**Examining the impact of physical activity on motor proficiency and sleep quality in children with ADHD.**

by

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# Statement of Originality

I, LIU Hok Ling, hereby declare that I am the sole author of the thesis and the material presented in this thesis is my original work except those indicated in the acknowledgement. I further declare that I have followed the University's policies and regulations on Academic Honesty, Copyright and Plagiarism in writing the thesis and no material in this thesis has been submitted for a degree in this or other universities.

## Abstract

*Background*: Attention deficit hyperactivity disorder (ADHD) is a frequently diagnosed neurodevelopmental disorder in children. Limitation in motor proficiency and sleep problems are commonly observed in the population. The study has been completed by three research articles to examine the impact of physical activity (PA) on motor proficiency and sleep quality in children with ADHD.

*Objectives:* There were three objectives of present study. First, a case study was designed to observe the effect of PA on motor proficiency and sleep quality in the population. Second, the systematic review and meta-analysis synthesized empirical studies investigated the effects of PA on motor proficiency in the population. Third, a randomized controlled trial (RCT) was to examine the impact of PA on sleep quality in children ADHD.

*Methods*: The study began with a case study recruited three 10- to 11-year-old students who have been clinically diagnosed with ADHD. They were made to play basketball as an intervention for 12 weeks, once per week, and 60 minutes per session. Baseline and post-intervention assessments have been completed seven days before and after the intervention immediately. Test of Gross Motor Development (TGMD-2) and sleep log were implemented to indicate motor proficiency and sleep quality. Then, a systematic review and meta-analysis was conducted which followed the Cochrane Guidelines for Systematic Reviews. In May 2022, a comprehensive search was conducted across eight electronic databases, resulting in the identification of 476 relevant studies. These studies were independently assessed by two reviewers. Through the application of predefined inclusion and exclusion criteria, a total of 12 studies were deemed suitable for systematic review, with 10 of them meeting the criteria for inclusion in the subsequent meta-analysis. Then, it followed by a RCT study. A total of 33 children diagnosed with ADHD (mean age = 10.12 years) were randomized into intervention group and control group respectively. 4 specific sleep parameters, including sleep efficiency, sleep onset latency, sleep duration, and wake after sleep onset, were assessed before and after the intervention period in both groups.

*Results*: The case study showed that regular physical activity—in the form of basketball in the current study—has a significant effect on motor proficiency and sleep quality in children with ADHD. Then, a beneficial effect of PA on overall motor proficiency (SMD= 1.12; 95% CI [0.63 to 1.61]; $p<.05$) was observed in the meta-analysis. Similar positive effects were found for motor proficiency composites, including object control, fine manual control, and body coordination. Third, the RCT presented indicated significant interaction effects in sleep duration ($F[1,31] = 7.67$, $p < 0.01$), sleep efficiency ($F[1, 31] = 6.28$, $p = 0.02$), and sleep onset latency ($F[1, 31] = 9.43$, $p = 0.004$).

*Conclusion*: Current findings highlight the benefits of PA on enhancing motor proficiency and sleep quality among children with ADHD respectively. A randomized control trial research with a larger scale is suggested to investigate further the impact of PA in motor proficiency and sleep quality in children with ADHD.

*Keywords*: Children, attention deficit hyperactivity, physical activity, motor proficiency, sleep quality

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To my dearest grandma.

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# List of Abbreviations

| | |
|---|---|
| ADHD | Attention deficits and hyperactivity disorder |
| ASD | Autism spectrum disorder |
| PA | Physical activity |
| TD | Typically developed |
| SMD | Standardized mean difference |
| CI | Confidence interval |
| DSM-IV | Diagnostic and Statistical Manual of Mental Disorders: DSM-IV |
| DSM-V | Diagnostic and Statistical Manual of Mental Disorders: DSM-V |
| RCTs | Randomized controlled trials |
| RevMan | Review Manager 5.4 |
| BOT | Bruininks-Oseretsky Test |
| M-ABC 2 | Movement Assessment Battery for Children |
| BMAT | Basic Motor Ability Test-Revised |
| TGMD-2 | Test of Gross Motor Development-2 |
| SE | Sleep efficiency |
| SOL | Sleep onset latency |
| SD | Sleep duration |
| WASO | Wake after sleep onset |
| PSQI | Pittsburgh Sleep Quality Index |
| MVPA | Moderate-to-vigorous physical activity |
| EEG | Electroencephalogram |

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**List of Publications**

There are two published online articles included in the thesis and one is submitted. The followings are the information,

Chapter 2

Liu, H. L. V. Effects of Physical Activity on Motor Proficiency and Sleep Quality in Children with ADHD: A Case Study. (Submitted to Journal of Developmental and Physical Disabilities)

Chapter 3

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Chapter 4

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## Chapter 1: Introduction

There are two objectives of this chapter: i) to summarize the background and aims of current study and ii) to present the research questions and significance.

### 1.1 Background

Attention deficit hyperactivity disorder (ADHD) is one of the most diagnosed neurodevelopmental disorders in children population (American Psychiatric Association, 2013). The global prevalence rate of children and adolescent with ADHD was approximately ranging from 4-10% in 2007 (Polanczyk et al., 2007; Sayal et al., 2018; Skounti et al., 2007) and has an uprising trend in recent year. In 2015, Thomas et al. (2015) has reported an increased rate of 7.2% in North America. Meanwhile, Cénat et al. (2022) have conducted a meta-analysis in regional prevalence rate of youth with ADHD and the study has indicated the rate of 12.4% in Asians. Furthermore, Seo et al. (2022) has presented a tremendous prevalence rate increase of 1.5 times between 2008 and 2018 in Korea. In Hong Kong, Cheung et al. (2015) have reported the 6.1% of prevalence rate of children with ADHD. Even though the prevalence rate in Hong Kong was below than the global tendency, the growing rate presented by the previous studies has indicated the rising trend in the future.

The signs and symptoms of ADHD  typically appear in childhood (American Psychiatric Association, 2013; Nijmeijer et al., 2008) and have a high rate of persistence into adolescence and adulthood (Cherkasova et al., 2022; Wilens & Spencer, 2010). The signs and symptoms of ADHD may have a significant impact in focusing and behaving in daily life and can be categorized into inattention, hyperactivity and impulsivity, for example, daydreaming frequently, talk excessively and having difficulty in social interaction (American Psychiatric

Association, 2013; Committee on Quality Improvement, 2000; Faraone et al., 2021). The core symptoms of ADHD are normally misunderstood with negative impressions, such as being irresponsible, having uncooperative behaviors with peers and laziness (Feldman & Reiff, 2014; Nijmeijer et al., 2008). As consequent, children with ADHD may grow with a lower self-esteem, less efficient learning progress and subordinated living quality than the typically developed (TD) population (Goulardins et al., 2017; Nijmeijer et al., 2008).

Apart from the aforementioned major symptoms, sleep problems and limitation in motor proficiency are the most common limitations faced by the ADHD children population (Bruininks, 2005; Goulardins et al., 2017; Kirov & Brand, 2014; Meltzer & Mindell, 2006; Tandon et al., 2019). In the last decade, numerous of research indicated the prevalence rate of motor proficiency limitation in children with ADHD was 30 to 67% (Egeland et al., 2012; Goulardins et al., 2017; Kaiser et al., 2015; Lelong et al., 2021). Meanwhile, previous studies have presented a substantial prevalence rate of 22-55% in sleep problems in children with ADHD (Cortese et al., 2009; Hvolby, 2015; Martin et al., 2019). The persisted consequence of the sleep problem is intensifying the impairment in function and behaviors and the symptoms of ADHD (Lycett et al., 2014; O'Brien, 2009; Sciberras et al., 2011). Both of the problems were commonly faced by the population, the following sub-sections would have a more detailed illustration.

### 1.2 Motor proficiency in children with ADHD

Other than the major symptoms, motor proficiency limitation is one of the most common obstacles suffered in the children with ADHD. Motor proficiency is defined as an indicator of motor development in children associated with the performance with gross, requiring muscle control in large body movement, and fine motor skills, movement that coordinated with the eyes and small muscle in hands and fingers (Bruininks, 2005; Tseng et al., 2004; Wrotniak et al., 2006). Motor proficiency limitation (Pan, Chang, et al., 2017; Piek et al., 1999), including fine (Fliers et al., 2008; Kaiser et al., 2015; Lelong et al., 2021; Pitcher et al., 2003) and gross motor skills (Kaiser et al., 2015; Kosari et al., 2013; Magistro et al., 2015; Pan et al., 2009; Pitcher et al., 2003), in children with ADHD has been discussed over decades. Denckla and Rudel (1978) conducted one of the first studies to explore motor proficiency in children with ADHD. The result indicated that children with ADHD had lower levels of motor proficiency than the TD children. Since then, several studies have investigated the relationship between ADHD and motor proficiency.

The association between motor proficiency and the symptoms of ADHD was first discussed in two decades ago. Piek et al. (1999) investigated the relationship between motor proficiency and ADHD symptoms in preschool children and indicated that children with ADHD had lower levels of motor proficiency than their peers without ADHD. Furthermore, the results found that lower motor proficiency was associated with more severe ADHD symptoms. The more the severe the symptoms, the more challenging the daily activities.

In the case of motor proficiency development in children with ADHD, Mokobane et al. (2019) found that children with ADHD had lower scores on measures of gross and fine motor skills compared to TD children. Meanwhile, a study conducted by Fliers et al. (2008) examined the motor skills of children with ADHD using the Movement Assessment Battery for Children (MABC). The researchers indicated that children with ADHD demonstrated difficulties in manual dexterity, balance, and catching compared to their TD peers. Additionally, it is observed that the motor skill limitations were associated with more severe ADHD symptoms. Kaiser et al. (2015) suggested that children with ADHD had lower performance on balance and coordination. Similarly, Buderath et al. (2009) and Hassan and Azzam (2012) have presented a lower resulting score on the measures of manual dexterity and ball skills compared to TD children.

Limitation in motor proficiency may result to a reduced physical activity participation in children with ADHD due to the difficulty in completing the motor tasks (Kaiser et al., 2015; Pan, Chang, et al., 2017). Meanwhile, Fliers et al. (2010) has reported the undertreatment of motor proficiency limitation in the ADHD population. The undertreatment of motor proficiency may result to the insufficient physical activity participation in children with ADHD that enhanced the risk of exposure in choric disease, such as obesity (Cook et al., 2015; Goulardins et al., 2016; Zuckerman et al., 2014). Moreover, lacking physical activity participation in children with ADHD would associate with social-communicative impairments and it would also be influential in personal growth and adopting a healthy lifestyle (Pan et al., 2019; Warburton & Bredin, 2017; Welsch et al., 2021).

With regard to motor proficiency and academic performance, children with ADHD who demonstrate with the lower level of motor proficiency, may have higher chance in a weaker academic performance when compare to the typically developed peers (Tseng et al., 2004). It has also shown that motor proficiency limitations in children with ADHD can negatively impact academic performance. The studies by Goulardins et al. (2017); Goulardins et al. (2016) found that children with ADHD and motor proficiency deficits had lower academic achievement scores compared to their peers without these deficits. Furthermore, Magistro et al. (2015) has indicated the correlated relationship among gross motor proficiency, impulsivity and inattention in ADHD population, and academic achievement and explained with cognitive functioning. The authors explained that problem-solving skills were similar in motor skills and mathematics learning process. Therefore, a potential confounded relationship between ADHD and motor proficiency may exist.

To summarize, the motor proficiency limitation in children with ADHD may not only result to a reduced physical activity participation, but also correlate to a weaker academic performance in comparing with the TD population.

**1.3 Sleep problems in children with ADHD**

Previously, numerous of studies have discussed the relationship between sleep problems and children with ADHD. The substantial prevalence of sleep problems of 25-55% has been reported by various of studies (Cortese et al., 2009; Cortese et al., 2013; Hvolby, 2015; Martin et al., 2019). In addition, the hyperarousal and sensory processing problems associated with ADHD may also contribute to sleep difficulties (Corkum et al., 2011).

The term "sleep problems" is used here to refer to the sleep problems suffered from the ADHD population. Refer to the previous studies, children with ADHD suffered from the sleep problems, including sleep disturbance, midnight awakening, sleep maintenance, and so on (Cortese et al., 2013; Papadopoulos et al., 2019; Yurumez & Kilic, 2016). The sleep problems reduce the daytime working efficiency and may persist into adulthood (Cortese et al., 2009; Nikles et al., 2020; Yurumez & Kilic, 2016).

One of the studies have examined children with ADHD had suffered from more significantly sleep problems than children without ADHD, including shorter sleep duration, more frequent night awakenings, and more daytime sleepiness (Cortese et al., 2013). Meanwhile, it has been discussed that children with ADHD had a higher prevalence of sleep-disordered breathing, such as snoring and sleep apnea, compared to children without ADHD (Cohen-Zion & Ancoli-Israel, 2004). The sleep problems have been specified for intensifying the symptoms of ADHD that related to behavioral and functional impairments (Cohen-Zion & Ancoli-Israel, 2004; Hvolby, 2015; Papadopoulos et al., 2019; Wajszilber et al., 2018). Meanwhile, a study by Yin et al. (2022) found that children with ADHD who had sleep problems exhibited more symptoms of inattention and hyperactivity than children with ADHD who did not have sleep problems.

Furthermore, sleep problems could result to negative impact, including poor daytime performance, difficulties in behavior, emotional instability and slower learning progress for children with ADHD (Dolezal et al., 2017; Gruber et al., 2012; Langberg et al., 2014; O'Brien, 2009). The negative impact of sleep problems is not limited to children, as research has shown that adults with ADHD who experience sleep problems would also exhibit poor academic performance (Dolezal et al., 2017; Langberg et al., 2014) and driving performance (Bioulac et al., 2015). Given the importance of sleep in brain development and the presentation and prognosis of ADHD symptoms (Lunsford-Avery et al., 2016), it is crucial that identifying the effective strategies for addressing sleep problems in ADHD children population. Nonetheless, the underlying mechanisms of the relationship between sleep problems and children with ADHD are remain uncleared.

### 1.4 Medical treatment in children with ADHD

Pharmacological medication is a common therapy to address sleep problems in individuals with ADHD (Hvolby, 2015). However, it is still controversial that the effectiveness of medication in improving sleep quality for individuals with ADHD. Meanwhile, some of the studies have demonstrated that medication, such as melatonin and clonidine, can successfully promote sleep in individuals with ADHD (Kratochvil et al., 2005; McWilliams et al., 2022). On the other hand, other research has shown that medication can worsen hyperactivity and behavioral difficulties at bedtime and decrease daytime activity (Cortese et al., 2013; De Crescenzo et al., 2014). The unclear conclusion regarding the effectiveness of pharmacological medication for sleep problems in individuals with ADHD is under consideration. Recent studies have reported the negative effects of medication may exacerbate ADHD symptoms and impact daytime activity levels (Cortese et al., 2013; De Crescenzo et al., 2014). Part of the studies suggest that medication can be effective in improving sleep, whereas some of the studies report negative effects on ADHD symptoms and daytime functioning. In short, the use of pharmacological medication for sleep problems in children with ADHD remains controversial.

The usage of pharmacological medication is common in relieving the sleep problems in the ADHD populations (Efron et al., 2014; Hvolby, 2015; Kidwell et al., 2015; Konofal et al., 2010). The controversy in applying pharmacological medication in the ADHD population has been widely discussed despite the positive effect in improving some of sleep problems (Corkum et al., 2020; Kidwell et al., 2015; Stein et al., 2012). The medical application may lead to the worsen hyperactivity symptoms and reduced daytime activity (Cortese et al., 2013; De Crescenzo et al., 2014; Stein et al., 2012).

Recently, pharmacological interventions are a widely used approach for addressing sleep problems in the individuals with ADHD (Hvolby, 2015; Stein et al., 2012). However, the efficacy and safety of these interventions remain a subject of debate. While some of the studies have reported successful outcomes with medications such as melatonin and clonidine for improving sleep in individuals with ADHD (Kratochvil et al., 2005; McWilliams et al., 2022), others have suggested that these medications may exacerbate hyperactivity and behavioral issues at bedtime, and lead to decreased daytime activity (Cortese et al., 2013; De Crescenzo et al., 2014). As the use of pharmacological interventions for sleep problems in individuals with ADHD lacks a definitive consensus, it is important to consider potential negative effects that could worsen ADHD symptoms and affect daily functioning (Cortese et al., 2013; De Crescenzo et al., 2014).

Physiotherapy is another professional treatment received by the children with ADHD for the motor problem (Fliers et al., 2010). Based on the professional equipment and treatment, the instant effectiveness may help improving the motor problems (Fliers et al., 2010; Kumari et al., 2020). Nonetheless, the cost of a physiotherapy appointment could become a financial burden of the family and lead to an approximately 10-20% additional expense (Libutzki et al., 2019; Zhao et al., 2019). Despite the instant effectiveness of physiotherapy, the cost may not be affordable for the families, and it can result in a delayed treatment in motor proficiency limitation.

Thus, current study proposed the accessibility of physical activity, a relatively more affordable method, as one of the possible treatments in both variables.

**1.5 Physical activity in children with ADHD**

Physical activity has been proposed as a non-pharmacological intervention for children with ADHD. According to the report from the World Health Organization published, physical activity is defined as "Any bodily movement produced by skeletal muscles that requires energy expenditure" (Bull et al., 2020). The intensity of physical activity can be classified by the subjective absolute scale. Meanwhile, moderate-intensity physical activity (MPA) can be defined with an individual's personal capacity scale with a 5 or 6 on a scale of 0-10 while vigorous-intensity physical activity (VPA) is a 7 or 8 on a scale of 0-10 (Bull et al., 2020).

The positive impact of physical activity on their cognitive, social, and emotional functioning has been well-documented in the previous literature. Notably, a systematic review and meta-analysis conducted by Sibley and Etnier (2003) revealed that exercise interventions could significantly improve the attention, inhibition, and academic performance in children with ADHD. Similarly, it has been reported that acute bouts of physical activity can enhance cognitive performance and reduce the symptoms of ADHD (Chueh et al., 2022). These findings underscore the potential of physical activity as a valuable intervention for children with ADHD, with implications for improved academic outcomes and social functioning.

Although PA has been suggested as a non-pharmacological intervention for children with ADHD, the impact of PA on this population is complex. A study completed by Gapin et al. (2011) has revealed that children with ADHD had lower levels of physical activity compared with their typically developing peers. It was potentially due to comorbid conditions like obesity and low muscle tone, which can impact children's motivation and ability to engage in physical activity. Additionally, previous study suggested that high-intensity physical activity might lead to a decline in cognitive performance for children with ADHD, compared to low-intensity PA (Pontifex et al., 2013). Thus, it is necessary to individualize the intensity and duration of physical activity based on each child's unique needs and abilities so as to optimize the potential benefits of physical activity for children with ADHD.

Previously, various of studies have been discussing the impact of physical activity on motor proficiency and sleep problems in different population. Promising effects of physical activity on sleep problems have been indicated in TD population (Hurdiel et al., 2017; Park, 2014; Wang & Boros, 2021). For instance, Wu et al. (2015) have presented the positive association between physical activity and sleep problems among Chinese college students and Greever et al. (2017) conducted a 12-week physical activity intervention to girls, aged 7-12 years old, to prove the significant effect to reduce the time of midnight awaken. Yet, lacking studies have been conducted in children with ADHD population.

Over the last decade, several studies have reported the benefits of physical activity on sleep quality across various populations (Tse et al., 2018; Tse et al., 2019; Wang & Boros, 2021). For instance, Hurdiel et al. (2017) and Park (2014) found that physical activity positively correlated with better sleep quality in typically developed adolescents. Similarly, Greever et al. (2017) reported that regular physical activity was linked with reduced midnight awakenings and improved sleep fragmentation. Baldursdottir et al. (2017) demonstrated significant improvements in sleep quality following a 3-week acute walking program for typically developing adolescents in Iceland. Additionally, Stone et al. (2012) noted that children who engage in high levels of physical activity are more likely to achieve the recommended sleep duration of 9 hours. Furthermore, sleep duration was one of the parameters can be increased by physical activity in TD children (Antczak et al., 2020; Jindal et al., 2021; Khan et al., 2015). These studies collectively suggest that physical activity can enhance multiple aspects of sleep quality among typically developing children and adolescents. Thus, investigating the potential of physical activity as an alternative intervention to improve sleep quality in children with ADHD is reasonable.

Despite limited intervention studies in this population, Tse et al. (2019) conducted a randomized controlled trial (RCT) using a 12-week basketball intervention to examine sleep quality and cognition in children with autism spectrum disorder (ASD), and found positive outcomes for sleep quality. Similar to ASD, ADHD is one of the neurodevelopmental disorders that may affect the sleep quality of the patients. The study of Tse et al. (2019) provided an insight of the experimental setting in physical activity and sleep quality in neurodevelopmental disorders. Therefore, the current study aimed to investigate the impact of a physical activity intervention with a RCT setting on sleep quality in children with ADHD.

### 1.6 The Lifelong Physical Activity Model

The Lifelong Physical Activity Model was the conceptual framework adapt in the study. Hulteen et al. (2018) have introduced the Lifelong Physical Activity Model which helps explaining the potential lifespan contribution between movement skill development and physical health. The model explained the development of movement skills across the lifetime, from reflexive movements to specialized movement skills, and how could the movement skills potentially encourage the development of physical activity across lifetime. Furthermore, the model presented the potential relationship between foundational movement skills and specialized movement skills while the motor proficiency barrier in between the two stages was explained. A failure in developing the foundational movement skill may consequence to an obstacle in obtaining the specialized movement skills and influential in fostering the physical activity across the lifetime.

In the previous section, the motor proficiency limitations in children with ADHD have been discussed. Meanwhile, the purposed model suggested the limitation in foundational movement skill development might result in a motor proficiency barrier that would negatively impact on developing the specialized movement skills and lifelong physical activity.

Current study suggests the positive impact of the physical activity interventions may enhance the motor proficiency in children with ADHD. Therefore, based on the model, the motor proficiency barrier might be reduced by improving the foundational movement skills. With the application of the model, the physical activity interventions consolidate the development in foundational movement skills. Then, with a recurring effect between physical activity and motor proficiency, the intervention may reduce the motor proficiency barrier and encourage the specialized movement skills. Therefore, it could result in developing a lifelong physical activity.

Nonetheless, lacking theoretical or conceptual models connected the variable of physical activity, motor proficiency and sleep quality in these years. As a result, the Lifelong Physical Activity Model was adapted in current study and attempted to connect as many variables as it could.

**1.7 Statement of the problem**

Based on the former results, limited studies focused on the impact of physical activity and motor proficiency and sleep quality in children with ADHD. Lacking experimental research was conducted in the specific field and population. For instance, type of physical activity and effect to the particular parameters were still unclear. Thus, the thesis attempted to fill in the research gaps by conducting three studies to investigate the impact of physical activity and motor proficiency and sleep quality in children with ADHD.

Current study adapted the mixed method, including both quantitative and qualitative methods, to investigate the effect the impact of physical activity on motor proficiency and sleep problem in children with ADHD. A research synthesis, a meta-analysis and systematic review, a randomized controlled trial (RCT) and a pre-test and post-test case study have been conducted for the study.

The research questions are stated as follow:

1) How does moderate to vigorous physical intensity activity impact on motor proficiency in children with ADHD?

