Neuroscience Methods*, *151*(1), 15-29. https://doi.org/10.1016/j.jneumeth.2005.09.018

Toumpaniari, K., Loyens, S., Mavilidi, M.-F., & Paas, F. (2015). Preschool children’s foreign language vocabulary learning by embodying words through physical activity and

doi:10.6342/NTU202210188

gesturing. *Educational Psychology Review*, *27*(3), 445-456. https://doi.org/10.1007/s10648-015-9316-4

Tsai, C.-L., & Wang, W.-L. (2015). Exercise-mode-related changes in task-switching performance in the elderly. *Frontiers in Behavioral Neuroscience*, *9*, 56. https://doi.org/10.3389/fnbeh.2015.00056

Tsai, C. L., Pai, M. C., Ukropec, J., & Ukropcová, B. (2016). The role of physical fitness in the neurocognitive performance of task switching in older persons with mild cognitive impairment. *Journal of Alzheimer's Disease*, *53*(1), 143-159. https://doi.org/10.3233/jad-151093

Tsai, C. L., Pan, C. Y., Chen, F. C., & Tseng, Y. T. (2017). Open- and closed-skill exercise interventions produce different neurocognitive effects on executive functions in the elderly: A 6-month randomized, controlled trial. *Frontiers in Aging Neuroscience*, *9*, 294. https://doi.org/10.3389/fnagi.2017.00294

Ureña, N., Fernández, N., Cárdenas, D., Madinabeitia, I., & Alarcón, F. (2020). Acute effect of cognitive compromise during physical exercise on self-regulation in early childhood education. *International Journal of Environmental Research and Public Health*, *17*(24), 9325. https://www.mdpi.com/1660-4601/17/24/9325

van Dinteren, R., Arns, M., Jongsma, M. L., & Kessels, R. P. (2014). P300 development across the lifespan: A systematic review and meta-analysis. *PLoS One*, *9*(2), 87347. https://doi.org/10.1371/journal.pone.0087347

van Merriënboer, J. J., & Sweller, J. (2010). Cognitive load theory in health professional education: Design principles and strategies. *Medical education*, *44*(1), 85-93. https://doi.org/10.1111/j.1365-2923.2009.03498.x

Voss, M., Kramer, A., Basak, C., Prakash, R., & Roberts, B. (2010). Are expert athletes 'expert' in the cognitive laboratory? A meta-analytic review of cognition and sport expertise. *Applied Cognitive Psychology*, *24*, 812-826. https://doi.org/10.1002/acp.1588

Wangler, S., Gevensleben, H., Albrecht, B., Studer, P., Rothenberger, A., Moll, G. H., & Heinrich, H. (2011). Neurofeedback in children with ADHD: Specific event-related potential findings of a randomized controlled trial. *Clinical Neurophysiology*, *122*(5), 942-950. https://doi.org/10.1016/j.clinph.2010.06.036

Wheeler, M. J., Green, D. J., Ellis, K. A., Cerin, E., Heinonen, I., Naylor, L. H., Larsen, R., Wennberg, P., Boraxbekk, C. J., Lewis, J., Eikelis, N., Lautenschlager, N. T., Kingwell, B. A., Lambert, G., Owen, N., & Dunstan, D. W. (2020). Distinct effects of acute exercise and breaks in sitting on working memory and executive function in older adults: A three-arm, randomised cross-over trial to evaluate the effects of exercise with and without breaks in sitting on cognition. *British Journal of Sports Medicine*, *54*(13), 776-781. https://doi.org/10.1136/bjsports-2018-100168

Wigal, S. B., Emmerson, N., Gehricke, J. G., & Galassetti, P. (2013). Exercise: Applications to childhood ADHD. *Journal of Attention Disorders*, *17*(4), 279-290. https://doi.org/10.1177/1087054712454192

Wilson, G. (2002). An analysis of mental workload in pilots during flight using multiple psychophysiological measures. *International Journal of Aviation Psychology*, *12*, 3-18. https://doi.org/10.1207/S15327108IJAP1201_2

Won, J., Wu, S., Ji, H., Smith, J. C., & Park, J. (2017). Executive function and the P300 after treadmill exercise and futsal in college soccer players. *Sports (Basel, Switzerland)*, *5*(4), 73. https://doi.org/10.3390/sports5040073

Worringer, B., Langner, R., Koch, I., Eickhoff, S. B., Eickhoff, C. R., & Binkofski, F. C. (2019). Common and distinct neural correlates of dual-tasking and task-switching: A meta-analytic review and a neuro-cognitive processing model of human multitasking. *Brain Structure and Function*, *224*(5), 1845-1869. https://doi.org/10.1007/s00429-019-01870-4

Wu, J., Xiao, H., Sun, H., Zou, L., & Zhu, L. Q. (2012). Role of dopamine receptors in ADHD: A systematic meta-analysis. *Molecular Neurobiology*, *45*(3), 605-620. https://doi.org/10.1007/s12035-012-8278-5

Yamazaki, Y., Sato, D., Yamashiro, K., Tsubaki, A., Takehara, N., Uetake, Y., Nakano, S., & Maruyama, A. (2018). Inter-individual differences in working memory improvement after acute mild and moderate aerobic exercise. *PLoS One*, *13*(12), 0210053. https://doi.org/10.1371/journal.pone.0210053

Yang, S. Y., Shan, C. L., Qing, H., Wang, W., Zhu, Y., Yin, M. M., Machado, S., Yuan, T. F., & Wu, T. (2015). The effects of aerobic exercise on cognitive function of alzheimer's disease patients. *CNS and Neurological Disorders-Drug Targets*, *14*(10), 1292-1297. https://doi.org/10.2174/1871527315666151111123319

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation [10.1002/cne.920180503]. *Journal of Comparative Neurology and Psychology*, *18*(5), 459-482. https://doi.org/10.1002/cne.920180503

Yokoyama, H., Okazaki, K., Imai, D., Yamashina, Y., Takeda, R., Naghavi, N., Ota, A., Hirasawa, Y., & Miyagawa, T. (2015). The effect of cognitive-motor dual-task training on cognitive function and plasma amyloid β peptide 42/40 ratio in healthy elderly persons: A randomized controlled trial. *BMC Geriatrics*, *15*, 60. https://doi.org/10.1186/s12877-015-0058-4

Young, J. Q., Van Merrienboer, J., Durning, S., & Ten Cate, O. (2014). Cognitive load theory: Implications for medical education: AMEE guide No. 86. *Medical Teacher*, *36*(5), 371-384. https://doi.org/10.3109/0142159x.2014.889290

Zhu, Y., Wu, H., Qi, M., Wang, S., Zhang, Q., Zhou, L., Wang, S., Wang, W., Wu, T., Xiao, M., Yang, S., Chen, H., Zhang, L., Zhang, K. C., Ma, J., & Wang, T. (2018). Effects of a specially designed aerobic dance routine on mild cognitive impairment. *Clinical Interventions in Aging*, *13*, 1691-1700. https://doi.org/10.2147/cia.S163067

Ziereis, S., & Jansen, P. (2015). Effects of physical activity on executive function and motor performance in children with ADHD. *Research in Developmental Disabilities*, *38*, 181-191. https://doi.org/10.1016/j.ridd.2014.12.005

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