2) Which parameters of motor proficiency could be beneficial from the physical activity intervention?

3) What is the effect of moderate to vigorous physical activity on sleep quality in children with ADHD?

4) Which type of sleep parameters can be improved by the physical activity intervention?

5) What are the potential benefits of moderate to vigorous physical activity to children with ADHD?

**1.8 Hypotheses**

The following hypotheses are stated based on the results of the previous relevant research.

Hypothesis 1: It is hypothesized that the effect of moderate to vigorous intensity physical activity would positively impact on the sleep duration in children with ADHD.

Hypothesis 2: It is hypothesized that the effect of moderate to vigorous intensity physical activity would positively impact on the sleep latency in children with ADHD.

Hypothesis 3: It is hypothesized that the effect of moderate to vigorous intensity physical activity would positively impact on the gross motor skill in children with ADHD.

Hypothesis 4: It is hypothesized that the effect of moderate to vigorous intensity physical activity would positively impact on the object control skill in children with ADHD.

Hypothesis 5: It is hypothesized that the effect of moderate to vigorous intensity physical activity would positively impact on the behavioral problem in children with ADHD.

**1.9 Significance of the study**

The significance and originality of this study lies in its exploration of the potential impact of physical activity on motor proficiency and sleep quality in children with ADHD.

It is crucial to understand the potential relationship among physical activity, motor proficiency, and sleep quality in children with ADHD in different aspects. First, inspiration can be provided for the potential non-pharmacological for children with ADHD. While medication and therapies are commonly used, applying physical activity as an alternative treatment may offer additional benefits and more affordable.

Then, investigating the impact of physical activity on motor proficiency can inform the development of tailored exercise programs for children with ADHD. By identifying specific motor skills that are affected and improved through physical activity, interventions can be designed to target these parameters effectively. The results may be significant for the healthcare professionals, educators, and parents to implement evidence-based interventions that optimize motor development in children with ADHD.

Furthermore, examining the relationship between physical activity and sleep quality in this population has important implications for their overall well-being. Sleep problems can exacerbate ADHD symptoms, which lead to a reduced daytime activity, impulsivity, and attention difficulties. By examining the potential positive effects of physical activity on sleep quality, this study may contribute to the development of comprehensive treatment strategies that addressing both motor proficiency and sleep problems in children with ADHD.

Lastly, these findings of the studies have the potential to inform clinical practice, educational interventions, and curriculum design. By highlighting the importance of physical activity in promoting motor proficiency and sleep quality, this research can contribute to improved outcomes and quality of life for children with ADHD.

## Chapter 2: Effects of Physical Activity on Motor Proficiency and Sleep Problems in Children with ADHD: A Case Study


### Abstract

Recently, there have been discussions on the benefits of motor proficiency and sleep quality in children with ADHD. However, there is a paucity on the studies performed on the effects of physical exercise on the motor proficiency and sleep quality in children with ADHD. Thus, the present study aimed to fill the research gap. The case study has recruited three 10- to 11-year-old students who have been clinically diagnosed with ADHD. They were made to play basketball as an intervention for 12 weeks, once per week, and 60 minutes per session. Baseline and post-intervention assessments have been completed seven days before and after the intervention immediately. Test of Gross Motor Development (TGMD-2) and sleep log were implemented to indicate motor proficiency and sleep quality. Results showed that regular physical exercise—in the form of basketball in the current study—has a significant effect on motor proficiency and sleep quality in children with ADHD. A randomized control trial research with a larger scale is suggested to investigate further the impact of physical activity in children with ADHD.


*Keywords*: ADHD, children, physical activity, motor proficiency, sleep problems

**Introduction**

Attention deficit hyperactivity disorder (ADHD) is defined as a neurodevelopmental disorder that is characterized by inattention, difficulty in following instructions, hyperactivity and impulsivity (American Psychiatric Association, 2013). Apart from these iconic characteristics, limited motor proficiency and sleep problem are also commonly found in the population (Nikles et al., 2020; Soorya & Halpern, 2009). In support of this, numerous studies indicate that half of the children with ADHD suffered from various types of motor deficits and sleep problems (Fliers et al., 2008; Goulardins et al., 2016; Sung et al., 2008). For example, Goulardins and colleagues (2017) indicated that 30% to 50% of children with ADHD suffer from limited motor proficiency, including both fine and gross motor skills. These may be reflected by the inattention, hyperactivity and impulsivity features in children with ADHD (Fliers et al., 2008). Moreover, Pan and colleagues (2009) also showed that children with ADHD demonstrated weaker locomotor skill and lesser object control ability in comparison with typically developed (TD) children.

Indeed, limited motor proficiencies are regarded as one of the barriers for physical activity (PA) participation in children with ADHD (Kaiser et al., 2015; Pan, Chang, et al., 2017), which, in turn, compromise their physical activity level and general well-being (Goulardins et al., 2013)

With regard to sleep problems, it was found to be also prevalent (25% to 70%) in children with ADHD (Kirov & Brand, 2014; Sung et al., 2008; Tsai et al., 2016). Previous studies showed that children with ADHD suffer from sleep onset delay (Konofal et al., 2010), may have difficulty to maintain sleep (van der Heijden et al., 2018) and have insufficient sleep duration (Gregory & Sadeh, 2012). Poor sleep quality is shown closely associated with exacerbated emotional regulation and behavioural problems (Kirov & Brand, 2014), poor cognitive functioning and social functioning (Pan et al., 2019), which can negatively affect the general well-being and quality of life among the population (Weiss & Salpekar, 2010). Thus, it is important to develop an effective intervention to improve the motor proficiency and sleep quality of children diagnosed with ADHD.

Currently, physiotherapy and pharmacological treatment are the common options in the treatment of motor proficiency and sleep problems. To illustrate, Konofal et al. (2010) stated that the intake of melatonin is commonly applied to manage sleep-onset insomnia. Fliers et al. (2010), on the other hand, presented regular physiotherapy as the means to improve the motor proficiency of the populations. Despite the well-evidenced effectiveness of these therapeutic treatments, negative side effects and the demanding cost of the treatment have been concerned (Dijk et al., 2021; Huang et al., 2011; Kularatna et al., 2022). For instance, Huang et al. (2011) revealed that prolonged pharmacological treatment can cause drowsiness which would negatively impact on daily activity. Also, these treatments are usually costly, requiring professional personnel and equipment. Therefore, researchers are looking for an intervention that is more natural, easy to implement and less costly.

One type of intervention that receives growing research attention is physical activity. It is widely shown that physical activity is beneficial for the motor development and sleep in children with TD (see Pan, Chu, et al. (2017) and Tandon et al. (2019) for a review). However, limited research has been previously conducted investigating the impact of physical activity on motor proficiency and sleep in children with ADHD. The purpose of this present study is, therefore, to fill this research gap.

## Methodology

### *Ethical Considerations*

In preparation for the study, complete study information was delivered to all subjects, including their parents and school. The study was approved by the Human Research Ethics Committee of the university before commencement. Written consents were obtained from both parents and subjects. All datasets were encrypted with passwords to prevent any leakage of sensitive information, and only the primary researcher have the access to the datasets.

### *Subjects and Settings*

In this experiment, three children were diagnosed with ADHD by an education psychologist and assessed based on the DSM-5 (American Psychiatric Association, 2013) and the Behavior Assessment System for Children (Second Edition) (BASC-2) (Kamphaus et al., 2007). They were recruited from a local special school in Hong Kong. The mean age of the subjects was 10 years (SD = 0.82), and the intellectual quotient (IQ = 50–69) of all subjects were indicated as a mild intellectual disability (ID) (American Psychiatric Association, 2013). The parents were asked to report the sleep condition of the subjects using the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989).

In relation to individual differences, the background information was obtained through reports provided by parents, teachers, and observations made by the researchers.

Subject A exhibited more severe symptoms of impulsivity. She was easily triggered by her environment, leading to emotional instability, particularly a propensity for anger. Additionally, prior to the intervention, she displayed a lack of physical activity and only engaged in the physical education lessons provided by the school.

Subject B displayed more intense symptoms of inattention and was easily distracted. Both parents and teachers reported low levels of attention in this subject. While the school provided regular sensory training, the parents reported that this training did not effectively improve the subject's sleep quality.

Similar to Subject B, Subject C faced challenges with attention. He experienced difficulties in following instructions, as reported by both parents and teachers. Additionally, he exhibited hyperactivity and attentiveness during physical education lessons. However, his parents reported that he did not participate in any extracurricular activities related to physical exercise.

It is worth noting that none of the subjects participated in any other studies during the intervention period. This intervention study marked the first time that all of the subjects were involved in this type of research.

A 12-week basketball intervention (1 session per week, 60 minutes per session) was conducted in group by the trained research assistants in an outdoor basketball court of the participating school. Each intervention session consisted of 10 minutes of warm-up activities (including five minutes for static warm-up and the other five minutes for dynamic warm-up), 20 minutes of skill learning and training and 10 minutes of cool-down period.

*Dependent Variables*

The dependent variables were motor proficiency and sleep quality. Pre- and post-intervention assessment were conducted one week before and immediately after the exercise intervention.

Test of gross motor development (TGMD-2) (Ulrich, 2000) and the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989), completed by the parents based on their observation, were used to measure motor proficiency and sleep quality, respectively.

TGMD-2 is a widely adapted measurement of motor proficiency in terms of locomotor and object control skills for children aged 3 to 11 years old. It consists of two subscales: locomotor skill and object control skill. Each subscale consists of six items. Locomotor items include (1) run, (2) gallop, (3) hop, (4) leap, (5) horizontal jump and (6) slide, while object control items include (1) striking a stationary ball, (2) stationary dribble, (3) kick, (4) catch, (5) overhand throw and (6) underhand roll (Ulrich, 2000).

PSQI is a 10-item self-rated questionnaire to assess sleep quality in seven domains: (1) subjective sleep quality, (2) sleep latency, (3) sleep duration, (4) sleep efficiency, (5) sleep disturbance, (6) use of sleep medication and (7) daytime dysfunction (Buysse et al., 1989). The scoring system is set from 0 (no difficulty) to 3 (severe difficulty), and the index is calculated by the summation of the scores. The higher the scores are, the worse the sleep quality is represented. In this study, the PSQI was completed by the parents of the subjects with reference to other studies under the similar setting (Ji & Liu, 2016; Tietze et al., 2014).

**Results**

Demographics of all the subjects were shown in Table 1.

Table 1. Demographic information of Chapter 2.

| Subject | Age | Sex | IQ | Diagnosis |
|---|---|---|---|---|
| A | 10 | Female | 50–69 | All subjects were diagnosed with ADHD by an education psychologist and assessed based on the DSM-5 and the Behavior Assessment System for Children (Second Edition). |
| B | 9 | Female | 50–69 | |
| C | 11 | Male | 50–69 | |

*Motor Proficiency*

Changes in the motor proficiency of all the subjects before and after the intervention were shown in Table 3. It is noted that the exercise intervention generally improved the motor proficiency of the subjects.

Table 2. Physical activity intervention program protocol of Chapter 2.

| Activity | Duration (mins) | Content | Purpose |
|---|---|---|---|
| 1. Warm-up activities | 10 | Static warm-up and dynamic warm-up, including stretching for large muscles groups. | Mental and physical preparation for the beginning of the program.<br><br>To briefly introduce the following session the previous content. |
| 2. The basketball training | 20 | To revise previous skills.<br><br>To deliver repeated individual and group progressive exercises in basic basketball skills, including<br>1. ball dribbling,<br>2. ball receiving,<br>3. passing and<br>4. shooting | To develop gross motor proficiency.<br><br>Experience various elements in basketball with full body movements. |
| 3. Group games | 20 | To conduct a group game with basketball, particularly in drilling new skills requiring full body movement. | To consolidate the basketball skills via the games.<br><br>To encourage full body movement with physical activity in moderate intensity.<br><br>To promote social interaction and engagement with instructors and peers. |
| 4. Cool-down activities | 10 | To share and conclude the intervention session with positive response. | To review the intervention session. |

With Subject A, she was far beyond the gross motor development in her related age group in both the locomotor and object control skill before the intervention. The gross motor quotient and its percentile fell beyond 1, indicating her highly delayed gross motor development. Her weakness was particularly on running, horizontal jumping, striking a stationary ball, and overhand throwing, which only gained one point at most.

After the intervention, she had a remarkable improvement in both locomotor and object control. In terms of locomotor skills, the greatest improvement was in running and hopping while overhand throwing was the most enhanced object control skill, improving her scores from one point to seven points (see Table 3). Both raw scores have improved with a better percentile rank. The gross motor quotient has developed from 46 to 73 with two percentiles increased.

Both the locomotor and object control proficiency of Subject B indicated that she was behind her age group, as shown on the baseline assessment. The delayed motor proficiency was proved by the lower rank of percentile (gross motor percentile: <1) and age equivalent (more than four years beyond the proficiency norm) of both subtests (see Table 3). The representation of gross motor percentile <1 indicated the gross motor proficiency of the subject was at the lowest 1% of the population, and it is presented by the score of TGMD-2.

There was improvement on her object control skill after the intervention. Her object control skill fared better with higher scores, from 18 to 41, with a better percentile rank, from < 1 to 37. Her gross motor quotient was raised from 52 to 73 after the intervention (see Table 3). However, an unstable emotion status was reported on the post-intervention assessment day where half of the assessment day was used in settling her unstable emotion. Although she was still able to perform the locomotor skill, the performance was not as complete as her usual performance. She was less cooperative, and the situation was remarked by the tester.

Among the three subjects, Subject C had a relatively better developed motor proficiency as he had the best results in both baseline and post-intervention assessments. His locomotor proficiency had already matched with the age group he belonged to in the baseline assessment. Even though his object control skills were better than the others, his development was still behind his original age group (see Table 3).

In the post-intervention measurement, he had an improved performance in both locomotor and object control subtests. He had a better performance in horizontal jumping, which led to an enhanced performance in locomotor proficiency, improving with 9 percentiles. Moreover, minor enhancement was indicated in his post-intervention object control subtest, resulting to an upper percentile rank—from 16 to 25 (see Table 3). The gross motor quotient was increased from 97 to 103 at the end of the intervention.

Table 3. Results of TGMD-2 of all subjects before and after physical activity intervention of Chapter 2.

| Item | Subject A | | Subject B | | Subject C | |
|---|---|---|---|---|---|---|
| | Baseline | Post-intervention | Baseline | Post-intervention | Baseline | Post-intervention |
| Locomotor subtest | | | | | | |
| 1. Run | 0 | **5** | 5 | 5 | 8 | 8 |
| 2. Gallop | 3 | 3 | 5 | 3 | 8 | 8 |
| 3. Hop | 4 | **9** | 7 | 3 | 10 | 10 |
| 4. Leap | 3 | **4** | 3 | **4** | 6 | 6 |
| 5. Horizontal jump | 1 | **6** | 3 | **8** | 6 | **8** |
| 6. Slide | 6 | **8** | 4 | 2 | 8 | 8 |
| Locomotor subtest raw score | 17 | **35** | 27 | 25 | 46 | **48** |
| Percentile | < 1 | **5** | 1 | < 1 | 75 | **84** |
| Age equivalent (years-month old) | < 3-0 | **5-9** | 4-3 | 4-0 | > 10-9 | **> 10-9** |
| Object control subtest | | | | | | |
| 1. Striking a stationary ball | 1 | 1 | 2 | **8** | 7 | 7 |
| 2. Stationary dribble | 3 | **8** | 3 | **6** | 8 | 8 |
| 3. Catch | 2 | **6** | 3 | **6** | 6 | 6 |
| 4. Kick | 2 | **8** | 4 | **8** | 8 | 8 |
| 5. Overhand throw | 1 | **7** | 3 | **6** | 8 | 8 |
| 6. Underhand roll | 3 | **4** | 3 | **7** | 3 | **5** |
| Object control subtest raw score | 12 | **34** | 18 | **41** | 40 | **42** |
| Percentile | < 1 | **9** | < 1 | **37** | 16 | **25** |
| Age equivalent (years-month old) | < 3-0 | **7-6** | 3-9 | **9-6** | 7-0 | **7-9** |
| Gross motor quotient | 46 | **73** | 52 | **73** | 97 | **103** |
| Gross motor quotient percentile | <1 | **3** | <1 | **3** | 42 | **58** |

*Sleep Quality*

The sleep quality difference of each subject before and after the intervention were presented in Table 4a and 4b. The improvement in the sleep quality of the subjects is demonstrated in the reduction of the frequency of being awakened at midnights, having nightmare and coughing, and less tried than the baseline assessment.

For Subject A, before the intervention, conditions in sleep latency (including the duration it takes to fall asleep and not being able sleep within 30 minutes) and sleep disturbance were noted. Also, coughing or snoring loudly and having bad dreams were reported. Subjective sleep quality was reported as good, scoring one point (see Table 4b).

Even though the frequency of getting up to use the bathroom was slightly increased, with the reduced sleep disturbance and better sleep latency, the subjective sleep quality was reported as very good, scoring zero after the intervention. The global PSQI score reduced from four to one after the intervention (see Table 4b). The lower global PSQI score represented the better sleep quality.

In the baseline observation for Subject B, feeling hot and having trouble staying awake while eating meals or engaging in social activity were reported, scoring one point. Furthermore, the subjective sleep quality was reported as fairly good with a global PSQI score of 3.

After the intervention, the component of sleep latency remained, which means taking 20 minutes to fall asleep and 9 hours of actual sleeping time. The score of sleep disturbance also remained while she had bad dream sometimes. Daytime dysfunction was improved by one point reduced which had lowered the global PSQI score from three to two (see Table 11b).

Table 4a. Results of PSQI Items of all subjects before and after physical activity intervention of Chapter 2.

| Item | Subject A | | Subject B | | Subject C | |
|---|---|---|---|---|---|---|
| | Baseline | Post-intervention | Baseline | Post-intervention | Baseline | Post-intervention |
| Time it takes to fall asleep | 20 minutes | 5 minutes | 20 minutes | 20 minutes | 15 minutes | 10 minutes |
| Actual sleeping time | 9 hours | 9.5 hours | 9 hours | 9 hours | 8 hours | 8 hours |
| Difficulty sleeping within 30 minutes | 1 | **0** | 0 | 0 | 0 | 0 |
| Waking up in the middle of the night or early morning | 1 | **0** | 0 | 0 | 2 | **0** |
| Getting up to use the bathroom | 1 | 2 | 0 | 0 | 0 | 0 |
| Breathing uncomfortably | 0 | 0 | 0 | 0 | 0 | 0 |
| Coughing or snoring loudly | 1 | **0** | 0 | 0 | 0 | 0 |
| Feeling too cold | 0 | 0 | 0 | 0 | 0 | 0 |
| Feeling too hot | 0 | 0 | 1 | **0** | 2 | **0** |
| Having bad dreams | 1 | **0** | 1 | 1 | 0 | 0 |
| Having pain | 0 | 0 | 0 | 0 | 0 | 0 |
| Other reasons (with description) | 0 | 0 | 0 | 0 | 0 | 0 |
| Frequency of taking medicine to help sleeping | 0 | 0 | 0 | 0 | 0 | 0 |
| Having trouble staying awake while eating meals or engaging in social activity | 0 | 0 | 1 | 0 | 1 | **0** |
| Problem in keeping up enough enthusiasm to get things done | 0 | 0 | 0 | 0 | 0 | 0 |
| Overall sleep quality | 1 | **0** | 1 | **0** | 1 | **0** |
| Total score | 6 | **2** | 3 | **1** | 6 | **0** |

The subjective sleep quality was reported as fairly good. In spite of having 8 hours actual sleep time, he had a condition in waking up in middle of the night or early morning, temperature sensation and having trouble staying awake while eating meals or engaging in social activity (see Table 4a). These conditions led to the issues in sleep disturbance and daytime dysfunction with a global PSQI score of three in the baseline observation of Subject C.

Table 4b. Results of PSQI components of all subjects before and after physical activity intervention of Chapter 2.

| Component no. | Components | Subject A | | Subject B | | Subject C | |
|---|---|---|---|---|---|---|---|
| | | Baseline | Post-intervention | Baseline | Post-intervention | Baseline | Post-intervention |
| 1 | Subjective sleep quality question | 1 | 0 | 1 | 0 | 1 | 0 |
| 2 | Sleep latency | 2 | 0 | 1 | 1 | 0 | 0 |
| 3 | Sleep duration | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | Sleep efficiency | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | Sleep disturbance | 1 | 1 | 1 | 1 | 1 | 0 |
| 6 | Use of sleep medication | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | Daytime dysfunction | 0 | 0 | 1 | 0 | 1 | 0 |
| Global PSQI Score | | 4 | 1 | 3 | 2 | 3 | 0 |

*Behavioural changes*

Other than the originated dependent variables, behavioural changes of the subjects were observed by the researchers throughout the intervention. Although the subjects had different personality and behavioural patterns, the intervention has reduced the typical behavioural symptoms in children with ADHD. Since the behavioural change was not an intended dependent variable in current study, a valid and reliable scale did not apply for a scientific analysis. The obvious behavioural changes were observed and recorded by the researchers.

In comparison, all subjects were more attentive with higher focus in the last intervention section than the first section with a progressive change. In the first intervention section, the subjects were easily distracted by the external environment. For instance, the subjects were distracted by a football, which accidently rolled into the training venue. The football drawn the attention of the subjects and they paused the training and chased after the ball for their curiosity to the ball. The order resumed until the researcher returned the ball. Similar situation occurred again in the $10^{th}$ training section. However, the subjects did not chase after the football and patiently waited for the researcher returning the ball. The attention and focus level of all participants was improved by observation.

Furthermore, the emotion status of the subjects was more stable in comparing the first and the last section of intervention. The emotion instability was observed, especially Subject C. The subjects had difficulty regulating their emotions, leading to frequent and intense mood swings. Moreover, the subjects had difficulty controlling their impulses, leading to impulsive emotional reactions. At the last section of the intervention, the subjects improved with better emotion regulation, for example, reduced number of anger and sadness.

**Discussion**

Present study examined the effect of a physical activity intervention, a 12-week basketball-themed program, on motor proficiency and sleep quality in children with ADHD. It is hypothesised that the intervention would be beneficial on both motor proficiency and sleep quality. Results revealed that differences were observed before and after the 12-week physical activity intervention with a basketball theme, within which each subject's motor proficiency and sleep quality were measured. There is limited research conducted on physical activity, motor proficiency and sleep quality in ADHD children population. Hence, current study is the first intervention that investigated the effect of physical activity in the motor proficiency and sleep quality in children with ADHD in Hong Kong.

The baseline measurement showed the delayed motor development of all subjects in both locomotor and object control skills. However, significant improvement was shown in the post-intervention assessment. With the results of the study, it is suggested that physical activity is an effective intervention to improve motor proficiency and sleep quality in children with ADHD. Improvement was recorded by the parents and the researcher throughout the study. One possible reason may be related to the nature of the basketball exercise intervention where multiple motor and object control skills (e.g., ball dribbling, passing and catching) were trained (Kioumourtzoglou et al., 1998). In the present study, subjects were asked to specifically practice these three skills and other related body movement and coordination, resulting in observational improvement in motor proficiency.

The benefits of physical activity were widely recognized especially on improving mental health, cognition and motor coordination (Silva et al., 2019). Consistent with previous studies (Pan et al., 2019; Tseng et al., 2004; Ziereis & Jansen, 2015), the baseline assessment indicated that all subjects had delayed gross motor proficiency, where their motor performances were far behind than their corresponding age groups. The linkage between delayed motor development and the symptoms of ADHD—for example, inattention and impulsivity—were indicated in previous research, associating them with negative impacts on physical activity participation (Cook et al., 2015; Goulardins et al., 2016; Tseng et al., 2004). Meanwhile, physical activity is crucial in maintaining health in children population (Boreham & Riddoch, 2001). Delayed motor proficiency is not only associated with the symptoms but also the health condition. Therefore, regular physical activity is highly suggested to the ADHD children population.

The observed improvements in the sleep quality are consistent with the results of other studies in a different population. Similar to a previous study in children with autism (Tse et al., 2019), the present study extended the sleep benefits of physical activity in children with ADHD. The results have proven that a 12-week regular basketball program was efficient in enhancing the sleep quality in the ADHD children population. The data revealed the effects particularly on the parameter of subjective sleep quality, sleep latency, sleep disturbance and daytime dysfunction.

The positive effects of physical activity toward sleep were also indicated in the general population (Dolezal et al., 2017). The study conducted by Dworak et al. (2007) suggested the high-intensity physical activity would result to shorter sleep onset latency in the population of healthy children. Moreover, in current study, a participant had an improved sleep latency after the 12-week physical activity intervention with the basketball-themed program with a moderate to vigorous intensity, suggesting that a moderate intensity of physical activity is beneficial to sleep latency in children with ADHD. The results presented in this study are consistent with previous studies, even in ADHD children population.

Another possible reason might relate to the conduction time of the physical activity intervention. To supplement the results found in this study, Tatsumi et al. (2015) have indicated that a higher intensity of physical activity can enhance the sleep quality in children with developmental disorders. In the present study, the sessions for the physical activity intervention were performed in the afternoon, after lunch, lasting for 60 minutes. Although the population of previous work did not match with the present study, the advantage of delivering physical activity during the daytime was consistent.

Tandon et al. (2019) pointed out that the population has suffered from various sleep problems (e.g., sleep disturbance and sleep insufficiency). Meanwhile, the sleep problems in the population may be associated with their symptoms, including inattention and hyperactivity, and executive function limitation. Besides, sleep quality is associated with physical and mental health, especially with high body mass index (BMI) and consequence to obesity, in children and young adult population (Clement-Carbonell et al., 2021; Ekstedt et al., 2013). Therefore, the results of the present study have become strong evidence in promoting physical activity, particularly on the factor of sleep in the population of children with ADHD.

Other than motor proficiency and sleep quality, behavioural changes were surprisingly observed in the physical activity intervention. The subjects had a higher attention and focus level on the last section of the intervention. Since inattention is one of the core symptoms diagnosed in children with ADHD (American Psychiatric Association, 2013), current observation was aligned with previous studies that physical activity may benefit to reducing the symptoms in children with ADHD (Hoza et al., 2016; Smith et al., 2013). During the intervention, the subjects had a higher focus level while comparing with the first and the last intervention section. They were more willing to follow the instruction and participated in the training exercise. Thus, the intervention conducted more efficiently than the first section.

Besides, the emotion stability of all participants was improved during the 12-week intervention. According to Mitchell et al. (2012); Rosenthal et al. (2024), emotion instability and dysregulation may consequence to impulsivity, which is one of the core symptoms in the ADHD population. Furthermore, emotion dysregulation may lead to social impairment in ADHD population (Bunford et al., 2018). Throughout the intervention, subjects had been reducing the rate of sudden anger and sadness. The intervention design included group games that raised the social interaction among the subjects. At the beginning, some of the subjects refused to participate in the group game section and presented with mood and anger. With the guidance of the researcher, the subjects were more willing to join the group game section and interacted with others. Based on the observed result, the regular physical activity might help regulating the emotion of children with ADHD and diminished the social impairment.

*Limitations*

While the potential benefits of physical activity on motor proficiency and sleep quality were shown in the present study, three major limitations exist. First, the sample size was small due to COVID-19, and there was no control group for comparison. Thus, the results may not be able to generalize into the population. Meanwhile, the case study was designed without a control group. It became challenging to determine whether the observed outcomes are solely attributed to the intervention or if other factors may have influenced the results. Large-scale random controlled trial study is required to further investigate the impact of physical activity on motor proficiency and sleep quality in children with ADHD. Second, there is a lack of objective measurement of sleep quality. Future studies should consider using actigraphy assessments to measure sleep quality. Third, as behavioural change was not an intended dependent variable, the measurement only depended on the observation by the researcher with no objective measurement applied.

**Conclusion**

In conclusion, the present study posits that physical activity may be an effective intervention to enhance the motor proficiency and sleep quality of children with ADHD. Other than motor proficiency and sleep quality, behavioural changes have been observed. Studies with larger sample size and randomized controlled trial design are required to further investigate the benefits of physical activity intervention in the future.

# Chapter 3: The effect of physical activity intervention on motor proficiency in children and adolescents with ADHD: A systematic review and meta-analysis.

***Abstract***

Attention deficit hyperactivity disorder (ADHD) is a frequently diagnosed neurodevelopmental disorder in children and adolescents. The objective of this review was to synthesize empirical studies that investigated the effects of physical activity (PA) on motor proficiency in this population. A systematic review and meta-analysis were conducted following the Cochrane Guidelines for Systematic Reviews. In May 2022, a systematic search of eight electronic databases retrieved 476 results, which were screened independently by two reviewers. Based on the inclusion and exclusion criteria, 12 studies were selected for systematic review, and 10 were included in the meta-analysis. A beneficial effect of PA on overall motor proficiency (SMD= 1.12; 95% CI [0.63 to 1.61]; $p$<.05) was observed. Similar positive effects were found for motor proficiency composites, including object control, fine manual control, and body coordination. These results indicate that PA improves the motor proficiency of children and adolescents with ADHD.

***Keywords***

Physical activity, Motor proficiency, Children and adolescents, ADHD

***Introduction***

Attention deficit hyperactivity disorder (ADHD) is widely recognized as one of the most prevalent neurodevelopmental disorders in children, with a worldwide prevalence ranging from 3% to 7%, and a rate of 6.1% among Hong Kong children (Cheung et al., 2015; Rowland et al., 2015). It is defined as a neurodevelopmental disorder characterized by three primary symptoms: inattention, hyperactivity, and impulsivity, which can significantly limit personal, social, academic, or occupational functioning (American Psychiatric Association, 2013). Unfortunately, these symptoms are often misinterpreted as irresponsible, lazy, or uncooperative behavior by peers, which can lead to lower self-esteem, learning progress, and quality of life among children with ADHD (American Psychiatric Association, 2013; Goulardins et al., 2017). Pharmacological treatment is currently the most common method for ameliorating the symptoms of ADHD in children (Arnold et al., 1997; Leahy, 2018). While these treatments have immediate and direct effects (Arnold et al., 1997), negative side effects such as weight gain, sleep problems, and decreased appetite have been documented (Sprich et al., 2016). Non-pharmacological treatments, such as psychological and behavioral interventions, have also been proposed as alternative treatments for children with ADHD (Caye et al., 2019). However, the cost of professional oversight of these treatments is relatively high (Schatz et al., 2015) , which may limit their scalability for a larger population of children who could potentially benefit from them.

In addition to the primary symptoms, between 30% and 50% of children with ADHD have limited motor proficiency, defined as a measure of motor development in children that encompasses gross and fine motor skills (Bruininks, 2005). This often results in lower physical activity (PA) participation rates among children with ADHD due to difficulties in completing various motor tasks (Kaiser et al., 2015; Pan, Chang, et al., 2017) , which in turn can lead to negative physical health consequences, such as obesity (Goulardins et al., 2016). The limitation in motor proficiency is also associated with social-communicative impairments and has a significant impact on personal growth and the adoption of a healthy lifestyle (Pan, Chang, et al., 2017; Papadopoulos et al., 2015). Notably, current pharmacological treatments have no effect on impaired motor proficiency. Over the past two decades, physical activity has garnered increasing research attention and has been considered as a therapeutic alternative for improving motor proficiency. Physical activity interventions are relatively easy to implement and have been shown to improve motor proficiency compared to other behavioural therapies. For example Pan et al. (2019) conducted a 12-week table tennis program for 30 children with ADHD and found significant improvements in locomotor and object-control performance, as measured by the Test of Gross Motor Development-2 (TGMD-2). Similarly, Silva et al. (2019) implemented an 8-week aquatic training program for 15 children with ADHD and observed significant improvements in motor coordination. However, inconsistent findings have been reported in the literature.

For example, Verret et al. (2012) found that 10 consecutive weeks of PA intervention did not improve object control performance. In another study, Pan, Chang, et al. (2017), specific fine motor skills were not affected by a 12-week PA training program. These discrepancies in the results may be due to the wide range of training parameters, such as the types, frequencies, and intensities of exercises, and the different components of motor proficiency, such as object control, manual control, etc., targeted by the different interventions. Therefore, further research is necessary to clarify the potential benefits of physical activity interventions on motor proficiency in children with ADHD.

While there have been several narrative reviews on the topic (Vysniauske et al., 2020) to the best of our knowledge, no meta-analysis or systematic review has been conducted to examine the impact PA on motor proficiency in children and adolescents with ADHD. Additionally, it is crucial to further investigate the effects of PA on specific types of motor skills through subgroup analysis of motor proficiency composites. Therefore, in response to this research gap, this study aimed to synthesize published studies on the potential benefits of PA interventions on motor proficiency in children and adolescents with ADHD.

***Method***

*Search strategy*

The present meta-analysis adhered to the guidelines provided in the Preferred Reporting Items for Systematic Review and Meta-analyses Statement (PRISMA) (Page et al., 2021). In March 2022, electronic databases including PsycINFO (via EBSCOhost), Sportdiscus (via EBSCOhost), CINAHL (via EBSCOhost), ERIC (via EBSCOhost), Scopus, MEDLINE (via EBSCOhost), PubMed, and EMBASE (via Ovid) were searched to identify relevant articles. The articles selected were restricted to those published in English, peer-reviewed, and related to human subjects. The initial search was conducted using four sets of keywords: “children or adolescents,” “ADHD or attention deficit hyperactivity disorder,” “physical activity or exercise,” and “motor proficiency.” The keywords were chosen based on prior research on PA and motor proficiency in children with ADHD and feedback obtained from experts in the field. The search terms used are presented in Table 1. In addition, a manual search was conducted by reviewing the reference lists of all included studies and relevant reviews.

Table 5. Systematic review search terms.

| Target population | Condition | Intervention | Outcome |
|---|---|---|---|
| Children | ADHD | Physical activity | Motor proficiency |
| Child | Attention deficit hyperactivity disorder | Exercise | Motor skills |
| Adolescents | Attention deficit-hyperactivity disorder | Fitness | Motor development |
| Teenager | Attention deficit disorder | Physical exercise | Motor ability |
| Youth | | Sport | Motoric |
| Kids | | Sports | Fine motor |
| Students | | Physical training | Gross motor |
| | | | Motor |
| | | | Motor skill |

*Inclusion and exclusion criteria*

*Types of studies*

The present review included only completed randomized controlled trials (RCTs) or non-randomized comparison studies (NRS) that provided sufficient statistical data to calculate the effect size for the primary outcome. This statistical data included mean (M), sample size (n), and standard deviation (SD) from both baseline and post-intervention. The review excluded review papers, government/case reports, conference papers, books, and policy documents.

*Types of participants*

The review included children and adolescents between the ages of 5 and 19 who had been diagnosed with ADHD based on standardized diagnostic criteria such as the DSM-IV or DSM-V. Studies that included participants with other disabilities or disorders that made it difficult to distinguish the sole effect on children and adolescents with ADHD were excluded from the review.

*Types of interventions*

Studies conducted in both clinical and field trials were included.

*Types of outcome measures*

This study only included studies that used validated instruments to measure motor proficiency. In systematic reviews and meta-analyses, the selection of a motor proficiency composite to combine the effect of interventions is crucial. For this study, we included all six composites of motor proficiency tests: locomotor, object control, fine manual control, manual coordination, body coordination, and strength and agility, as each of them contributes to overall motor proficiency. If a study contains multiple indicators, we recommend incorporating all of them to present a complete picture of the effect of PA intervention on motor proficiency because assessment tools vary in their indicators.

*Study selection and data extraction*

To commence the study selection process, two evaluators independently conducted a multi-step search process and performed screenings on the title, abstracts, and full-length articles. Any discrepancies that emerged between the two reviewers were debated until they reached an agreement. When a consensus could not be achieved, a third evaluator was responsible for the final verdict. A standardized data extraction form was used to capture relevant data, such as bibliographic information (author and year), research design, participant characteristics (sample size, sex, age range), intervention details (dosage, frequency, length, intensity, intervention design), outcome measures, and findings, to extract the critical features of each study.

*Quality assessment*

Two independent reviewers applied the Physiotherapy Evidence Database (PEDro) scale to assess the methodological quality of all included studies (Maher et al., 2003). In case of discrepancies regarding quality ratings, the reviewers discussed until they reached a consensus. If the reviewers could not reach an agreement, a third researcher made the final decision. The PEDro scale is a reliable and valid instrument for assessing the quality of randomized controlled trials (RCTs) focusing on physical exercise in children with ADHD. The scale comprises 11 criteria related to eligibility, randomization, allocation, blinding (of subjects and experimenters), intention-to-treat, between-group comparison, and point measures (Liang, Li, Wong, Sum, & Sit, 2021; Maher et al., 2003). Each item is scored from 0 to 10, and the median score is 5. However, blinding may not be possible in some PA intervention trials (Sherrington et al., 2010). Thus, the scoring system categorizes studies into three groups: high quality (score ≥6), moderate quality (score of 4-5), and low quality (score ≤3) (Jeyanthi et al., 2019; Liang, Li, Wong, Sum, & Sit, 2021).

*Data analysis*

The present study used a meta-analysis to investigate the impact of physical activity interventions on motor proficiency. We conducted subgroup meta-analyses to explore the effects of physical activity on different domains of motor proficiency, including locomotor, object control, fine manual control, manual coordination, body coordination, and strength and agility. We extracted the data for each composite from each study, and when the data was not available, we analyzed overall motor proficiency. To conduct the data analysis, we used Review Manager (RevMan) 5.4 software and assessed the standardized mean differences (SMD) instead of the Hedge's adjusted g. We reported the SMD with 95% Confidence Intervals (CIs) as the continuous outcomes, with a significance level of $\alpha < 0.05$. We used the

$I^2$ statistic to assess the heterogeneity of the studies, and subgroup analyses were conducted to examine the influence of PA intervention characteristics and motor proficiency domains measured. Sensitivity analyses were used to determine the influence of the PA intervention for each composite.

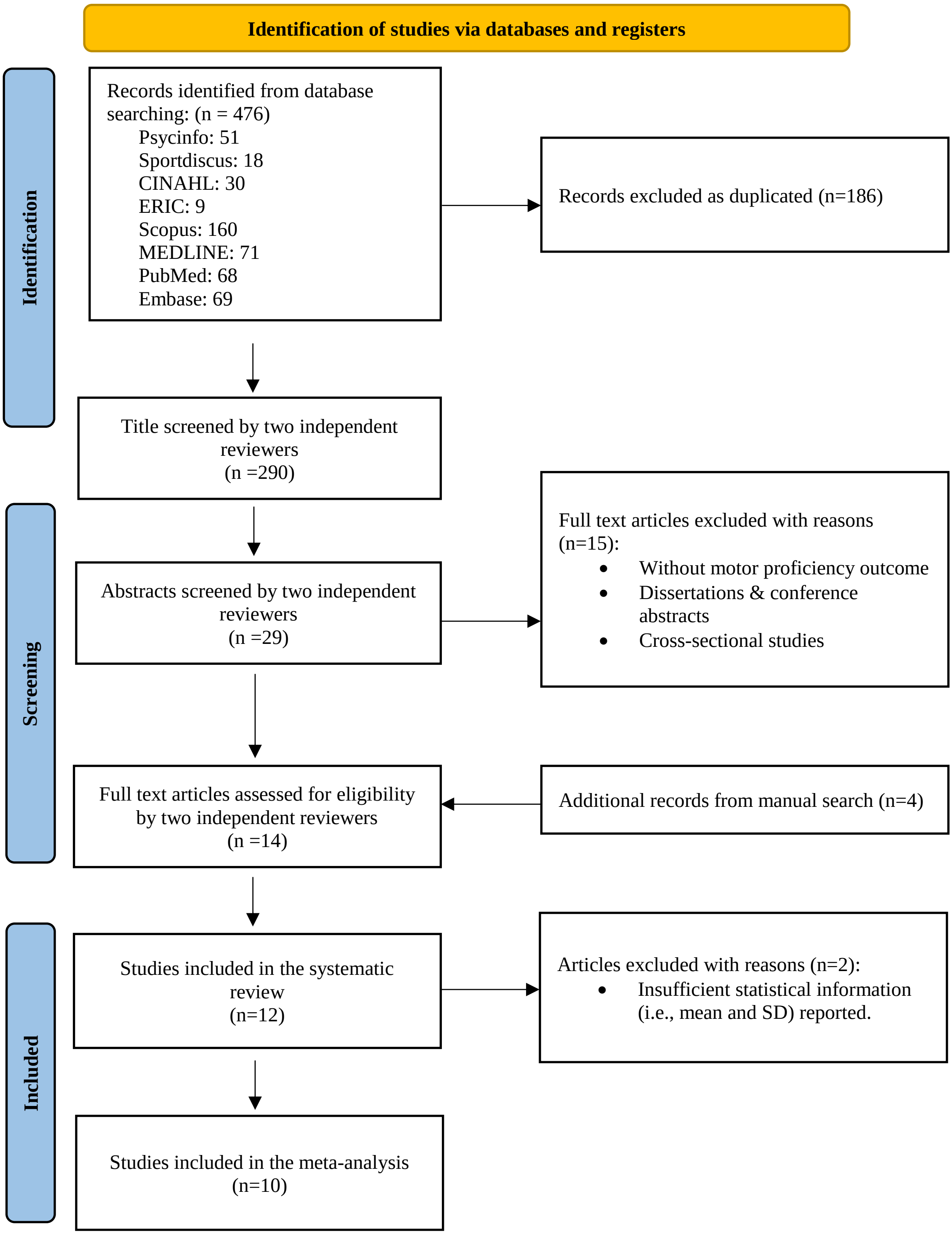
To present the results of the meta-analyses, we constructed forest plots and we applied the Egger test for publication bias (Egger et al., 1997). It is associated with the random effects model to estimate the publication-bias-adjusted true effect size associated with the number of studies needed to balance the plot. Our methodology was consistent with the study design by Welsch et al. (2021), and we followed the interpretation from the Cochrane guidelines (Higgins & Green, 2011) in assessing the heterogeneity of the studies.

## ***Results***

### *Study identification*

The initial search of eight databases yielded 476 articles, and after removing duplicates, 290 articles underwent further screening. After excluding non-relevant articles, 29 articles remained and were read in full text. Two articles were excluded due to inadequate statistical data and study type, leaving 12 studies for the systematic review. 10 of these studies were included in the meta-analysis. Efforts were made to contact the authors for additional data or clarification, but no responses were received. A flow diagram illustrating the search and screening procedures is presented in Figure 1.

Figure 1. PRISMA flow diagram.



*Quality assessment*

Table 6 presents the quality assessment of the included studies. All studies matched at least four criteria, and most of them were RCTs. The resulting quality was high, associated with the mean score of 6.08 (SD=1.19). Most of the studies had clearly stated the recruitment criteria and maintained a high retention rate.

Table 6. Assessment of methodological study quality of the included studies (PEDro).

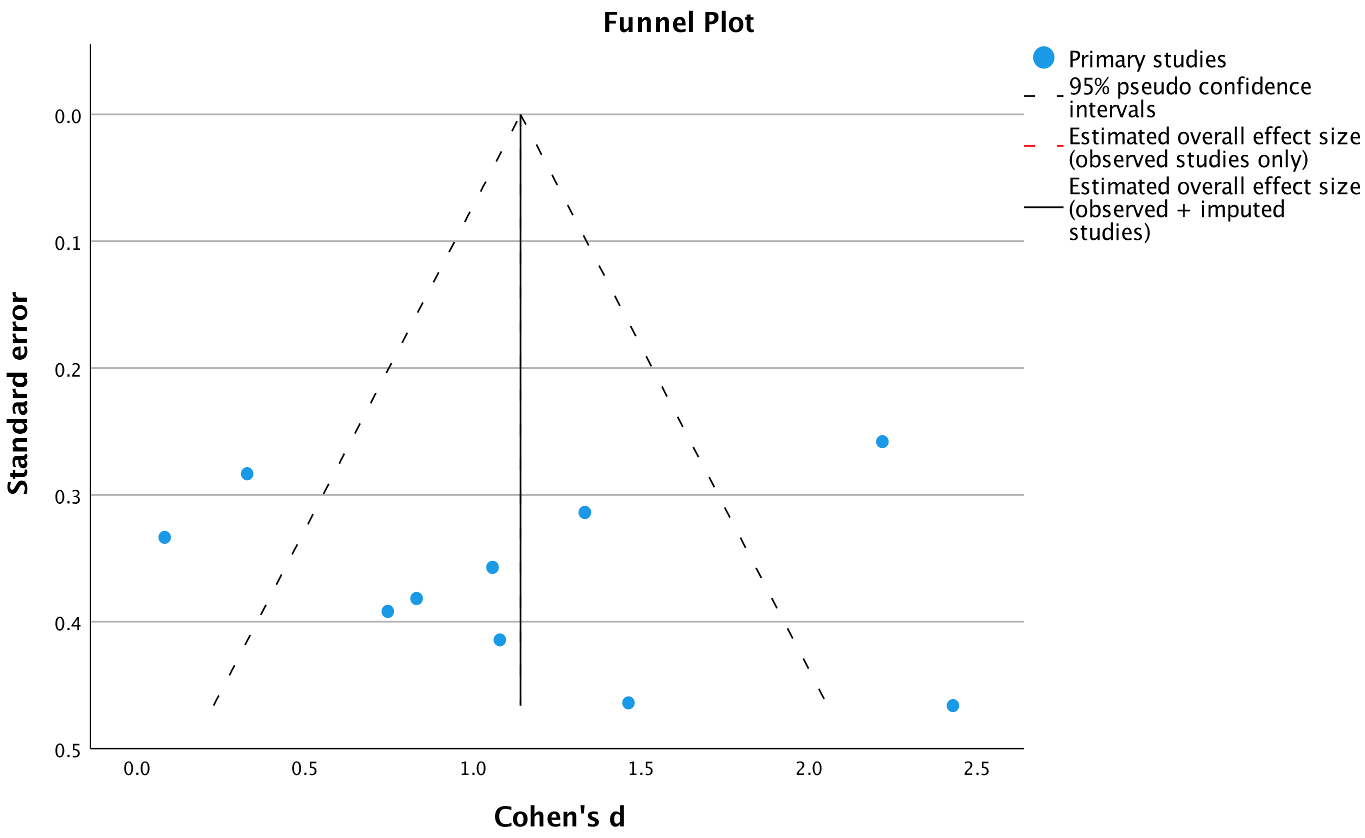
| **Author(s)** | **Year** | **EC** | **RA** | **CA** | **SB** | **BS** | **BT** | **BA** | **CR** | **ITA** | **BC** | **PMV** | **TS** | **OSQ** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Golubovic et al.* | 2014 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 5 | Moderate |
| Chang et al.* | 2014 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 5 | Moderate |
| O'Connor et al.* | 2014 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 5 | Moderate |
| Ziereis et al. | 2015 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 5 | Moderate |
| Pan et al.* | 2017 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 7 | High |
| Torabi et al.* | 2018 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 6 | High |
| Meßler et al.* | 2018 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 7 | High |
| Benzing and Schmidt * | 2019 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 9 | High |
| Pan et al.* | 2019 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 6 | High |
| Silva et al.* | 2019 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 5 | Moderate |
| Jeyanthi et al. | 2021 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 6 | High |
| Orangi et al.* | 2021 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 7 | High |

EC=eligibility criteria; RA=random allocation; CA=concealed allocation; SB=similar baseline; BS=blinding subjects; BT=blinding therapists; BA=blinding assessors; CR=completion rate; ITA=intention-to-treat-analysis; BC=between-group comparisons; PMV=point measures and variability; TS=total score; QSQ=overall study quality; Yes=1; No=0; *= included in meta-analysis

*Publication bias*

The is funnel plot is presented in Figure 2. We conducted an Egger test to examine the presence of publication bias in our meta-analysis. The intercept of the Egger regression-based test was not statistically significant, b = 0.39, SE = 1.38, $t_{(1)} = 0.79$, $p = 0.60$, 95% CI [-2.785, 3.563]. The standard error of the effect size was estimated to be 2.086. The meta-regression model used was random effects. These results suggest that there is no significant publication bias in our meta-analysis.

Figure 2. Funnel plot for the visual inspection of publication bias.



*Characteristics of included studies*

The characteristics of the included studies are summarized in Table 7 & Table 8. They contain the descriptive data of participants, diagnosis, location and setting, interventions (types, intensity, and duration), follow-ups, outcomes, measurement tools, and major results. All included studies were published in the last decade (between 2014 to 2021). In terms of the study location, seven studies were conducted in Asia, including Taiwan (Chang et al., 2014; Pan, Chu, et al., 2017; Pan et al., 2019), Iran (Orangi et al., 2021; Torabi et al., 2018; Yazd et al., 2015) and India (Jeyanthi et al., 2021). Three studies were performed in Europe, including Germany (Meßler et al., 2018; Ziereis & Jansen, 2015) and Switzerland (Benzing et al., 2018). One study came from the USA (O'Connor et al., 2014) and the remaining one was conducted in Brazil (Silva et al., 2019).

Table 7. Study characteristics of Chapter 3.

| | Participant Characteristics | | | Intervention Components | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Author(s) (Year, Country/ Region)** | **Sample** | **Participants (Age Range, M, SD; Sex-M%)** | **Diagnostic Methods, subtype** | **Sample Size (IG/CG)** | **Setting** | **Type** | **Intensity** | **Length (mins)** | **Follow-up assessment** |
| Golubovic et al. (2014), Serbia | ADHD | Age range NR, M=6.38, SD=1, M-100% | Conners' Rating Scale | 36 (18/18) | Sports school | Physical exercise programme | NR | 3 sessions (60)/week | NR |
| Chang et al. (2014), Taiwan | ADHD | 5-10, M=8.44, SD=8.29, M-85% | ADHD (DSM-IV); Inattentive (7), Hyperactivity / impulsivity (2), Combined (18) | 27 (13/14) | Local swimming pool | Aquatic exercise | moderate | 2 sessions (90)/week | Within one week |
| O' Conner et al. (2014), the USA | ADHD | 5.56-7.98, M=6.64, SD: NR, M-74% | ADHD (DSM – Disruptive Behaviour Disorder rating scales); Inattentive (6), Hyperactivity / impulsivity (15), Combined (77) | 98 (52/46) | Recreational camp like setting | Summer treatment programme (STP) | NR | NR | Final 3 days of STP |
| Ziereis and Jansen (2015), Germany | ADHD | 7-12, M=9.45, SD=1.43, M-74% | ADHD (ICD-10; FBB-ADHS/KITAP) subtype (NR) | 43 (27/16) | University of Regnsburg's Institute of Sport Science | Multiple physical exercise programs | NR | 1 session (60)/week | Short-term effect was measured immediately after first day program. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Long-term effect was measured 1 week after the program. |
| Pan et al. (2017), Taiwan | ADHD | 7-14, M=9.05, SD= 2.59, M-100% | ADHD (DSM-IV-TR); Inattentive (2), Hyperactivity / impulsivity (6), Combined (16) | 48 (12/36) | Gymnasium at the university | PA training program (including SDHRP and physical fitness training) | NR | 1 session (90)/week | 2 weeks |
| Meßler et al. (2018), Germany | ADHD | 8-13, M=11, SD=1, M-100% | ADHD (DSM-IV-TR); subtype (NR) | 28 (14/14) | Local indoor or outdoor venue | HIIT | High | 3 sessions (4)/week | 3-4 Days |
| Torabi et al. (2018), Iran | ADHD | Age range NR, M=12.7, SD=1.08, M-40% | Conner's parental questionnaire; clinical interview; subtype (NR) | 50 (25/25) | Laboratory of University of Tehran | High-intensity intermittent training | High | 3-6 sessions (NR)/week | NR |
| Benzing and Schmidt (2019), Switzerland | ADHD | 8-12, M=10.63, SD=1.32, M-82.4% | ADHD (ICD-10); subtype (NR) | 51 (28/23) | Clinical trial in Bern | Exergaming programme | NR | 3 sessions (30)/week | NR |
| Pan et al. (2019), Taiwan | ADHD | 7-12, M=9.08, SD=1.43, M-100% | ADHD (DSM-IV-TR); subtype (NR) | 60 (15/45) | Gymnasium at the university | Table tennis | NR | 2 sessions (70)/week | Within two weeks |
| Sliva et al. (2019), Brazil | ADHD | 11-14, M=12, SD=1.5, M-70% | ADHD (DSM-IV-TR); subtype (NR) | 33 (18/15) | Rogationist Youth School in Criciúma City | Swimming | Moderate | 2 sessions (45)/week | 48 hours |

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|---|---|---|---|---|---|---|---|---|---|
| Orangi et al. (2021), Iran | ADHD | 10-13, IG (M=11.32, SD= 1.00)<br>CG (M=11.26, SD=0.92)<br>M-100% | ADHD rating scale by Dupaul, Power, Aastopoulos, and Reid; subtype (NR) | 36<br>(18/18) | A gym | Aerobic training | NR | 3 sessions (60)/week | NR |
| Jeyanthi et al. (2021), India | ADHD | 8-12, M=NR, SD=NR, M-100% | ADHD (DSM-V); Hyperactivity / impulsivity (3), Combined (7) | 20<br>(10/10) | NR | Structure exercise programme | NR | 3 sessions (45)/week | NR |

NR = not reported; NA= not applicable; HR= heart rate; IG = Intervention group; CG = Control group; SDHRP = simulated developmental horse-riding program; PA = Physical activity; HIIT = High intensity interval training

Table 8. Summary of study results of Chapter 3.

| Author(s) (year) | Outcomes of interest | Measures | Results |
|---|---|---|---|
| Golubovic et al. (2014) | 1. Motor ability | 1. Motor measuring tests | • Within-group effects: forward bend (*t*(16)=-3.83, *p*<.01); sit-ups (*t*(16)=-2.12, *p*<.05). |
| Chang et al. (2014) | 1. Motor ability<br>2. Inhibition | 1. Basic Motor Ability Test-Revised (BMAT)<br>2. Go/Nogo Task | • Between-group effect: bead moving score (*t*(25)=2.17, *p*=.04).<br>• *Go stimulus*, between-group effect reaction (*F*(1, 25)=10.36, *p*=.004).<br>• *Nogo stimulus*: effect of time (*F*(1, 25) =6.00, *p*=.02) and group x time interaction effect (F(1, 25) =8.30, *p*=.001). |
| O' Conner et al. (2014) | 1. Athletic competence<br>2. Motor proficiency | 1. Sport knowledge and performance tasks and Skill tasks<br>2. Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) | • Sport knowledge and performance: soccer (*F*(1,81)=26.9, *p*<.01); knowledge of tee ball (*F*(1,83)=26.62, *p*<.01) and performance in tee ball (*F*(1,82)=17.87, *p*<.01).<br>• In ball trapping (*F*(1,84)=7.34, *p*<.01); dribbling penalties (*F*(1,82)=7.23, *p*<.01) and catching accuracy (*F*(1,85)=11.95, *p*<.01).<br>• Group difference of BOTMP (*F*(1,77)=6.45, *p*=.012. |
| Ziereis and Jansen (2015) | 1. Working memory (WM)<br>2. Motor performance | 1. The digit span (forwards / backwards) and the letter-number-sequencing task of the HAWIK-IV<br>2. Movement Assessment Battery for Children (M-ABC 2) | • Executive functioning: no significant effect<br>• Three main effects of time: i) index-score WM (*F*(1,33)=17.80, *p*<.01); ii) digit-span forward (*F*(1,33)=24.261, *p*<.01) and iii) letter-number sequencing (*F*(1,33)=6.128, *p*<.05).<br>• Group x time interaction effects: catching (*F*(2,33)=8.197, *p*<.01) and the variable total score M-ABC (*F*(2,33)=9.925, *p*<.01). |
| Pan et al. (2017) | 1. Motor proficiency | 1. Bruininks-Oseretsky Test of Motor | • Post-training effects (*p*<.01) were found in total motor composite, in which fine manual control, partial $\eta^2$ = 0.29; manual |

| | | | |
|---|---|---|---|
| | 2. Physical fitness | Proficiency, Second Edition (BOT-2)<br>2. The 20-m progressive aerobic cardiovascular endurance run (PACER), isometric push-up, curl-up. and back-saver sit-and reach tests from the Brockport Physical Fitness Test (BPFT) | coordination, partial $\eta^2 = 0.23$; body coordination, partial $\eta^2 = 0.39$; strength and agility, partial $\eta^2 = 0.28$.<br>• Time effect in ADHD training group 20-m PACER and sit-and-reach in both legs (*p*<.01) with the post-hoc result. |
| Meßler et al. (2018) | 1. Physical fitness<br>2. Motor skills<br>3. Quality of life | 1. Maximal power output, peak oxygen uptake and oxygen uptake<br>2. Movement Assessment Battery for Children (M-ABC 2)<br>3. KINDL questionnaire | • Peak power during the incremental test ($p \leq .01$; $\eta^2_p = .28$; $F = 9.122$).<br>• The group of HIIT: manual dexterity ($p \leq .05$; $\eta^2_p = .15$; $F = 4.458$) and ball skills ($p = .03$; $\eta^2_p = .18$; $F = 5.686$).<br>• Parents' perspective on emotional well-being: ($p = .04$; $\eta^2_p = .16$; $F = 4.775$)<br>• Self-esteem by both guardians ($p \leq .01$; $\eta^2_p = .30$; $F = 11.019$) and boys ($p \leq .01$; $\eta^2_p = .25$; $F = 8.792$).<br>• The rating of quality of life by guardians ($p \leq .01$; $\eta^2_p = .24$; $F = 7.975$). |
| Torabi et al. (2018) | 1. Insulin resistance<br>2. Adiponectin<br>3. Motor proficiency | 1. Food dietary records<br>2. Biochemical evaluation<br>3. Bruininks-Oseretsky test of motor proficiency (BOTMP) | • A significantly decreased level of insulin resistance in the experimental groups ($p<0.05$).<br>• A significantly increased level of adiponectin in the experimental groups ($p<0.05$).<br>• Motor proficiency in the experimental groups of both genders ($p<0.05$). |
| Benzing and Schmidt (2019) | 1. Executive functions<br>2. Motor skills | 1. Simon Task, Flanker Task and modified | • Simon Task $F(2, 48) = 4.08$, p= 0.049, $d = 0.58$ and Flanker task $F(2, 48) = 5.09$, p = 0.029, $d = 0.65$. |

| | | | |
|---|---|---|---|
| | | version of the color span backward task<br>2. German Motor Test | • No significant difference in updating $F(2, 48) = 0.50$, p = 0.482, $d = 0.20$.<br>• Group difference $F(2, 48) = 7.69$, p = 0.008, $d = 0.80$. |
| Pan et al. (2019) | 1. Motor skills<br>2. Executive functions | 1. Test of Gross Motor Development-2 (TGMD-2)<br>2. Stroop color and word test and Winconsin Card Sorting Test (WCST) | • ADHD training group: locomotor ($F = 89.64$, $p < .01$) and object-control skills ($F = 156.00$, $p < .01$).<br>• ADHD non-training: locomotor skills ($F = 26.39$, $p < .01$).<br>• Between-group training effect ($F = 7.47$, $p < .01$). Within-group differences in ADHD training ($F = 172.35$, $p < .01$) and TD non-training groups ($F = 6.50$, $p <.05$).<br>• WCST: ADHD training group and ADHD non-training group ($F = 3.65$, $p < .05$).<br>• Time differences in ADHD training group ($F = 13.12$, $p < .01$). |
| Sliva et al. (2019) | 1. Mental health<br>2. Cognitive parameters<br>3. Motor coordination<br>4. Physical fitness | 1. Child depression inventory (CDI)<br>2. The test of trails<br>3. The battery of corporal coordination tests for children<br>4. The tests of flexibility and abdominal resistance | • A significant decreased level of depression ($p$=.048) and stress ($p$=.039) were found.<br>• The group effect was significant for cognitive flexibility ($p$=.042) and selective attention ($p$=.047).<br>• Significant increase in lower limbs ($p$=.05) and laterality ($p$=.041) were indicated as time effects. No significant differences were found for balance.<br>• Group effects for flexibility test ($p$=.049) and abdominal resistance ($p$=.037) were significant. |
| Orangi et al. (2021) | 1. Anxiety<br>2. Depression<br>3. Motor proficiency<br>4. Cognitive ability | 1. The Child Anxiety Scale<br>2. The Center for Epidemiological Studies Depression Scale (CES-D)<br>3. The short form of Bruininks-Oseretsky Test of Motor | • Within group difference reported for: anxiety (F=109.513, P=0.000, $\eta^2$=0.768); depression (F=155.377, P=0.000, $\eta^2$=0.825) and motor proficiency (F=80.190, P=0.000, $\eta^2$=0.708).<br>• Within group differences for cognitive ability: working memory (F=50.400, P=0.000, $\eta^2$=0.604), perceptual reasoning (F=55.004, P=0.000, $\eta^2$=0.625) and processing speed (F=60.520, P=0.000, $\eta^2$=0.647). |

| | | | |
|---|---|---|---|
| | | Proficiency- 2nd Edition (BOT-2)<br>4. The Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) | |
| Jeyanthi et al. (2021) | 1. Motor skills<br>2. Physical fitness<br>3. Attention | 1. Single leg triple hop test, seated medicine ball throw, nine-hole peg test<br>2. Integrated physical fitness test<br>3. Trail making test | • Main effect: single leg triple hop (right leg) $F(1,20) = 13.49$, $p < 0.05$; single leg triple hop (left leg) $F(1,20) = 7.87$, $p < 0.05$; seated medicine ball throw $F$ (1,20) = 5.30, $p < 0.05$; time effect $F(1,20) = 19.66$, $p < 0.05$ and group x time interaction $F$ (1,20) = 1.11, $p < 0.05$.<br>• Body composition: main effect F (1,20) = 7.3, $p < 0.05$.<br>• Muscle strength: group x time effects for right hand F (1,20) = 4.67, $p < 0.05$ and left hand F (1,20) = 8.67, $p < 0.05$.<br>• For leg explosive power, interaction effect F(1,20) = 4.9, $p < 0.05$<br>• Time effect for lower limbs ($p$=.05) and laterality ($p$=.041). |

*Study designs*.

The sample size ranged from 20 to 98. The total number of participants was 377 and the ages were between 5 and 14 years. In terms of diagnostic characteristic, in all included studies the participants were diagnosed with ADHD according to standard criteria, whereas in 7 studies (Benzing et al., 2018; Golubovic et al., 2014; Meßler et al., 2018; Orangi et al., 2021; Pan et al., 2019; Silva et al., 2019; Ziereis & Jansen, 2015) did not report the subtypes of ADHD. Correspondingly, the DSM-IV or DSM-V was commonly adopted by the studies' clinicians or psychiatrists as the gold standard diagnostic instrument (Wiggins et al., 2019).

Regarding the intensity, only three studies reported the intensity of the intervention as moderate to vigorous intensity physical activity (MVPA) (Chang et al., 2014; Meßler et al., 2018; Torabi et al., 2018). Meanwhile, one of the studies did not state the specific intensity, only the contents of the intervention (Ziereis & Jansen, 2015). The remaining nine studies did not report the intensity (Benzing et al., 2018; Golubovic et al., 2014; Jeyanthi et al., 2021; O'Connor et al., 2014; Orangi et al., 2021; Pan, Chang, et al., 2017; Pan et al., 2019; Silva et al., 2019; Yazd et al., 2015). Studies did not report any objective measurements of PA intensity, such as from accelerometers. The frequency of interventions ranged from one to three sessions per week and one of the interventions was a one-time summer treatment program (O'Connor et al., 2014). The duration of the intervention lasted from 3 weeks to 12 weeks, with each session ranging from 12 minutes to 90 minutes. Regarding the measurements of motor proficiency, five studies (O'Connor et al., 2014; Orangi et al., 2021; Pan, Chang, et al., 2017; Torabi et al., 2018; Yazd et al., 2015) adopted different versions of the Bruininks-Oseretsky Test (BOT) of Motor Proficiency, two studies (Meßler et al., 2018; Ziereis & Jansen, 2015) applied the Movement Assessment Battery for Children (M-ABC 2), one study (Chang et al., 2014) used the Basic Motor Ability Test-Revised (BMAT) and one study (Pan et al., 2019) used the Test of Gross Motor Development-2 (TGMD-2). Meanwhile, the remaining studies (Benzing et al., 2018; Chang et al., 2014; Golubovic et al., 2014) used alternative motor tasks such as motor measuring tests, the Basic Motor Ability Test-Revised (BMAT) and a German Motor Test.

*Meta-analysis of effects on overall motor proficiency and each composite*

Ten studies were included in the meta-analysis after further screening the 12 studies included in the systematic review. The reason for excluding the two studies from the meta-analysis was insufficient statistical information (i.e., standard deviation and mean of the testing items). The only information included was the *F* value which was not sufficient for RevMan to generate the result for a meta-analysis.

The meta-analysis included a total of 214 individuals with ADHD. Figure 3a presents the combined effect size for motor proficiency. The meta-analysis revealed a positive large intervention effect (SDM= 1.12, Z = 4.47, $p < 0.01$) on overall motor proficiency among children and adolescents with ADHD (95% CI [0.63 to 1.61], $p$ <0.01) and substantial heterogeneity ($\chi^2$ = 44.8, $I^2$ =80%, $p$ <0.01).

The six motor proficiency composites from the 10 studies were extracted and further analyzed. In these studies, all the motor proficiency composites were measured using the TGMD-2, BOT-2, and the relevant assessments. The detailed results are shown in Figure 3b.

*Locomotor.* Three studies measured locomotor skills (Benzing et al., 2018; Golubovic et al., 2014; Pan et al., 2019), and an overall medium effect was found (*SMD* = 0.32; 95%-*CI* [-0.44,1.09]; $p$ = 0.41).

*Object control.* Object control was measured in three of the included studies (Chang et al., 2014; Meßler et al., 2018; Pan et al., 2019). The overall effect of PA interventions on object control was large (*SMD* = 1.26; 95%-*CI* [0.80, 1.73]; $p < 0.01$).

*Fine manual control.* Two included studies measured fine manual control (Chang et al., 2014; Pan, Chang, et al., 2017) with a large effect size (*SMD* = 1.19; 95%-*CI* [0.27, 2.10]; $p = 0.01$).

*Manual coordination*. Manual coordination was measured in three studies (Meßler et al., 2018; Pan, Chang, et al., 2017; Silva et al., 2019), and the analysis showed a large effect (*SMD* = 1.09; 95%-*CI* [0.04, 2.13]; $p = 0.04$).

*Body coordination*. Six studies used body coordination as an outcome measure (Benzing et al., 2018; Chang et al., 2014; Golubovic et al., 2014; Meßler et al., 2018; Pan, Chang, et al., 2017; Silva et al., 2019). The overall effect of the PA intervention indicated a medium effect size for body coordination (*SMD* = 0.47; 95%-*CI* [0.03, 0.91]; $p = 0.04$).

*Strength and agility*. Four included studies (Benzing et al., 2018; Golubovic et al., 2014; Pan, Chang, et al., 2017; Silva et al., 2019) recorded strength and agility, however the analysis revealed no effect for this outcome (*SMD* = 0.68; 95%-*CI* [-0.36, 1.73]; $p = 0.20$).

Figure 3a. The combined effect size on motor proficiency.

| Study or Subgroup | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Total | Mean | SD | Total | Weight | IV, Random, 95% CI | Year |
| Golubovic et al 2013 | 188.5 | 47.52 | 18 | 184.11 | 58.72 | 18 | 10.4% | 0.08 [−0.57, 0.73] | 2013 |
| O'Connor et al. 2014 | 53.82 | 2.07 | 52 | 49.26 | 2.04 | 46 | 11.2% | 2.20 [1.69, 2.71] | 2014 |
| Chang et al. 2014 | 18.28 | 3.54 | 14 | 14.38 | 3.69 | 13 | 9.4% | 1.05 [0.23, 1.86] | 2014 |
| Pan et al. 2017 | 57.25 | 10.86 | 12 | 44.5 | 5.84 | 12 | 8.9% | 1.41 [0.50, 2.32] | 2017 |
| Meßler et al. 2018 | 11.1 | 2.5 | 14 | 8.7 | 3.8 | 14 | 9.7% | 0.72 [−0.04, 1.49] | 2018 |
| Torabi et al. 2018 | 41.8 | 9.5 | 25 | 30.9 | 6.6 | 25 | 10.6% | 1.31 [0.70, 1.93] | 2018 |
| Pan et al. 2019 | 43.33 | 2.5 | 15 | 40.6 | 3.91 | 15 | 9.8% | 0.81 [0.06, 1.56] | 2019 |
| Benzing et al. 2019 | 103.77 | 8.51 | 28 | 101.27 | 6.39 | 23 | 11.0% | 0.32 [−0.23, 0.88] | 2019 |
| Silva et al. 2020 | 108 | 8 | 18 | 85 | 11 | 15 | 8.8% | 2.37 [1.45, 3.29] | 2020 |
| Orangi et al. 2021 | 61.72 | 4.52 | 18 | 56.88 | 4.63 | 18 | 10.1% | 1.03 [0.33, 1.73] | 2021 |
| **Total (95% CI)** | | | **214** | | | **199** | **100.0%** | **1.12 [0.63, 1.61]** | |

Heterogeneity: $Tau^2 = 0.49$; $Chi^2 = 44.80$, df = 9 ($P < 0.00001$); $I^2 = 80\%$
Test for overall effect: $Z = 4.47$ ($P < 0.00001$)

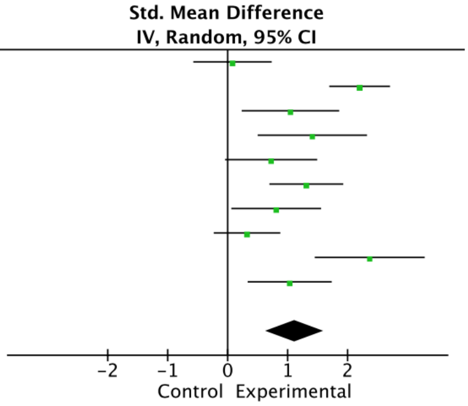
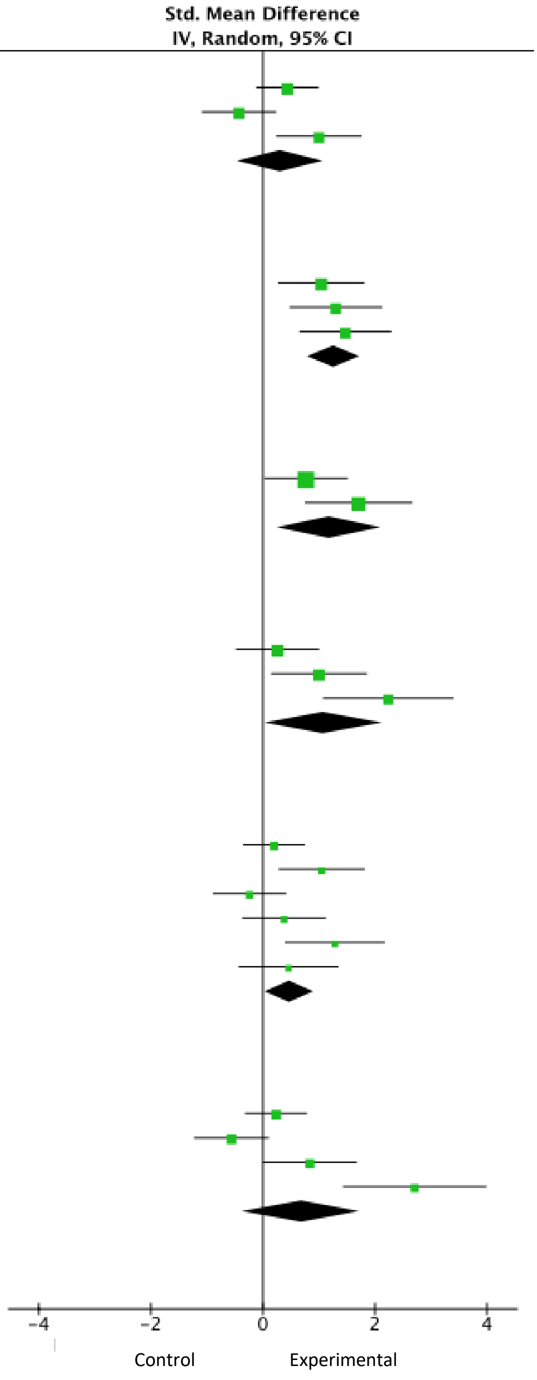


Figure 3b. The effect size on each motor proficiency composites.

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| **1.2.1 Locomotor** | | | | | | | | |
| Benzing et al. 2019 | 110.48 | 9.68 | 28 | 105.81 | 11.4 | 23 | 35.9% | 0.44 [−0.12, 1.00] |
| Golubovic et al 2013 | 121.72 | 15.95 | 18 | 129.66 | 20.18 | 18 | 33.3% | −0.43 [−1.09, 0.23] |
| Pan et al. 2019 | 43.44 | 2.5 | 15 | 40 | 4.02 | 15 | 30.7% | 1.00 [0.23, 1.77] |
| **Subtotal (95% CI)** | | | **61** | | | **56** | **100.0%** | **0.32 [−0.44, 1.09]** |
| Heterogeneity: Tau² = 0.34; Chi² = 8.08, df = 2 (P = 0.02); I² = 75% | | | | | | | | |
| Test for overall effect: Z = 0.83 (P = 0.41) | | | | | | | | |
| **1.2.2 Object Control** | | | | | | | | |
| Chang et al. 2014 | 18.25 | 3.54 | 15 | 14.38 | 3.69 | 15 | 36.4% | 1.04 [0.27, 1.81] |
| Meßler et al. 2018 | 12.8 | 3 | 14 | 9.1 | 2.5 | 14 | 31.5% | 1.30 [0.47, 2.13] |
| Pan et al. 2019 | 45.27 | 1.94 | 15 | 40.6 | 3.91 | 15 | 32.1% | 1.47 [0.65, 2.29] |
| **Subtotal (95% CI)** | | | **44** | | | **44** | **100.0%** | **1.26 [0.80, 1.73]** |
| Heterogeneity: Tau² = 0.00; Chi² = 0.58, df = 2 (P = 0.75); I² = 0% | | | | | | | | |
| Test for overall effect: Z = 5.33 (P < 0.00001) | | | | | | | | |
| **1.2.3 Fine manual control** | | | | | | | | |
| Chang et al. 2014 | 35.79 | 4.87 | 15 | 32.38 | 3.69 | 15 | 55.4% | 0.77 [0.02, 1.51] |
| Pan et al. 2017 | 45.67 | 6.07 | 12 | 36.17 | 4.57 | 12 | 44.6% | 1.71 [0.75, 2.67] |
| **Subtotal (95% CI)** | | | **27** | | | **27** | **100.0%** | **1.19 [0.27, 2.10]** |
| Heterogeneity: Tau² = 0.25; Chi² = 2.30, df = 1 (P = 0.13); I² = 56% | | | | | | | | |
| Test for overall effect: Z = 2.54 (P = 0.01) | | | | | | | | |
| **1.2.4 Manual coordination** | | | | | | | | |
| Meßler et al. 2018 | 9.4 | 2.5 | 14 | 8.6 | 3.4 | 14 | 36.7% | 0.26 [−0.48, 1.00] |
| Pan et al. 2017 | 60.25 | 10.69 | 12 | 50.58 | 7.72 | 12 | 34.5% | 1.00 [0.14, 1.86] |
| Silva et al. 2020 | 76 | 5 | 10 | 59 | 9 | 10 | 28.8% | 2.24 [1.07, 3.41] |
| **Subtotal (95% CI)** | | | **36** | | | **36** | **100.0%** | **1.09 [0.04, 2.13]** |
| Heterogeneity: Tau² = 0.63; Chi² = 7.91, df = 2 (P = 0.02); I² = 75% | | | | | | | | |
| Test for overall effect: Z = 2.04 (P = 0.04) | | | | | | | | |
| **1.2.5 Body coordination** | | | | | | | | |
| Benzing et al. 2019 | 103.53 | 11.1 | 28 | 101.35 | 10.47 | 23 | 21.2% | 0.20 [−0.35, 0.75] |
| Chang et al. 2014 | 18.28 | 3.54 | 15 | 14.38 | 3.69 | 15 | 16.1% | 1.05 [0.28, 1.82] |
| Golubovic et al 2013 | 17.61 | 3.69 | 18 | 18.5 | 3.6 | 18 | 18.6% | −0.24 [−0.89, 0.42] |
| Meßler et al. 2018 | 10.4 | 2.6 | 14 | 9.2 | 3.5 | 14 | 16.6% | 0.38 [−0.37, 1.13] |
| Pan et al. 2017 | 52 | 8.01 | 12 | 43.5 | 4.19 | 12 | 13.7% | 1.28 [0.39, 2.18] |
| Silva et al. 2020 | 108 | 11 | 10 | 102 | 14 | 10 | 13.8% | 0.46 [−0.43, 1.35] |
| **Subtotal (95% CI)** | | | **97** | | | **92** | **100.0%** | **0.47 [0.03, 0.91]** |
| Heterogeneity: Tau² = 0.16; Chi² = 10.66, df = 5 (P = 0.06); I² = 53% | | | | | | | | |
| Test for overall effect: Z = 2.09 (P = 0.04) | | | | | | | | |
| **1.2.6 Strength and agility** | | | | | | | | |
| Benzing et al. 2019 | 108.47 | 10.29 | 28 | 105.95 | 10.79 | 23 | 27.6% | 0.24 [−0.32, 0.79] |
| Golubovic et al 2013 | 21.5 | 6.01 | 18 | 25.66 | 8.28 | 18 | 26.7% | −0.56 [−1.23, 0.11] |
| Pan et al. 2017 | 62.75 | 10.78 | 12 | 53.92 | 9.53 | 12 | 25.1% | 0.84 [−0.00, 1.68] |
| Silva et al. 2020 | 38 | 3 | 10 | 28 | 4 | 10 | 20.6% | 2.71 [1.43, 3.99] |
| **Subtotal (95% CI)** | | | **68** | | | **63** | **100.0%** | **0.68 [−0.36, 1.73]** |
| Heterogeneity: Tau² = 0.94; Chi² = 21.57, df = 3 (P < 0.0001); I² = 86% | | | | | | | | |
| Test for overall effect: Z = 1.29 (P = 0.20) | | | | | | | | |




Test for subgroup differences: Chi² = 8.50, df = 5 (P = 0.13), I² = 41.2%

***Discussion***

To the best of our knowledge, this study represents the first meta-analysis that examines the impact of physical activity (PA) interventions on motor proficiency in children and adolescents diagnosed with Attention Deficit Hyperactivity Disorder (ADHD). Motor proficiency plays a critical role in determining PA and fitness levels in children, which have been linked to executive functions and mental health (Pan, Chang, et al., 2017; Rigoli et al., 2017; Rigoli et al., 2012; Stodden et al., 2008). Another strength of this review is that it comprehensively examines all six motor proficiency composites. Based on the findings from 12 studies in the systematic review and 10 studies in the meta-analysis involving 413 participants, this study concludes that PA interventions significantly enhance motor proficiency in children with ADHD, as compared to control conditions. Most of the motor proficiency composites show medium to large effects. This review corroborates earlier research by Vysniauske et al. (2020) and provides additional details on motor proficiency. Vysniauske et al. (2020) have indicated the positive effect of physical activity on the functional outcomes, including motor proficiency, in children with ADHD. Meanwhile current study focused only on motor proficiency and the results were aligned.

The positive effects of physical activity (PA) on motor proficiency were observed in five out of six motor proficiency composites, including locomotor skill, object control skill, fine manual control, manual coordination, and body coordination. These results are consistent with previous studies in the general population (Gallotta et al., 2018; Iivonen et al., 2013; Jones et al., 2020). These consistent results provide strong evidence to support the generalizability of the positive impact of PA on motor proficiency, regardless of whether individuals have ADHD or not.

The present review revealed that PA interventions did not have a significant effect on strength and agility in children and adolescents with ADHD, which contradicts the findings of Golubovic et al. (2014). This inconsistency in the results may be partially explained by the difference in the duration of the PA intervention. In the current review, none of the included studies had a prolonged intervention lasting more than 12 weeks, whereas in the study by Golubovic et al. (2014), the intervention lasted for 6 months with one 60-minute session per week. Although some of the included studies reported a significant improvement in strength and agility, the overall effect was not significant when the studies were combined.

We conducted a preliminary review of the intervention dosage due to the lack of reported data on the frequency of PA interventions from the included studies. Although there were no objective measures of physical activity in any of the studies, positive acute effects were reported for interventions ranging from 3 to 12 weeks in duration. O'Connor et al. (2014) even found significant positive effects on motor proficiency after a one-time summer program. In terms of intensity, it was impossible to reach any conclusions about the intensity needed to generate a positive effect of PA on motor proficiency because none of the studies included objective measures of physical activity. However, based on previous studies in the general population and the descriptions of the interventions provided in the studies included in the review and meta-analysis, it can be concluded that moderate-to-vigorous physical activity (MVPA) is beneficial to motor proficiency in children with ADHD. The intervention duration varied in the included studies, ranging from 10 minutes of high-intensity interval training (Torabi et al., 2018) to 90 minutes of a simulated developmental horse-riding program (Pan, Chang, et al., 2017). These findings highlight that various intervention durations can have a positive effect on motor proficiency in children with ADHD.

The present study highlights the significance of promoting regular physical activity (PA) in children with ADHD, particularly in Hong Kong. Landry and Driscoll (2012) investigated the correlation between inadequate PA and various health issues, including obesity and other chronic diseases, in the United States of America. Similarly, Huang et al. (2018) reported a similar situation in Hong Kong, with the children being less active than their American counterparts. Furthermore, Mercurio et al. (2021) found that children with ADHD were less physically active than typically developing children. This inactivity can have important implications for physical health and the development of motor proficiency. Consequently, the present study not only supports the positive impact of PA on children with ADHD but also emphasizes the need to enhance their participation in PA to improve their health outcomes.

The review and meta-analysis presented in this study have certain limitations that need to be addressed. Firstly, some of the included studies lacked sufficient information to allow for further moderator analyses. Specifically, some studies only provided the overall score of the motor proficiency test without the individual scores for each composite. Despite sending emails to the corresponding authors of these studies, no responses were received. Secondly, the findings of this review are limited to children and adolescents with ADHD and cannot be generalized to adults with ADHD. Thirdly, the utilization of SMD, which emphasizes effect sizes, could lead to an overestimation of the actual effect. Hedge's adjusted g would be a more suitable option, but it could not be generated by RevMan for meta-analyses that involve clinical populations with small sample sizes, as it contains a pooled standard deviation in the denominator and is error-corrected (Hartung et al., 2008). Lastly, the subgroup analyses included only a limited number of studies, resulting in wide 95% CI intervals. Therefore, the results of the meta-analyses lack precision, and their interpretation requires extra attention.

***Conclusion***

Based on the systematic review and meta-analysis conducted on the effect of physical activity intervention on motor proficiency in children and adolescents with ADHD, it is evident that PA has a positive influence on the motor proficiency of this population. The findings reveal that five out of six motor proficiency composites were positively impacted by PA, despite the effect sizes being small. The current study provides strong evidence supporting the generalization of the positive effects of PA for all individuals, irrespective of whether they have ADHD or not. Furthermore, the results underscore the importance of promoting regular PA in children and adolescents with ADHD, particularly in regions like Hong Kong where inadequate PA has been linked to health problems. Nevertheless, the present study has some limitations, including insufficient information in some studies and the paucity of research in adults with ADHD. Future studies should address these limitations and investigate the optimal duration and intensity of PA interventions to enhance motor proficiency in this population.

# Chapter 4: Examining the impact of physical activity on sleep quality in children with ADHD.

## Abstract

The occurrence of sleep issues is commonly observed in children diagnosed with attention deficit hyperactivity disorder (ADHD). This study aimed to explore the influence of physical activity on the quality of sleep in young adolescents with ADHD. A total of 33 children, with an average age of 10.12 years, who had been diagnosed with ADHD, were divided randomly into two groups: an intervention group and a control group. The intervention group received a 12-week jogging programme. Four specific sleep measures, including sleep efficiency, sleep onset latency, sleep duration, and wake after sleep onset, were evaluated before and after the intervention period for both groups. The results indicated significant interaction effects in sleep duration ($F[1,31] = 7.67$, $p < 0.01$), sleep efficiency ($F[1, 31] = 6.28$, $p = 0.02$), and sleep onset latency ($F[1, 31] = 9.43$, $p = 0.004$). These findings underscore the positive effects of physical activity in enhancing sleep quality among children with ADHD.

**Keywords**

attention deficit hyperactivity disorder, children, physical activity, sleep

**Introduction**

Attention deficit hyperactivity disorder (ADHD) is one of the most common neurodevelopmental disorders diagnosed in children and young adolescence population and characterized by inattentiveness, hyperactivity and impulsivity (American Psychiatric Association, 2013). The core symptoms are frequently misinterpreted to irresponsibility, laziness, or being uncooperative among peers and may be persisted to adulthood. Consequently, a lower self-esteem, living quality and slower learning progression were commonly observed in the population (American Psychiatric Association, 2013). In addition to the above core symptoms, sleep problems is also very common among children with ADHD (Kirov & Brand, 2014; Meltzer & Mindell, 2006; Tandon et al., 2019). Numerous of studies have reported the substantial prevalence of sleep problems of 25-55% (Cortese et al., 2009; Hvolby, 2015; Martin et al., 2019). Efron et al. (2014) have further presented that 62% of children with ADHD suffered from moderate to severe sleep problems and 22% of them accepted medication in Australia. Sleep-onset delay (SOD), bedtime resistance and night awakenings were the most frequently discussed sleep problems in children with ADHD (Cortese et al., 2009; Papadopoulos et al., 2019). The sleep problems in ADHD children population may also persist into adolescence and adulthood (Lunsford-Avery et al., 2016; Martin et al., 2019; Snitselaar et al., 2017). For instance, adults with ADHD may suffer from reduced sleep quality, increased sleep onset latency (SOL) and shorter sleep duration (SD) (Hvolby, 2015; Snitselaar et al., 2017).

Previous studies specify that poor sleep can exacerbate the symptoms of ADHD, which correlated with behavioral and functional impairments (Hvolby, 2015; O'Brien, 2009; Papadopoulos et al., 2019). Furthermore, the sleep problems are often associated with insufficient daytime performance which impact on problematic behavior, unstable emotions and slower learning progress (O'Brien, 2009). Even for adults with ADHD, the sleep problems were negatively related to academic functioning in college (Langberg et al., 2014) and driving performance (Bioulac et al., 2015). Considering that sleep is critical in brain development and symptoms presentation and prognosis (Lunsford-Avery et al., 2016), it is important to find the effective strategies to improve the sleep problems in children with ADHD.

Pharmacological medication is one of the common therapies to remedy the sleep problems in the ADHD population (Hvolby, 2015). The application of pharmacological medication to enhance sleep quality in ADHD population is still controversial. Kratochvil et al. (2005) and McWilliams et al. (2022) have presented that the medication (e.g. melatonin and clonidine) could successfully promoted sleep in ADHD population. However, the use of medication could have a result to worsen of hyperactivity or behavioral difficulties at bedtime and lower daytime activity (Cortese et al., 2013; De Crescenzo et al., 2014). Without a promising conclusion in the application of pharmacological medication, the negative effect of the pharmacological therapy may be consequent to amplify the symptoms of ADHD and affect the daytime activity (Cortese et al., 2013; De Crescenzo et al., 2014).

In the past decade, numerous of studies have presented the evidential benefits of physical activity on sleep quality in various of population (Wang & Boros, 2021). Hurdiel et al. (2017); Park (2014) indicated the positive effect of physical activeness to better sleep quality in typically developing (TD) adolescences population. For example, Greever et al. (2017) found that regular physical activity was associated with the reduced number of midnight awakenings and higher sleep fragmentation (Greever et al., 2017). Furthermore, Baldursdottir et al. (2017) presented the significant results in a 3-week acute walking programme to better sleep quality in TD adolescents in Iceland. Moreover, Stone et al. (2012) suggested the higher rate of physical activity in children population would be easier to maintain a recommended sleep duration of 9 hours. Overall, the results of these previous studies well demonstrated that physical activity is beneficial in improving multiple facets of sleep quality among TD children and adolescents.

This is the first randomized control trial to investigate the effect of physical activity on sleep quality in children with ADHD. Although Liang, Li, Wong, Sum, Wang, et al. (2021) have indicated the positive mediating effect of physical activity to sleep quality in the population, the cross sectional data might not be able to fully present the effect between variables. With the intervention, the findings would make an important contribution to the field and generate insight of clinical significance. Therefore, it is reasonable to clarify the potential application of physical activity as an alternative intervention to enhance sleep quality in children with ADHD.

Previously, lacking studies with intervention have been completed in such population. Tse et al. (2019) has conducted a RCT study with a 12-week basketball intervention in sleep quality and cognition with the significant results in children with autism spectrum disorder. The study has shown the potential in physical activity that beneficial to sleep quality in children with neurodevelopmental disorder. Therefore, the objective of the current study was to investigate the impact of a physical activity intervention on sleep quality in children with ADHD. It was hypothesized that the intervention would have a positive effect on sleep quality in the purposed population.

## Method

### *Participants*

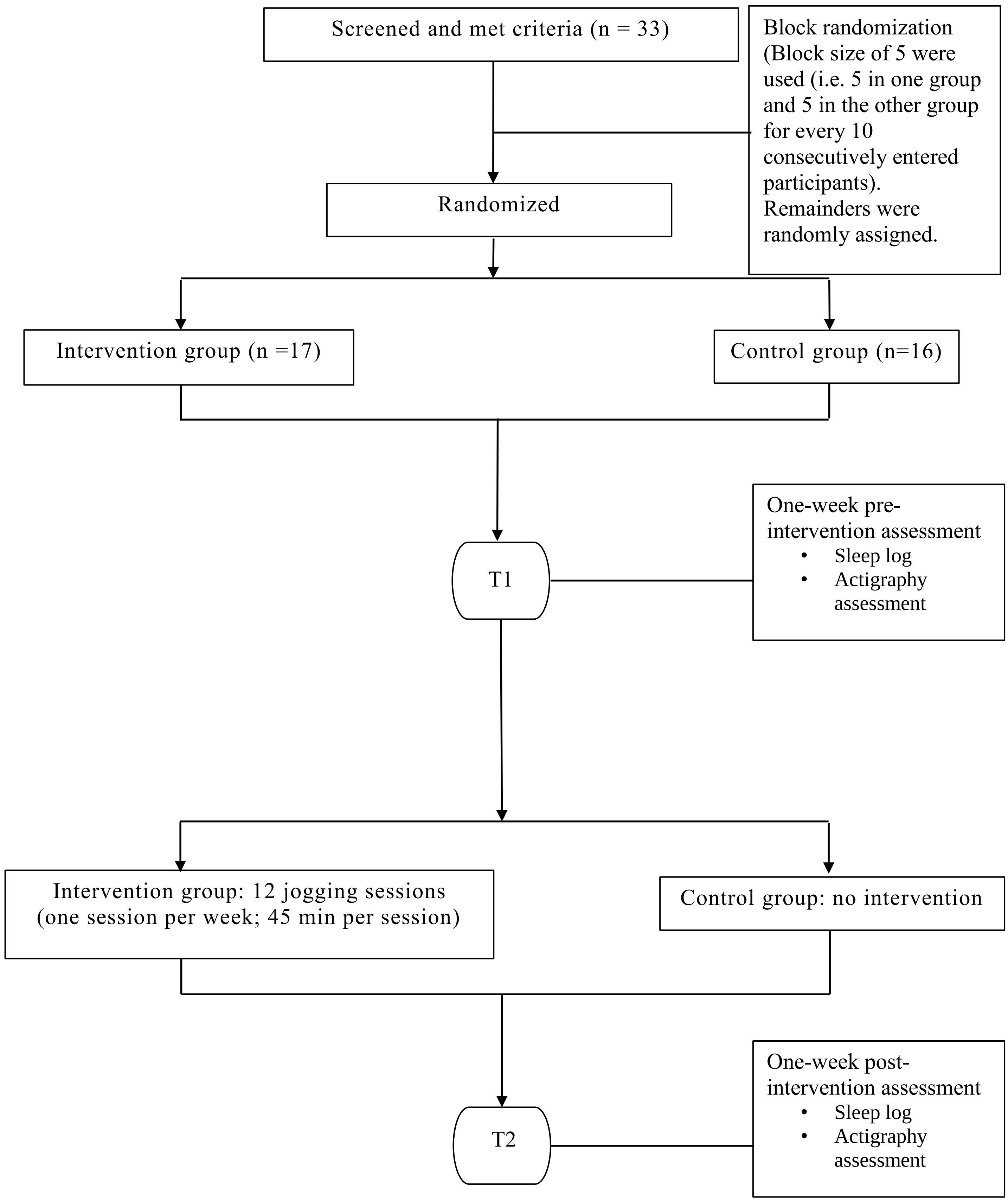
The study was approved by the ethics committee of the Education University of Hong Kong. Due to the limited related RCT study, the sample size might not be calculated by G* Power software (Faul et al., 2007). A total of 33 participants (26 boys and 7 girls) were successfully recruited from a local special school after the screening by a trained research assistant. There were four participants were reported with pharmacological medication background of dextroamphetamine and amphetamine. The prescription has been reviewed by one of the collaborators, who is a physician in pediatric, and confirmed no impact in sleep. The inclusion were as follows: i) age between 8 and 12 years; ii) a diagnosis of ADHD made by a physician based on the Diagnostic and Statistical Manual of Mental Disorders, 5th edition (American Psychiatric Association, 2013); iii) a non-verbal IQ above 40 as assessed by the Wechsler Intelligence Scale for Children (Bracken, 1993); iv) able to follow instruction; v) able to perform the requested physical intervention and vi) no prior training in jogging. The exclusion criteria were: i) having other medical conditions that restricted their physical activity, such as asthma, cardiac disease; and ii) having a complex neurological disorder, for instance, epilepsy, fragile X syndrome, tuberous sclerosis.

### *Study design and procedures*

To investigate the effects of a 12-week jogging intervention on sleep quality in adolescents with ADHD, a randomized controlled trial was conducted. Jogging was chosen as the intervention based on previous studies that utilized walking programs, as jogging offers a higher intensity compared to walking (Spierer et al., 2011). Besides, previous studies have indicated the effects of jogging in children with ADHD in different parameters which presented the validity of jogging (Gapin et al., 2011; Ziereis & Jansen, 2015). The participants were randomly assigned to either the intervention group (n=17, 14 boys and three girls, with a mean age of 9.82 ± 1.23) or the control group (n=16, 12 boys and four girls, with a mean age of 10.43 ± 0.96). Block randomization was implemented to ensure equal allocation ratios for both groups (Efird, 2011). A block size of five was used, with five participants assigned to each group for every 10 consecutive participants, while the remaining participants were randomly assigned to either the intervention or control group. The block randomization process was carried out by the primary researcher. Information regarding current medication was obtained from the participants' parents.

Each participant underwent two one-week assessments to evaluate their regular sleep patterns. The first assessment (T1: baseline) was conducted before the intervention, while the second assessment (T2: post-intervention) took place immediately after the 12-week jogging physical activity intervention. The procedure of the study is illustrated in Figure 4.

Figure 4. The flow chart of Chapter 4.



*Intervention group*. The intervention consisted of a 12-week jogging program conducted once a week, with each session lasting 45 minutes. The sessions took place in the morning at the school's gymnasium. The ratio of instructors to participants ranged from 1:3 to 1:2, depending on the attendance. The overall attendance rate was 97.06%. Participants were instructed to wear sportswear and sports shoes instead of their school uniform. Each intervention session followed a standardized format, which included three main activities: a 10-minute warm-up, a 25-minute jogging exercise and a 5-minute cool-down period. The jogging exercise included varied posture and motor learning exercise, such as skipping, high knees and hopping on two feet into one foot. were provided during the jogging exercise section. A 5-minutes break would be given due to the response of the participants. Verbal compliments were reinforced to the efforts in learning of the participants for motivation.

*Control group*. Participants assigned to the control group did not receive any jogging intervention. Additionally, during the period between the two measurements, participants were instructed to continue their normal daily routines without engaging in any additional physical activity or participating in any physical activity programmes.

*Measures*

The current study included four parameters to assess sleep: i) Sleep efficiency (SE), calculated as the actual sleep time divided by time spent in bed and presented as a percentage; ii) Sleep onset latency (SOL), which measures the time it takes to fall asleep and is presented in minutes; iii) Sleep duration (SD), presented in hours; and iv) Wake after sleep onset (WASO), which represents the duration of wakefulness after falling asleep and is presented in minutes. These parameters were measured using both a sleep log (Morgan et al., 2007) and an actigraphy accelerometer (GTX3 model, ActiGraph, Pensacola, FL) (Tse et al., 2019; Wachob & Lorenzi, 2015). The selection of these parameters was based on their ability to effectively measure sleep behaviors and sleep quality in adolescents with ADHD (Moore et al., 2011; Mullin et al., 2011).

Regarding the actigraphy assessments, all participants were instructed to wear the device on their non-dominant wrist continuously for seven consecutive days (from Monday to Sunday), with the exception of during baths. Non-wearing time was defined as a period of 60 consecutive minutes with a tolerance of 2 minutes of sporadic movement (Wachob & Lorenzi, 2015). Invalid data were considered for the nighttime period (10 p.m. to 7 a.m.) if the wearing duration was less than 8 hours, and such data were excluded from the analysis. The Sadeh algorithm (Sadeh et al., 1994) was used to determine sleep onset and sleep offset. Participants' parents were involved in recording the sleep log and sleep patterns, which included bedtime, sleep start and end times, wake-up time, and sleep duration. The sleep pattern was reported in the sleep log throughout the assessment period (T1 and T2).

*Data analysis*

Statistical analyses were conducted using SPSS (version 28.0) for Mac (SPSS Inc., Chicago, IL, USA). The results are presented as mean values with standard deviations. The data entry process was performed by a research assistant who was unaware of the group assignments, ensuring blinding. A linear mixed model (LMM) was utilized to examine the effects of the intervention on sleep, considering all sleep parameters measured through the sleep log and actigraphy accelerometer. To evaluate the validity of the sleep log, Spearman's correlations were calculated to assess the relationship between the sleep log and actigraphy assessments for sleep efficiency (SE) and sleep duration (SD). However, the remaining parameters (wake after sleep onset [WASO] and sleep onset latency [SOL]) could not be measured simultaneously by both the sleep log and actigraphy assessment, and thus, their validity could not be evaluated. Furthermore, a series of 2 (block: baseline vs. post) x 2 (group: intervention vs. control) repeated measures analyses of variance (ANOVAs) were conducted to analyze the effects of the intervention. Statistical significance was defined as a p-value < 0.05.

**Results**

Demographic data for the two groups are shown in Table 9.

Table 9. Demographic statistics of participants of each group of Chapter 4.

| | Intervention group (n =17) | Control group (n =16) |
|---|---|---|
| Gender | 14 boys and 3 girls | 12 boys and 4 girls |
| Age (years) | 9.82±1.24 | 10.44±0.96 |
| Weight (kg) | 35.29±4.77 | 36.11±4.29 |
| Height (m) | 1.37±0.09 | 1.36±0.09 |
| BMI (kg/$m^2$) | 18.87±2.38 | 19.64±2.78 |
| Medication (n) | | |
| Yes | 2 | 2 |
| No | 15 | 14 |

*Actigraphy assessments*.

Table 10 has presented the linear mixed model of actigraphy in current study. For sleep efficiency, we found a significant time effect ($F$[1,31] = 10.68, $p$ = 0.03) and no significant group ($F$[1, 31] = 0.12, $p$ = 0.71) interaction effect ($F$[1,31] = 0.84, $p$ = 0.37). In terms of wake after sleep onset, significant time effect ($F$[1,31] = 14.10, $p$ <0.01) was examined. However, no significant group ($F$[1,31] = 0.32, $p$ = 0.77) and interaction effect ($F$[1,31] = 1.12, $p$ = 0.30) were indicated. For sleep duration, significant group ($F$[1,31] = 7.64, $p$ = 0.01) and interaction effects ($F$[1,31] = 7.67, $p$ <0.01) were found. Nonetheless, the time effect (*F*[1,31] = 2.10, *p* = 0.89) was reported insignificantly. Follow-up tests revealed that the sleep duration of the control group (mean = 5.75, SD = 0.27) was significantly shorter than the intervention group (mean = 6.79, SD = 0.26) at T2 (*t*[15] = 3.20, *p* = 0.003).

Table 10. Sleep parameters by actigraphy assessment of Chapter 4.

| Sleep parameters | Intervention group (SD) | Control group (SD) | p-value (group effect) | p-value (interaction effect) |
|---|---|---|---|---|
| Sleep efficiency (%) | | | | 0.37 |
| T1 | 82.64 (11.58) | 83.87 (5.96) | 0.71 | |
| T2 | 91.66 (8.30) | 88.94 (8.26) | 0.35 | |
| p-value (time effect) | *<0.01* | 0.11 | | |
| Wake after sleep onset (min) | | | | 0.30 |
| T1 | 87.07 (54.59) | 70.19 (35.00) | 0.30 | |
| T2 | 39.30 (45.22) | 43.41 (33.95) | 0.77 | |
| p-value (time effect) | *<0.01* | 0.70 | | |
| Sleep duration (hour) | | | | *<0.01* |
| T1 | 6.72 (0.24) | 6.91 (0.83) | 0.59 | |
| T2 | 6.79 (0.26) | 5.75 (1.05) | *0.01* | |
| p-value (time effect) | 0.89 | *<0.01* | | |

*Sleep log*.

Table 11 has presented the linear mixed model of sleep log in current study. For sleep efficiency, significant time (*F*[1, 31] = 10.07, *p* = 0.003), group (*F*[1, 31] = 5.77, *p* = 0.02) and interaction (*F*[1, 31] = 6.28, *p* = 0.02) effects were found. Follow-up tests revealed that the significant increase of sleep efficiency in the intervention group (mean = 95.64, SD = 0.61) than the control group (mean = 91.46, SD = 0.86) at T2 (*t*[16] = -4.58, *p* < .001). For sleep onset latency, significant time (*F*[1, 31] = 9.86, *p* = 0.004) and interaction (*F*[1, 31] = 9.43, *p* = 0.004) effects were found. Nonetheless, the group effect (*F*[1, 31] = 2.28, *p* = 0.14) was indicated. Follow-up tests revealed that the significant decrease of sleep onset latency in the intervention group (mean = 22.38, SD = 2.70) than the control group (mean = 39.4, SD =

2.76) at T2 (*t*[16] = 4.60, $p$ <.001). For sleep duration, no significant time (*F*[1, 31] = 10.71, $p$ = 0.26) was indicated. Moreover, insignificant interaction (*F*[1, 31] = 2.79, $p$ = 0.11) and group (*F*[1, 31] = 0.47, $p$ = 0.75) were found.

Table 11. Sleep parameters measured by sleep log of Chapter 4.

| Sleep parameters | | Intervention group (SD) | Control group (SD) | p-value (group effect) | p-value (interaction effect) |
|---|---|---|---|---|---|
| Sleep efficiency (%) | | | | | *0.018* |
| | T1 | 91.08 (0.84) | 91.99 (0.63) | 0.75 | |
| | T2 | 95.64 (0.61) | 91.46 (0.86) | *<0.01* | |
| p-value (time effect) | | *<0.01* | 0.65 | | |
| Sleep Onset Latency (min) | | | | | *0.004* |
| | T1 | 45.36 (4.44) | 39.6 (4.56) | 0.37 | |
| | T2 | 22.38 (2.70) | 39.4 (2.76) | *<0.01* | |
| p-value (time effect) | | *<0.01* | 0.96 | | |
| Sleep duration (hour) | | | | | 0.11 |
| | T1 | 7.68 (0.29) | 7.14 (0.30) | 0.20 | |
| | T2 | 7.99 (0.23) | 8.10 (0.24) | 0.75 | |
| p-value (time effect) | | 0.26 | *<0.01* | | |

**Discussion**

Current study investigated the impact of physical activity intervention (a 12-week jogging program) on sleep quality in young adolescent with ADHD. The significant key findings of the interaction effect in sleep duration, sleep efficiency and sleep onset latency indicated the meaningfulness of physical activity in young adolescent with ADHD.

To our best understanding, very limited RCT study of physical activity and sleep in ADHD young adolescent population was conducted previously. The current results have aligned with the study of Liang, Li, Wong, Sum, Wang, et al. (2021) that indicated physical activity had a key role in sleep quality in children with ADHD. One of the remarkable differences between Liang's and current study was the setting of the study. In current study, it has been conducted as a RCT while Liang has presented the study with no physical activity intervention (Liang, Li, Wong, Sum, Wang, et al., 2021). Therefore, the physical activity intervention effect could not be measured by the study of Liang. It has been indicated that moderate to vigorous intensity physical activity (MVPA) conducted a significant effect in sleep onset latency and promoted better sleep quality (Kredlow et al., 2015; Liang, Li, Wong, Sum, Wang, et al., 2021).

In the current study, the intervention group displayed increased sleep duration, improved sleep efficiency, decreased sleep onset latency, and reduced wake after sleep onset compared to the control group. These findings were consistent across measurements obtained from both actigraphy and sleep logs. It is important to note that the subjectivity involved in completing the sleep log, which relies on parental observation, may introduce some variability in the results compared to the objective actigraphy measurements. The insignificant results of two measurements under the intervention group in sleep duration were similar to the study by

Kredlow et al. (2015). Kredlow et al. (2015) has shown the small-to-medium effect of regular PA to sleep duration which associated with the niche improvement of sleep duration in the intervention group in current study.

The key findings in the study were the significant interaction effects in sleep duration, sleep efficiency and sleep onset latency in the young adolescent with ADHD. With the improved sleep parameters and quality, better daytime functions could be developed, and the severe behavioral related symptoms could be reduced (Becker, 2020; Konofal et al., 2010; Lee et al., 2019). Furthermore, the poor sleep quality might have a persistency in the ADHD population. The poor sleep quality faced in childhood may influentially persist into adulthood (Diaz-Roman et al., 2018; Scott et al., 2013). Therefore, current study not only indicated the effects of physical activity on improving the particular sleep parameters, but also encourage the population participates in a regular physical activity with moderate to vigorous intensity. By promoting the regular physical activity participation, the poor sleep quality persistency may be potentially reduced in the ADHD population.

One of the possible explanations for the above findings is the secretion level of melatonin after physical activity in young adolescent with neurodevelopmental disorder (Lee et al., 2014; Tse et al., 2018). Melatonin is a hormone that plays a crucial role in regulating the circadian rhythm and facilitating natural sleep onset and maintenance (Van der Heijden et al., 2007). Typically, melatonin secretion rises shortly after darkness sets in, reaches its peak during the middle of the night, and gradually declines in the early morning hours (Weiss et al., 2006). The response of melatonin maintains a regular and normal circadian rhythm ad sleeping through the night. In the comparison with TD children and young adolescent, delayed secretion of melatonin was presented in the ADHD population and in the consequence to insomnia (Heijden et al., 2005; Weiss et al., 2006). In order to regulate the melatonin level, long-term supplemental melatonin treatment is suggested as the remedy of insomnia in children and adolescents with ADHD over decades (Hoebert et al., 2009; Van der Heijden et al., 2007; Weiss et al., 2006). Previously, Montaruli et al. (2017) suggested the melatonin levels could be moderated by PA, especially the morning and the evening sessions could help adjusting the circadian rhythm.

Similar study completed by Tse et al. (2018) in ASD children population, the RCT study has designed with a 12-week jogging intervention and suggested the regular PA interacted with the secretion of melatonin. As a result, improving the overall sleep quality. Nonetheless, the interaction between PA and the level of melatonin was still an unknown of current study due to no related biological sample, urine sample, has been collected from the participants. The effect of melatonin between PA and sleep remained uncertain in current study. Future studies examining the underlying mechanism of how PA affects overall sleep quality in children with ADHD are therefore warranted.

Furthermore, the improvement of sleep quality would be beneficial to ADHD children and adolescent population, especially in daytime performance, cognition, behavioral problems and executive functions, for instance, reducing daytime dizziness (Gruber et al., 2012; Van der Heijden et al., 2007). Besides, persistent sleep disturbance might not only be influential in attention-related EF, but also associated with insomnia diagnosis (Armstrong et al., 2014; Carpena et al., 2022). Moreover, the sleep abnormalities might negatively related to the physical, emotional and behavioral impairment in the population (Wajszilber et al., 2018). In current study, the positive effect in PA to sleep has been evidential that PA could possibly be served as a nature remedy in improving sleep quality and reducing the associated problems and impairments in young adolescent with ADHD. Therefore, future research is suggested to examine the potential relation between PA, sleep and executive function in young adolescent with ADHD.

Despite highlighting the positive impact of PA on sleep quality in young adolescents with ADHD, it is essential to acknowledge a significant limitation. The researchers did not assess the baseline physical activity level, such as the duration of daily PA over a one-week period, and the participants' jogging skill level prior to randomization or as criteria for inclusion or exclusion. This omission raises concerns regarding the maintenance of similar physical activity and jogging skill levels between the two groups. Without proper control, it becomes challenging to determine the specific effects of the treatment. Future studies should incorporate these assessments at baseline to address this issue. Additionally, it is worth noting that the current randomized controlled trial (RCT) protocol was not published in advance. To enhance the validity and reliability of future similar studies, it is recommended to consider publishing the protocol beforehand. Furthermore, a longitudinal study is suggested to examine the long-term effect of physical activity on sleep quality in the ADHD population and reduce the poor sleep quality persistency across the lifespan.

**Conclusion**

The 12-week jogging program in the present study improved certain sleep quality parameters in children with ADHD. Physicians and educators might consider advocating regular physical activity to young adolescent with ADHD to reduce their symptoms in sleep disturbance.

**Chapter 5: General Discussion**

The objectives of current study purposed to investigate the impact of physical activity intervention on motor proficiency and sleep problems in children with ADHD. The study completed with 3 original research articles and the linked connection of each article is discussed in the chapter. Moreover, the implication, future research direction and limitations are discussed.

Current study investigated the impact of physical activity, motor proficiency and sleep problem in children with ADHD. Consist with the hypothesis, physical activity, motor proficiency, and sleep problems are interrelated in children with ADHD. Current study has demonstrated that physical activity can improve both motor proficiency and sleep quality in children with ADHD, leading to an enhancement in overall functioning.

In general, the results of the study could generally respond to the research questions and hypothesis. First, the findings indicated the positive results of physical activity on motor proficiency. Despite the fact that Chapter 2 was not a RCT designed study, it presented the effect of physical activity on gross motor composites, including locomotor skills and object control skills. Due to the design of the instrument, the changes of fine motor skill could not be reflect in the study. Meanwhile, Chapter 3 synthesised and summarized the effect of physical activity on motor proficiency. It indicated with the effect size and showed the potential direction in designing physical activity programme to children with ADHD. Furthermore, Chapter 4 first presented the results that physical activity intervention were significant to sleep quality with particular parameters, including sleep duration, sleep efficiency and sleep onset latency.

Meanwhile, in Chapter 2, it was surprisingly observed the behavioural changes in children with ADHD. Since the behavioural and symptoms changes were not the initial variables of the study design. Therefore, the changes were only recorded by observation without a subjective instrument. Through the observation, the effect of physical activity on children with ADHD could not only limit to motor proficiency and sleep quality, but explore the behavioural and symptoms changes.

**5.1 The study sequences**

With the format of folio, the thesis has included three original studies to examine the research questions. This section discussed about the sequence of the studies.

The first part of the thesis was a case study (Chapter 2) with a limited sample size (n=3) and conducted during the pandemic. As the first study of the thesis, the results of Chapter 2 consolidated the direction of the thesis. Despite the sample size, the effect of physical activity positively enhanced the sleep quality and motor proficiency in children with ADHD. Without prior study, Chapter 2 provided evidence in constructing a randomized control trial in the coming chapter.

Followed by Chapter 2, the systematic review and meta-analysis (Chapter 3) revealed the effect of physical activity on motor proficiency and the composites. The results of Chapter 3 confirmed the effects of physical activity on motor proficiency and aligned with the results in Chapter 2.

Lastly, Chapter 4 was a randomized control trial to examine the effect of physical activity on sleep quality in children with ADHD. Unlike Chapter 2, Chapter 4 applied both subjective and objective instruments, PSQI and Actigraphy, for measuring the sleep quality. The significant results of the RCT confirmed the direction of the thesis direction.

**5.2 The Lifelong Physical Activity Model**

The thesis applied the Lifelong Physical Activity Model by Hulteen et al. (2018). It explained the potential lifespan contribution between movement skill development and physical health. In the chapters, it indicated the improvement of motor proficiency in children with ADHD resulting from the moderate to vigorous intensity physical activity intervention. Furthermore, the results aligned with the previous research in investigating the effect of physical activity on motor proficiency in children with ADHD (Pan, Chang, et al., 2017; Pan et al., 2019) and developed the foundational movement skills.

In Chapter 2, the study designed with jogging as the intervention while Chapter 4 reviewed various of moderate to vigorous intensity physical activity, including aquatic training and table tennis. The types of physical activity included as both traditional and non-traditional foundational movement skills in the model. The findings in the above chapters indicated the significant effects of moderate to vigorous physical activity on motor proficiency. Consequently, it could fill the proficiency barrier in the model and encouraged the specialized movement skills development in the population. The improved foundational movement skills and specialized movement skills may contribute to promote a “lifetime of physical activity” in children with ADHD which may foster their physical health.

Previously, research indicated the limited physical activity in the ADHD population and lead to a potential risk in physical and mental health (Björk et al., 2018; Ogrodnik et al., 2023). Based on the model, the results of current studies were evidential in a bi-directional effect in physical activity and motor proficiency. Through the regular physical activity participation, the motor proficiency would be enhanced. With the improvement, the proficiency barrier was reduced, help fostering the specialized movement skills, and promote lifetime physical activity (Hulteen et al., 2018). Although the thesis was limited with no longitudinal study, the 12-week physical activity intervention and the results in the systematic review (Chapter 3) have well-documented in the potential of regular physical activity that could benefit to the motor proficiency development.

**5.3 Physical activity, motor proficiency and sleep problems in children with ADHD**

Chapter 2 and 3 conducted with the focus on motor proficiency with the results that aligned with previous research by different scholars that physical activity interventions were beneficial in motor proficiency in children with ADHD (Kosari et al., 2013; Pan, Chang, et al., 2017; Pan et al., 2019; Ziereis & Jansen, 2015). Other than indicating the specific motor proficiency composites, Chapter 3 also suggested weekly moderate to vigorous intensity physical activity in 45 – 60 minutes to children with ADHD. With the meaningful results, the potential physical activity prescription for children with ADHD was disc

Based on the previous chapters and studies, the case study of Chapter 4 has shown the possible impact of physical activity on motor proficiency and sleep problems. Moreover, Chapter 4 summarized the positive effects of physical activity in both motor proficiency and sleep problems. With a 12-week moderate to vigorous intensity physical activity intervention (i.e. basketball), the results of the RCT revealed the tendency of physical activity impact on motor proficiency and sleep problems in children with ADHD. The consisted findings with the study by Tse et al. (2019) and results of Chapter 4 revealed that PA is beneficial to reduce sleep problems not only in children with ASD, but also with ADHD.

The interconnection between motor proficiency and sleep problems in the treatment of children with ADHD is of utmost importance since the factors can mutually affect each other and impact the overall well-being of the population (Li et al., 2021; Liang, Li, Wong, Sum, Wang, et al., 2021). Previous studies have emphasized the significance in considering both the motor proficiency and sleep problems in the children with ADHD (Liang, Li, Wong, Sum, Wang, et al., 2021; Papadopoulos et al., 2019), which consist with the findings of Chapter 4.

From the previous two chapters, the interconnection between motor proficiency and sleep problems in children with ADHD can be discussed as the followings. Sleep problems, such as insomnia, are common in children with ADHD. It can worsen motor proficiency difficulties. Poor sleep quality could result in fatigue and lack of focus, making it difficult for children with ADHD to engage in physical activity and practice their motor skills (Cortese et al., 2013). Moreover, sleep problems are common in children with ADHD, and can exacerbate difficulties with motor proficiency. Poor sleep can result in fatigue and lack of focus, making it difficult for children with ADHD to engage in physical activity and practice their motor skills (Cortese et al., 2013). Furthermore, anxiety and hyperactivity, common symptoms of ADHD, can also contribute to sleep problems in children with the disorder (Cortese et al., 2013).

Addressing the motor proficiency and sleep problems is crucial for optimizing the non-pharmacological treatment outcomes. In current study, chapters targeted on motor proficiency have been shown to improve motor abilities (Liu et al., 2023). The possible implications is discussed in next session.

**5.3 The underlying mechanism of the effects of physical activity in motor proficiency**

In terms of motor proficiency, one of the possible key factors of the effect of PA in motor proficiency mainly related to neuroscience. Dahan et al. (2018) has stated the motor regulation process and the positive result in the electroencephalogram (EEG) to prove the effects of PA while Pan et al. (2019) suggested the effects of physical activity may foster brain health. Furthermore, Lojovich (2010) and Knaepen et al. (2010) have outlined the neurological impacts of exercise, which involve the elevation of brain-derived neurotrophic factor. These combined factors appear to play a role in promoting cell growth and neural adaptability, which suggested by Halperin et al. (2012).

Besides, cognition and EF are the possible underlying mechanism which suggested by previous studies (Den Heijer et al., 2017; Pan et al., 2019). Engaging in physical activity has been shown to have beneficial effects on cognitive function, encompassing areas such as attention, memory, and executive functions (Hillman et al., 2008; Tomporowski, 2003). These cognitive processes are integral to motor proficiency, as they aid in motor planning, sequencing, and the capacity to adjust movements in response to environmental changes. Through its positive impact on cognitive function, physical activity indirectly promotes the development and execution of motor skills, facilitating overall motor proficiency.

Nonetheless, the specific interaction between physical activity and EEG and cognition could not be clarified in the current study, due to the absence of biological samples from the participants. Therefore, the underlying mechanisms between physical activity and motor proficiency remains uncertain.

**5.4 The underlying mechanism of the effects of physical activity in sleep problems**

Previously, the secretion level of melatonin after physical activity in children with neurodevelopmental disorder one of the possible explanations in improving sleep problems form the above findings (Lee et al., 2014; Tse et al., 2018). Melatonin, a hormone that plays a vital role in regulating the body's internal clock and promoting natural sleep onset and maintenance, exhibits distinct patterns of secretion throughout the night (Van Der Stigchel et al., 2007). Typically, melatonin levels rise shortly after darkness sets in, peak during the mid-night hours, and gradually decline during the early morning (Weiss et al., 2006).

To address this issue, long-term melatonin supplementation has been recommended as a treatment for insomnia in children and adolescents with ADHD over extended periods of time (Hoebert et al., 2009). Additionally, previous studies by Montaruli et al. (2017) have suggested that physical activity, particularly morning and evening sessions, may help regulate melatonin levels and facilitate adjustment of the circadian rhythm. In a study conducted by Tse et al. (2018) on children with autism spectrum disorder (ASD), a 12-week physical activity intervention was implemented, indicating a positive correlation between regular physical activity and melatonin secretion, resulting in improved sleep quality.

However, the specific interaction between physical activity and melatonin levels could not be determined in the current study, as no biological samples, such as urine, were collected from the participants. Therefore, the relationship between physical activity, melatonin, and sleep effectiveness remains uncertain. The current study, Chapter 3 and 4, provides evidence supporting the positive impact of physical activity on sleep quality, suggesting that physical activity could serve as a natural intervention to improve sleep quality and reduce associated problems and impairments in young adolescents with ADHD.

## 5.5 Implications

There are numerous of implications that can be advocated with the previous results. The series of studies highlight the positive significance of promoting regular physical activity in children with ADHD under different circumstances.

By considering both motor proficiency and sleep problems in children with ADHD, healthcare professionals and educators can provide a comprehensive and personalized approach to address the uniqueness of the children. For example, to provide additional extra curriculum activities related to physical activity to the population after school. The combination of physical activity and sleep hygiene practices, children with ADHD may experience an improved motor proficiency and better sleep patterns. The holistic approach ensures that the child's motor proficiency and sleep patterns are optimized and leading to an improved overall functioning and well-being.

Based on the results of the above chapters, a specific dosage and frequency of physical activity prescription could be recommended to children with ADHD. In the previous chapter, pharmacological medication and physiotherapy are the common treatments in children with ADHD which may become one of the financial burdens. Additionally, the study has provided evidence in promoting regular physical activity in children with ADHD. Refer to the previous results in the study, an additional weekly moderate to vigorous intensity physical activity participation, with the duration of 45 - 60 minutes, encourage the improvement in motor proficiency and sleep quality in children with ADHD. The design of the activity could both focusing on the motor proficiency development and social interaction.

In terms of the type of physical activity, with the support of the Lifelong Physical Activity Model (Hulteen et al., 2018), the physical activity programme can target on the foundational motor proficiency first, such as running, kicking, and swimming. Thus, in school setting, the conventional training could already be beneficial to the motor proficiency in children with ADHD.

Since traditional motor skills could help developing the specialized motor skills then promoting lifetime physical activity, parents and educators are recommended to deliver to physical activity program with the traditional motor skills first. The physical activity could be as simple as cycling and swimming, which have less restrictions and easy to implement. Afterward, specialized motor skills can be the target of the physical activity programme to consolidate the motor skills required in a sport. For instance, after the child learn how to kick the football, he could learn passing and shooting as the next stage of the physical activity program. The progressive learning process could consolidate the foundational motor proficiency into specialized motor proficiency, then promote a lifelong physical activity in the ADHD population.

The results showed the evidence in advocating additional physical activity programme regularly, which can be organized by schools, parents or even activity groups.

## Chapter 6: Conclusions

In conclusion, the systematic review and meta-analysis suggest that physical activity interventions have a positive impact on motor proficiency in children and adolescents with ADHD. The following chapters also indicate that physical activity can improve sleep quality parameters in children with ADHD. These findings support the promotion of regular physical activity in individuals with ADHD, emphasizing its importance for overall well-being. However, the study has limitations, such as the niche sample size and a lack of research in adolescents and adults with ADHD. Future studies should address these limitations and explore optimal duration and intensity of physical activity interventions. Larger sample sizes and randomized controlled trials are needed to further investigate the benefits of physical activity intervention in this population.

### 6.1 Future directions

Present study examined the effects of physical activity in motor proficiency and sleep problems in children with ADHD. The following future directions are suggested in exploring the maximal effect of physical activity in children with ADHD.

First, the future research is suggested to examine the mediate or moderate the effects of physical activity, motor proficiency and sleep quality in children with ADHD. Previously, a study by Liang, Li, Wong, Sum, Wang, et al. (2021) has presented the positive mediating effect of sleep to executive functions. Similar model can be designed for motor proficiency and sleep quality. Moreover, future study can explore whether factors such as cognitive function, executive functioning, or psychosocial variables mediate or moderate the effects of physical activity on these outcomes. Through the mediating analysis, a theoretical model in the effects of physical activity can evaluate whether the proposed theoretical framework adequately explains the observed relationships so as to maximise the effect of physical activity and promote well-being and better quality of life in the ADHD population.

Second, the longitudinal studies are suggested in examining the long-term effects of physical activity on motor proficiency and sleep quality in children with ADHD. The longitudinal study would allow observation in the outcome changes over time and assess the sustainability of the benefits of physical activity. By collecting data at different stages of development, the natural trajectory of these outcomes can be captured and determined how physical activity may influence these changes. Moreover, the longitudinal design enable the investigation of the effects of physical activity on motor proficiency and sleep quality persist or diminish over time.

Third, other than motor proficiency and sleep quality, behavioural and ADHD symptoms could be one of the future directions. By analysing the effects on the above mentioned variables, it helps completing the model of physical activity in children with ADHD. Although some of the current studies investigated the direct relationship of the variable and physical activity, limited study has specifically focus on the problems faced by the ADHD population and examine the moderating effect of each variables.

Forth, studies in examining the underlying mechanisms of the effect of physical activity on motor proficiency and sleep quality are necessary for clarification and maximization the effect physical activity. By understanding the underlying mechanisms, a more specific physical activity programme and prescription can be designed. Moreover, studying the underlying mechanisms of the effect of physical activity on motor proficiency and sleep quality can also contribute to the development of complementary interventions. For example, if research reveals that physical activity improves motor skills through enhanced neural plasticity, interventions such as cognitive training or sensory integration therapy could be combined with physical activity programs to further enhance motor proficiency.

Other than the Lifelong Physical Activity Model, one of the future directions recommended was constructing a theoretical framework to connect physical activity, motor proficiency and sleep quality in children with ADHD. There was no theoretical framework connecting the above variables in both TD and ADHD population. By constructing the theoretical framework, the connection of the above variables could be well explained and deeply understand the effect of physical activity.

**6.2 Limitations**

There were some limitations in the study that should be aware. In Chapter 2, there is a lack of objective measurement of sleep quality. The sleep quality only recorded by the parents-reported PSQI without objective instrument (i.e., the Actigraphy). Furthermore, the researchers did not assess the initial physical activity level and jogging skill of each participant before randomization, which could have ensured that both groups had similar daily physical activity and jogging skill levels. This lack of control makes it challenging to determine the true effects of the treatment. To address this issue, future studies should include baseline assessments to account for these factors.

In Chapter 3, the insufficient information of the included studies was an obstacle in conducting a moderating analysis. Meanwhile, part of the studies only reported the overall score of the motor proficiency test, instead of the individual scores for each composite.

Moreover, due to the limitation of RevMan, the utilization of SMD may overestimate the actual effect while Hedge’s adjusted g would present a more precise result. Additionally, the intervention protocols in Chapter 2 and 4 were not published in advance, and it is suggested that future studies of a similar nature should consider publishing the protocol beforehand to enhance the study's validity and reliability. Due to the pandemic, the sample of size of Chapter 2 was niche and only allowed to conduct a case study.

**References**


American Psychiatric Association, D. S. M. T. F. (2013). *Diagnostic and statistical manual of mental disorders : DSM-5* (5th ed. ed.). American Psychiatric Association.

Antczak, D., Lonsdale, C., Lee, J., Hilland, T., Duncan, M. J., del Pozo Cruz, B., Hulteen, R. M., Parker, P. D., & Sanders, T. (2020). Physical activity and sleep are inconsistently related in healthy children: A systematic review and meta-analysis. *Sleep Medicine Reviews, 51*, 101278.

Armstrong, J. M., Ruttle, P. L., Klein, M. H., Essex, M. J., & Benca, R. M. (2014). Associations of child insomnia, sleep movement, and their persistence with mental health symptoms in childhood and adolescence. *Sleep, 37*(5), 901-909.

Arnold, L. E., Abikoff, H. B., Cantwell, D. P., Conners, C. K., Elliott, G., Greenhill, L. L., Hechtman, L., Hinshaw, S. P., Hoza, B., Jensen, P. S., Kraemer, H. C., March, J. S., Newcorn, J. H., Pelham, W. E., Richters, J. E., Schiller, E., Severe, J. B., Swanson, J. M., Vereen, D., & Wells, K. C. (1997). National Institute of Mental Health Collaborative Multimodal Treatment Study of Children With ADHD (the MTA): Design Challenges and Choices. *Arch Gen Psychiatry, 54*(9), 865-870. https://doi.org/10.1001/archpsyc.1997.01830210113015

Baldursdottir, B., Taehtinen, R. E., Sigfusdottir, I. D., Krettek, A., & Valdimarsdottir, H. B. (2017). Impact of a physical activity intervention on adolescents' subjective sleep quality: a pilot study. *Global health promotion, 24*(4), 14-22. https://doi.org/10.1177/1757975915626112

Becker, S. P. (2020). ADHD and sleep: Recent advances and future directions. *Current opinion in psychology, 34*, 50-56.

Benzing, V., Chang, Y.-K., & Schmidt, M. (2018). Acute Physical Activity Enhances Executive Functions in Children with ADHD. *Scientific reports, 8*(1), 1-10. https://doi.org/10.1038/s41598-018-30067-8

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

Bioulac, S., Chaufton, C., Taillard, J., Claret, A., Sagaspe, P., Fabrigoule, C., Bouvard, M. P., & Philip, P. (2015). Excessive daytime sleepiness in adult patients with ADHD as measured by the maintenance of wakefulness test, an electrophysiologic measure. *The journal of clinical psychiatry, 76*(7), 943-948. https://doi.org/10.4088/JCP.14m09087

Björk, A., Rönngren, Y., Selander, J., Vinberg, S., Hellzen, O., & Olofsson, N. (2018, 2018/01/01). Health, lifestyle habits, and physical fitness among adults with ADHD compared with a random sample of a Swedish general population. *Society, Health & Vulnerability, 9*(1), 1553916. https://doi.org/10.1080/20021518.2018.1553916

Boreham, C., & Riddoch, C. (2001). The physical activity, fitness and health of children. *J SPORT SCI, 19*(12), 915-929. https://doi.org/10.1080/026404101317108426

Bracken, B. A. (1993). *Wechsler intelligence scale for children* (3rd ed.). Psychoeducational Corp.

Bruininks, R., Bruininks, B. (2005). *Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition (BOT-2): Manual.* AGS Publishing.

Buderath, P., Gärtner, K., Frings, M., Christiansen, H., Schoch, B., Konczak, J., Gizewski, E. R., Hebebrand, J., & Timmann, D. (2009, 2009/02/01/). Postural and gait performance in children with attention deficit/hyperactivity disorder. *Gait & Posture, 29*(2), 249-254. https://doi.org/https://doi.org/10.1016/j.gaitpost.2008.08.016

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J. P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., Lambert, E., Leitzmann, M., Milton, K., Ortega, F. B., Ranasinghe, C., Stamatakis, E., Tiedemann, A., Troiano, R. P., van der Ploeg, H. P., Wari, V., & Willumsen, J. F. (2020, Dec). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med*, *54*(24), 1451-1462. https://doi.org/10.1136/bjsports-2020-102955

Bunford, N., Evans, S. W., & Langberg, J. M. (2018). Emotion dysregulation is associated with social impairment among young adolescents with ADHD. *Journal of Attention Disorders*, *22*(1), 66-82.

Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh sleep quality index: A new instrument for psychiatric practice and research. *Psychiatry Res*, *28*(2), 193-213. https://doi.org/10.1016/0165-1781(89)90047-4

Carpena, M. X., Matijasevich, A., Loret de Mola, C., Santos, I. S., Munhoz, T. N., & Tovo-Rodrigues, L. (2022, 2022/01/01/). The effects of persistent sleep disturbances during early childhood over adolescent ADHD, and the mediating effect of attention-related executive functions: Data from the 2004 Pelotas Birth Cohort. *Journal of Affective Disorders*, *296*, 175-182. https://doi.org/https://doi.org/10.1016/j.jad.2021.09.053

Caye, A., Swanson, J. M., Coghill, D., & Rohde, L. A. (2019, 2019/03/01). Treatment strategies for ADHD: an evidence-based guide to select optimal treatment. *Molecular Psychiatry*, *24*(3), 390-408. https://doi.org/10.1038/s41380-018-0116-3

Cénat, J. M., Kokou-Kpolou, C. K., Blais-Rochette, C., Morse, C., Vandette, M.-P., Dalexis, R. D., Darius, W. P., Noorishad, P.-G., Labelle, P. R., & Kogan, C. S. (2022). Prevalence of ADHD among Black Youth Compared to White, Latino and Asian Youth: A Meta-Analysis. *Journal of clinical child and adolescent psychology*, *ahead-of-print*(ahead-of-print), 1-16. https://doi.org/10.1080/15374416.2022.2051524

Chang, Y.-K., Hung, C.-L., Huang, C.-J., Hatfield, B. D., & Hung, T.-M. (2014). Effects of an Aquatic Exercise Program on Inhibitory Control in Children with ADHD: A Preliminary Study. *ARCH CLIN NEUROPSYCH*, *29*(3), 217-223. https://doi.org/10.1093/arclin/acu003

Cherkasova, M. V., Roy, A., Molina, B. S. G., Scott, G., Weiss, G., Barkley, R. A., Biederman, J., Uchida, M., Hinshaw, S. P., Owens, E. B., & Hechtman, L. (2022, 2022/03/01/). Review: Adult Outcome as Seen Through Controlled Prospective Follow-up Studies of Children With Attention-Deficit/Hyperactivity Disorder Followed Into Adulthood. *Journal of the American Academy of Child & Adolescent Psychiatry, 61*(3), 378-391. https://doi.org/https://doi.org/10.1016/j.jaac.2021.05.019

Cheung, K. K. W., Wong, I. C. K., Ip, P., Chan, P. K. L., Lin, C. H. Y., Wong, L. Y. L., & Chan, E. W. (2015). Experiences of adolescents and young adults with ADHD in Hong Kong: treatment services and clinical management. *BMC Psychiatry, 15*(1), 95-95. https://doi.org/10.1186/s12888-015-0478-x

Chueh, T.-Y., Hsieh, S.-S., Tsai, Y.-J., Yu, C.-L., Hung, C.-L., Benzing, V., Schmidt, M., Chang, Y.-K., Hillman, C. H., & Hung, T.-M. (2022, 2022/01/01/). Effects of a single bout of moderate-to-vigorous physical activity on executive functions in children with attention-deficit/hyperactivity disorder: A systematic review and meta-analysis. *Psychology of Sport and Exercise, 58*, 102097. https://doi.org/https://doi.org/10.1016/j.psychsport.2021.102097

Clement-Carbonell, V., Portilla-Tamarit, I., Rubio-Aparicio, M., & Madrid-Valero, J. J. (2021). Sleep quality, mental and physical health: A differential relationship. *Int J Environ Res Public Health, 18*(2), 1-8. https://doi.org/10.3390/ijerph18020460

Cohen-Zion, M., & Ancoli-Israel, S. (2004, Oct). Sleep in children with attention-deficit hyperactivity disorder (ADHD): a review of naturalistic and stimulant intervention studies. *Sleep Med Rev, 8*(5), 379-402. https://doi.org/10.1016/j.smrv.2004.06.002

Committee on Quality Improvement, S. o. A.-D. H. D. (2000). Clinical Practice Guideline: Diagnosis and Evaluation of the Child With Attention-Deficit/Hyperactivity Disorder. *Pediatrics, 105*(5), 1158-1170. https://doi.org/10.1542/peds.105.5.1158

Cook, B. G., Li, D., & Heinrich, K. M. (2015). Obesity, Physical Activity, and Sedentary Behavior of Youth With Learning Disabilities and ADHD. *J LEARN DISABIL-US, 48*(6), 563-576. https://doi.org/10.1177/0022219413518582

Corkum, P., Begum, E. A., Rusak, B., Rajda, M., Shea, S., MacPherson, M., Williams, T., Spurr, K., & Davidson, F. (2020, Mar). The Effects of Extended-Release Stimulant Medication on Sleep in Children with ADHD. *J Can Acad Child Adolesc Psychiatry, 29*(1), 33-43.

Corkum, P., Davidson, F., & Macpherson, M. (2011, Jun). A framework for the assessment and treatment of sleep problems in children with attention-deficit/hyperactivity disorder. *Pediatr Clin North Am, 58*(3), 667-683. https://doi.org/10.1016/j.pcl.2011.03.004

Cortese, S., Faraone, S. V., Konofal, E., & Lecendreux, M. (2009). Sleep in Children With Attention-Deficit/Hyperactivity Disorder: Meta-Analysis of Subjective and Objective Studies. *Journal of the American Academy of Child and Adolescent Psychiatry, 48*(9), 894-908. https://doi.org/10.1097/CHI.0b013e3181ae09c9

Cortese, S. M. D. P. D., Brown, T. E. P. D., Corkum, P. P. D., Gruber, R. P. D., O'Brien, L. M. P. D., Stein, M. P. D., Weiss, M. M. D. P. D., & Owens, J. M. D. M. P. H. (2013). Assessment and Management of Sleep Problems in Youths With Attention-Deficit/Hyperactivity Disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, *52*(8), 784-796. https://doi.org/10.1016/j.jaac.2013.06.001

Dahan, A., Ryder, C. H., & Reiner, M. (2018, 2018/05/15/). Components of Motor Deficiencies in ADHD and Possible Interventions. *Neuroscience*, *378*, 34-53. https://doi.org/https://doi.org/10.1016/j.neuroscience.2016.05.040

De Crescenzo, F., Armando, M., Mazzone, L., Ciliberto, M., Sciannamea, M., Figueroa, C., Janiri, L., Quested, D., & Vicari, S. (2014, 2014/03/01). The use of actigraphy in the monitoring of methylphenidate versus placebo in ADHD: a meta-analysis. *ADHD Attention Deficit and Hyperactivity Disorders*, *6*(1), 49-58. https://doi.org/10.1007/s12402-013-0122-x

Den Heijer, A. E., Groen, Y., Tucha, L., Fuermaier, A. B., Koerts, J., Lange, K. W., Thome, J., & Tucha, O. (2017). Sweat it out? The effects of physical exercise on cognition and behavior in children and adults with ADHD: a systematic literature review. *Journal of Neural Transmission*, *124*, 3-26.

Denckla, M. B., & Rudel, R. G. (1978). Anomalies of motor development in hyperactive boys. *Annals of Neurology*, *3*(3), 231-233. https://doi.org/https://doi.org/10.1002/ana.410030308

Diaz-Roman, A., Mitchell, R., & Cortese, S. (2018). Sleep in adults with ADHD: systematic review and meta-analysis of subjective and objective studies. *Neuroscience & Biobehavioral Reviews*, *89*, 61-71.

Dijk, H. H., Wessels, L. M., Constanti, M., van den Hoofdakker, B. J., Hoekstra, P. J., & Groenman, A. P. (2021). Cost-effectiveness and cost utility of treatment of attention-deficit/hyperactivity disorder: a systematic review. *Journal of child and adolescent psychopharmacology*, *31*(9), 578-596.

Dolezal, B. A., Neufeld, E. V., Boland, D. M., Martin, J. L., & Cooper, C. B. (2017). Interrelationship between Sleep and Exercise: A Systematic Review. *Adv Prev Med*, *2017*, 1364387-1364314. https://doi.org/10.1155/2017/1364387

Dworak, M., Wiater, A., Alfer, D., Stephan, E., Hollmann, W., & Strüder, H. K. (2007). Increased slow wave sleep and reduced stage 2 sleep in children depending on exercise intensity. *SLEEP MED*, *9*(3), 266-272. https://doi.org/10.1016/j.sleep.2007.04.017

Efird, J. (2011). Blocked randomization with randomly selected block sizes. *International journal of environmental research and public health*, *8*(1), 15-20. https://doi.org/10.3390/ijerph8010015

Efron, D., Lycett, K., & Sciberras, E. (2014, 2014/04/01/). Use of sleep medication in children with ADHD. *Sleep Medicine, 15*(4), 472-475. https://doi.org/https://doi.org/10.1016/j.sleep.2013.10.018

Egeland, J., Ueland, T., & Johansen, S. (2012). Central Processing Energetic Factors Mediate Impaired Motor Control in ADHD Combined Subtype But Not in ADHD Inattentive Subtype. *Journal of learning disabilities, 45*(4), 361-370. https://doi.org/10.1177/0022219411407922

Egger, M., Smith, G. D., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *BMJ, 315*(7109), 629-634. https://doi.org/10.1136/bmj.315.7109.629

Ekstedt, M., Nyberg, G., Ingre, M., Ekblom, Ö., & Marcus, C. (2013). Sleep, physical activity and BMI in six to ten-year-old children measured by accelerometry: A cross-sectional study. *Int J Behav Nutr Phys Act, 10*(1), 82-82. https://doi.org/10.1186/1479-5868-10-82

Faraone, S. V., Banaschewski, T., Coghill, D., Zheng, Y., Biederman, J., Bellgrove, M. A., Newcorn, J. H., Gignac, M., Al Saud, N. M., Manor, I., Rohde, L. A., Yang, L., Cortese, S., Almagor, D., Stein, M. A., Albatti, T. H., Aljoudi, H. F., Alqahtani, M. M. J., Asherson, P., Atwoli, L., Bölte, S., Buitelaar, J. K., Crunelle, C. L., Daley, D., Dalsgaard, S., Döpfner, M., Espinet, S., Fitzgerald, M., Franke, B., Gerlach, M., Haavik, J., Hartman, C. A., Hartung, C. M., Hinshaw, S. P., Hoekstra, P. J., Hollis, C., Kollins, S. H., Sandra Kooij, J. J., Kuntsi, J., Larsson, H., Li, T., Liu, J., Merzon, E., Mattingly, G., Mattos, P., McCarthy, S., Mikami, A. Y., Molina, B. S. G., Nigg, J. T., Purper-Ouakil, D., Omigbodun, O. O., Polanczyk, G. V., Pollak, Y., Poulton, A. S., Rajkumar, R. P., Reding, A., Reif, A., Rubia, K., Rucklidge, J., Romanos, M., Ramos-Quiroga, J. A., Schellekens, A., Scheres, A., Schoeman, R., Schweitzer, J. B., Shah, H., Solanto, M. V., Sonuga-Barke, E., Soutullo, C., Steinhausen, H. C., Swanson, J. M., Thapar, A., Tripp, G., van de Glind, G., van den Brink, W., Van der Oord, S., Venter, A., Vitiello, B., Walitza, S., & Wang, Y. (2021, Sep). The World Federation of ADHD International Consensus Statement: 208 Evidence-based conclusions about the disorder. *Neurosci Biobehav Rev, 128*, 789-818. https://doi.org/10.1016/j.neubiorev.2021.01.022

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007, May). G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods, 39*(2), 175-191. https://doi.org/10.3758/bf03193146

Feldman, H. M., & Reiff, M. I. (2014). Attention Deficit–Hyperactivity Disorder in Children and Adolescents. *The New England journal of medicine, 370*(9), 838-846. https://doi.org/10.1056/NEJMcp1307215

Fliers, E., Rommelse, N., Vermeulen, S. H. H. M., Altink, M., Buschgens, C. J. M., Faraone, S. V., Sergeant, J. A., Franke, B., & Buitelaar, J. K. (2008). Motor coordination problems in children and adolescents with ADHD rated by parents and teachers: effects of age and gender. *J Neural Transm, 115*(2), 211-220. https://doi.org/10.1007/s00702-007-0827-0

Fliers, E. A., Franke, B., Lambregts-Rommelse, N. N. J., Altink, M. E., Buschgens, C. J. M., Nijhuis-van der Sanden, M. W. G., Sergeant, J. A., Faraone, S. V., & Buitelaar, J. K. (2010). Undertreatment of Motor Problems in Children with ADHD. *CHILD ADOL MENT H-UK*, *15*(2), 85-90. https://doi.org/10.1111/j.1475-3588.2009.00538.x

Gallotta, M. C., Baldari, C., & Guidetti, L. (2018). Motor proficiency and physical activity in preschool girls: a preliminary study. *Early child development and care*, *188*(10), 1381-1391. https://doi.org/10.1080/03004430.2016.1261337

Gapin, J. I., Labban, J. D., & Etnier, J. L. (2011, Jun). The effects of physical activity on attention deficit hyperactivity disorder symptoms: the evidence. *Prev Med*, *52 Suppl 1*, S70-74. https://doi.org/10.1016/j.ypmed.2011.01.022

Golubovic, S., Milutinovic, D., & Golubovic, B. (2014). Benefits of physical exercises in developing certain fitness levels in children with hyperactivity. *Journal of psychiatric and mental health nursing*, *21*(7), 594-600. https://doi.org/10.1111/jpm.12091

Goulardins, J. B., Marques, J. C. B., Casella, E. B., Nascimento, R. O., & Oliveira, J. A. (2013). Motor profile of children with attention deficit hyperactivity disorder, combined type. *Research in Developmental Disabilities*, *34*(1), 40-45. https://doi.org/10.1016/j.ridd.2012.07.014

Goulardins, J. B., Marques, J. C. B., & De Oliveira, J. A. (2017). Attention Deficit Hyperactivity Disorder and Motor Impairment: A Critical Review. *Perceptual and Motor Skills*, *124*(2), 425-440. https://doi.org/10.1177/0031512517690607

Goulardins, J. B., Rigoli, D., Piek, J. P., Kane, R., Palácio, S. G., Casella, E. B., Nascimento, R. O., Hasue, R. H., & Oliveira, J. A. (2016). The relationship between motor skills, ADHD symptoms, and childhood body weight. *Research in Developmental Disabilities*, *55*, 279-286. https://doi.org/10.1016/j.ridd.2016.05.005

Greever, C. J., Ahmadi, M., Sirard, J., & Alhassan, S. (2017). Associations among physical activity, screen time, and sleep in low socioeconomic status urban girls. *Preventive medicine reports*, *5*(C), 275-278. https://doi.org/10.1016/j.pmedr.2017.01.014

Gregory, A. M., & Sadeh, A. (2012). Sleep, emotional and behavioral difficulties in children and adolescents. *Sleep Med Rev*, *16*(2), 129-136. https://doi.org/10.1016/j.smrv.2011.03.007

Gruber, R., Cassoff, J., Frenette, S., Wiebe, S., & Carrier, J. (2012). Impact of sleep extension and restriction on children's emotional lability and impulsivity. *Pediatrics (Evanston)*, *130*(5), e1155-e1161. https://doi.org/10.1542/peds.2012-0564

Halperin, J. M., Bédard, A.-C. V., & Curchack-Lichtin, J. T. (2012). Preventive interventions for ADHD: a neurodevelopmental perspective. *Neurotherapeutics*, *9*, 531-541.

Hartung, J., Knapp, G., & Sinha, B. K. (2008). *Statistical meta-analysis with applications*. John Wiley & Sons.

Hassan, D. M., & Azzam, H. (2012). Sensory integration in attention deficit hyperactivity disorder: Implications to postural control. *Contemporary trends in ADHD research, 3*, 1-12.

Heijden, K. B., Smits, M. G., Someren, E. J. W., & Boudewijn Gunning, W. (2005). Prediction of melatonin efficacy by pretreatment dim light melatonin onset in children with idiopathic chronic sleep onset insomnia. *Journal of sleep research, 14*(2), 187-194. https://doi.org/10.1111/j.1365-2869.2005.00451.x

Higgins, J. P. T., & Green, S. (2011). *Cochrane Handbook for Systematic Reviews of Interventions*. [publisher not identified].

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008, 2008/01/01). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9*(1), 58-65. https://doi.org/10.1038/nrn2298

Hoebert, M., Van Der Heijden, K. B., Van Geijlswijk, I. M., & Smits, M. G. (2009). Long-term follow-up of melatonin treatment in children with ADHD and chronic sleep onset insomnia. *Journal of Pineal Research, 47*(1), 1-7. https://doi.org/https://doi.org/10.1111/j.1600-079X.2009.00681.x

Hoza, B., Martin, C. P., Pirog, A., & Shoulberg, E. K. (2016, 2016/11/02). Using Physical Activity to Manage ADHD Symptoms:The State of the Evidence. *Current Psychiatry Reports, 18*(12), 113. https://doi.org/10.1007/s11920-016-0749-3

Huang, W. Y., Wong, S. H. S., Sit, C. H. P., Wong, M. C. S., Sum, R. K. W., Wong, S. W. S., & Yu, J. J. (2018). Results from Hong Kong's 2018 report card on physical activity for children and youth. *Journal of physical activity & health, 15*(2), S370-S372. https://doi.org/10.1123/JPAH.2018-0468

Huang, Y.-S., Tsai, M.-H., & Guilleminault, C. (2011). Pharmacological treatment of ADHD and the short and long term effects on sleep. *CPD, 17*(15), 1450-1458. https://doi.org/10.2174/138161211796197179

Hulteen, R. M., Morgan, P. J., Barnett, L. M., Stodden, D. F., & Lubans, D. R. (2018). Development of foundational movement skills: A conceptual model for physical activity across the lifespan. *Sports medicine, 48*, 1533-1540.

Hurdiel, R., Watier, T., Honn, K., Pezé, T., Zunquin, G., & Theunynck, D. (2017). Effects of a 12-week physical activities programme on sleep in female university students. *Research in sports medicine, 25*(2), 191-196. https://doi.org/10.1080/15438627.2017.1282354

Hvolby, A. (2015, 2015/03/01). Associations of sleep disturbance with ADHD: implications for treatment. *ADHD Attention Deficit and Hyperactivity Disorders, 7*(1), 1-18. https://doi.org/10.1007/s12402-014-0151-0

Iivonen, K. S., Sääkslahti, A. K., Mehtälä, A., Villberg, J. J., Tammelin, T. H., Kulmala, J. S., & Poskiparta, M. (2013). Relationship between Fundamental Motor Skills and

Physical Activity in 4-Year-Old Preschool Children. *Perceptual and Motor Skills, 117*(2), 627-646. https://doi.org/10.2466/10.06.PMS.117x22z7

Jeyanthi, S., Arumugam, N., & Parasher, R. K. (2019, 2019/06/01). Effect of physical exercises on attention, motor skill and physical fitness in children with attention deficit hyperactivity disorder: a systematic review. *ADHD Attention Deficit and Hyperactivity Disorders, 11*(2), 125-137. https://doi.org/10.1007/s12402-018-0270-0

Jeyanthi, S., Arumugam, N., & Parasher, R. K. (2021). Effectiveness of structured exercises on motor skills, physical fitness and attention in children with ADHD compared to typically developing children-A pilot study. *eNeurologicalSci, 24*, 100357-100357. https://doi.org/10.1016/j.ensci.2021.100357

Ji, X., & Liu, J. (2016). Subjective sleep measures for adolescents: a systematic review. *Child: care, health and development, 42*(6), 825-839.

Jindal, I., Puyau, M., Adolph, A., Butte, N., Musaad, S., & Bacha, F. (2021). The relationship of sleep duration and quality to energy expenditure and physical activity in children. *Pediatric Obesity, 16*(6), e12751.

Jones, D., Innerd, A., Giles, E. L., & Azevedo, L. B. (2020). Association between fundamental motor skills and physical activity in the early years: A systematic review and meta-analysis. *Journal of sport and health science, 9*(6), 542-552. https://doi.org/10.1016/j.jshs.2020.03.001

Kaiser, M. L., Schoemaker, M. M., Albaret, J. M., & Geuze, R. H. (2015). What is the evidence of impaired motor skills and motor control among children with attention deficit hyperactivity disorder (ADHD)? Systematic review of the literature. *Research in Developmental Disabilities, 36*, 338-357. https://doi.org/10.1016/j.ridd.2014.09.023

Kamphaus, R. W., VanDeventer, M. C., Brueggemann, A., & Barry, M. (2007). Behavior Assessment System for Children-Second Edition. In *The clinical assessment of children and adolescents: A practitioner's handbook.* (pp. 311-326). Lawrence Erlbaum Associates Publishers.

Khan, M. K., Chu, Y. L., Kirk, S. F., & Veugelers, P. J. (2015). Are sleep duration and sleep quality associated with diet quality, physical activity, and body weight status? A population-based study of Canadian children. *Canadian Journal of Public Health, 106*, e277-e282.

Kidwell, K. M., Van Dyk, T. R., Lundahl, A., & Nelson, T. D. (2015). Stimulant Medications and Sleep for Youth With ADHD: A Meta-analysis. *Pediatrics, 136*(6), 1144-1153. https://doi.org/10.1542/peds.2015-1708

Kioumourtzoglou, E., Derri, V., Tzetzls, G., & Theodorakis, Y. (1998). Cognitive, Perceptual, and Motor Abilities in Skilled Basketball Performance. *Percept Mot Skills, 86*(3), 771-786. https://doi.org/10.2466/pms.1998.86.3.771

Kirov, R., & Brand, S. (2014). Sleep problems and their effect in ADHD. *EXPERT REV NEUROTHER*, *14*(3), 287-299. https://doi.org/10.1586/14737175.2014.885382

Knaepen, K., Goekint, M., Heyman, E. M., & Meeusen, R. (2010, Sep 1). Neuroplasticity - exercise-induced response of peripheral brain-derived neurotrophic factor: a systematic review of experimental studies in human subjects. *Sports Med*, *40*(9), 765-801. https://doi.org/10.2165/11534530-000000000-00000

Konofal, E., Lecendreux, M., & Cortese, S. (2010). Sleep and ADHD. *SLEEP MED*, *11*(7), 652-658. https://doi.org/10.1016/j.sleep.2010.02.012

Kosari, S., Hemayat-Talab, R., Arab-Ameri, E., & Keyhani, F. (2013). The Effect of Physical Exercise on the Development of Gross Motor Skills in Children with Attention Deficit / Hyperactivity Disorder [Research Article]. *Zahedan J Res Med Sci*, *15*(2), e93113. https://sites.kowsarpub.com/zjrms/articles/93113.html

Kratochvil, C. J., Lake, M., Pliszka, S. R., & Walkup, J. T. (2005). Pharmacological Management of Treatment-Induced Insomnia in ADHD. *Journal of the American Academy of Child and Adolescent Psychiatry*, *44*(5), 499-501. https://doi.org/10.1097/01.chi.0000155322.32500.3a

Kredlow, M. A., Capozzoli, M. C., Hearon, B. A., Calkins, A. W., & Otto, M. W. (2015, Jun). The effects of physical activity on sleep: a meta-analytic review. *J Behav Med*, *38*(3), 427-449. https://doi.org/10.1007/s10865-015-9617-6

Kularatna, S., Jadambaa, A., Senanayake, S., Brain, D., Hawker, N., Kasparian, N. A., Abell, B., Auld, B., Eagleson, K., & Justo, R. (2022). The cost of neurodevelopmental disability: scoping review of economic evaluation methods. *ClinicoEconomics and Outcomes Research*, 665-682.

Kumari, P., Selvam, P. S., & Karki, K. (2020). Effectiveness of physiotherapy techniques in children with attention-deficit hyperactivity disorder. *Drug Invention Today*, *13*(5).

Landry, B. W., & Driscoll, S. W. (2012, 2012/11/01/). Physical Activity in Children and Adolescents. *PM&R*, *4*(11), 826-832. https://doi.org/https://doi.org/10.1016/j.pmrj.2012.09.585

Langberg, J. M., Dvorsky, M. R., Becker, S. P., & Molitor, S. J. (2014). The impact of daytime sleepiness on the school performance of college students with attention deficit hyperactivity disorder (ADHD): a prospective longitudinal study. *Journal of sleep research*, *23*(3), 320-327. https://doi.org/10.1111/jsr.12121

Leahy, L. G. (2018). Diagnosis and treatment of ADHD in children vs adults: What nurses should know. *ARCH PSYCHIAT NURS*, *32*(6), 890-895. https://doi.org/10.1016/j.apnu.2018.06.013

Lee, H., Kim, S., & Kim, D. (2014). Effects of exercise with or without light exposure on sleep quality and hormone reponses. *J Exerc Nutrition Biochem*, *18*(3), 293-299. https://doi.org/10.5717/jenb.2014.18.3.293

Lee, S.-H., Kim, H.-B., & Lee, K.-W. (2019). Association between sleep duration and attention-deficit hyperactivity disorder: A systematic review and meta-analysis of observational studies☆. *Journal of Affective Disorders, 256*, 62-69.

Lelong, M., Zysset, A., Nievergelt, M., Luder, R., Götz, U., Schulze, C., & Wieber, F. (2021). How effective is fine motor training in children with ADHD? A scoping review. *BMC pediatrics, 21*(1), 490-490. https://doi.org/10.1186/s12887-021-02916-5

Li, R., Liang, X., Liu, F., Zhou, Z., Zhang, Z., Lu, Y., Wang, P., & Yang, B. (2021). Mediating Effect of Motor Competence on the Relationship between Physical Activity and Quality of Life in Children with Attention Deficit Hyperactivity Disorder. *Biomed Res Int, 2021*, 4814250. https://doi.org/10.1155/2021/4814250

Liang, X., Li, R., Wong, S. H. S., Sum, R. K. W., & Sit, C. H. P. (2021). The impact of exercise interventions concerning executive functions of children and adolescents with attention-deficit/hyperactive disorder: a systematic review and meta-analysis. *The international journal of behavioral nutrition and physical activity, 18*(1), 68-68. https://doi.org/10.1186/s12966-021-01135-6

Liang, X., Li, R., Wong, S. H. S., Sum, R. K. W., Wang, P., Yang, B., & Sit, C. H. P. (2021). Physical Activity and Executive Function in Children With ADHD: The Mediating Role of Sleep. *Front Pediatr, 9*, 775589. https://doi.org/10.3389/fped.2021.775589

Libutzki, B., Ludwig, S., May, M., Jacobsen, R. H., Reif, A., & Hartman, C. A. (2019). Direct medical costs of ADHD and its comorbid conditions on basis of a claims data analysis. *European Psychiatry, 58*, 38-44.

Liu, H. L. V., Sun, F., Anderson, D., & Tse, A. C. Y. (2023). The effect of physical activity intervention on motor proficiency in children and adolescents with ADHD: A systematic review and meta-analysis. *Child Psychiatry & Human Development*. https://doi.org/10.1007/s10578-023-01546-5

Lojovich, J. M. (2010). The relationship between aerobic exercise and cognition: is movement medicinal? *The Journal of head trauma rehabilitation, 25*(3), 184-192.

Lunsford-Avery, J. R., Krystal, A. D., & Kollins, S. H. (2016, 2016/12/01/). Sleep disturbances in adolescents with ADHD: A systematic review and framework for future research. *Clinical Psychology Review, 50*, 159-174. https://doi.org/https://doi.org/10.1016/j.cpr.2016.10.004

Lycett, K., Mensah, F. K., Hiscock, H., & Sciberras, E. (2014, 2014/11/01/). A prospective study of sleep problems in children with ADHD. *Sleep Medicine, 15*(11), 1354-1361. https://doi.org/https://doi.org/10.1016/j.sleep.2014.06.004

Magistro, D., Bardaglio, G., & Rabaglietti, E. (2015). Gross motor skills and academic achievement in typically developing children: The mediating effect of ADHD related Behaviours. *Cogniţie, creier, comportament, 19*(2), 149-163.

Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro Scale for Rating Quality of Randomized Controlled Trials. *Phys Ther, 83*(8), 713-721. https://doi.org/10.1093/ptj/83.8.713

Martin, C. A., Papadopoulos, N., Chellew, T., Rinehart, N. J., & Sciberras, E. (2019, 2019/10/01/). Associations between parenting stress, parent mental health and child sleep problems for children with ADHD and ASD: Systematic review. *Research in Developmental Disabilities, 93*, 103463. https://doi.org/https://doi.org/10.1016/j.ridd.2019.103463

McWilliams, S., Zhou, T., Stockler, S., Elbe, D., & Ipsiroglu, O. S. (2022, 2022/06/01/). Sleep as an outcome measure in ADHD randomized controlled trials: A scoping review. *Sleep Medicine Reviews, 63*, 101613. https://doi.org/https://doi.org/10.1016/j.smrv.2022.101613

Meltzer, L. J., & Mindell, J. A. (2006). Sleep and Sleep Disorders in Children and Adolescents. *Psychiatric Clinics, 29*(4), 1059-1076. https://doi.org/10.1016/j.psc.2006.08.004

Mercurio, L. Y., Amanullah, S., Gill, N., & Gjelsvik, A. (2021). Children With ADHD Engage in Less Physical Activity. *Journal of Attention Disorders, 25*(8), 1187-1195. https://doi.org/10.1177/1087054719887789

Meßler, C. F., Holmberg, H.-C., & Sperlich, B. (2018). Multimodal Therapy Involving High-Intensity Interval Training Improves the Physical Fitness, Motor Skills, Social Behavior, and Quality of Life of Boys With ADHD: A Randomized Controlled Study. *J Atten Disord, 22*(8), 806-812. https://doi.org/10.1177/1087054716636936

Mitchell, J. T., Robertson, C. D., Anastopolous, A. D., Nelson-Gray, R. O., & Kollins, S. H. (2012). Emotion dysregulation and emotional impulsivity among adults with attention-deficit/hyperactivity disorder: results of a preliminary study. *Journal of Psychopathology and Behavioral Assessment, 34*, 510-519.

Mokobane, M., Pillay, B. J., & Meyer, A. (2019). Fine motor deficits and attention deficit hyperactivity disorder in primary school children. *S Afr J Psychiatr, 25*, 1232. https://doi.org/10.4102/sajpsychiatry.v25i0.1232

Montaruli, A., Galasso, L., Caumo, A., Cè, E., Pesenti, C., Roveda, E., & Esposito, F. (2017, 2017/12/01). The circadian typology: the role of physical activity and melatonin. *Sport Sciences for Health, 13*(3), 469-476. https://doi.org/10.1007/s11332-017-0389-y

Moore, M., Kirchner, H. L., Drotar, D., Johnson, N., Rosen, C., & Redline, S. (2011, Mar). Correlates of adolescent sleep time and variability in sleep time: the role of individual and health related characteristics. *SLEEP MED, 12*(3), 239-245. https://doi.org/10.1016/j.sleep.2010.07.020

Morgan, K., David, B., & Gasoigne, C. (2007). *Daily sleep diary*. https://www.nhs.uk/livewell/insomnia/documents/sleepdiary.pdf

Mullin, B. C., Harvey, A. G., & Hinshaw, S. P. (2011). A preliminary study of sleep in adolescents with bipolar disorder, ADHD, and non-patient controls. *Bipolar disorders*, *13*(4), 425-432. https://doi.org/10.1111/j.1399-5618.2011.00933.x

Nijmeijer, J. S., Minderaa, R. B., Buitelaar, J. K., Mulligan, A., Hartman, C. A., & Hoekstra, P. J. (2008, 2008/04/01/). Attention-deficit/hyperactivity disorder and social dysfunctioning. *Clinical Psychology Review*, *28*(4), 692-708. https://doi.org/https://doi.org/10.1016/j.cpr.2007.10.003

Nikles, J., Mitchell, G. K., de Miranda Araújo, R., Harris, T., Heussler, H. S., Punja, S., Vohra, S., & Senior, H. E. J. (2020). A systematic review of the effectiveness of sleep hygiene in children with ADHD. *Psychol Health Med*, *25*(4), 497-518. https://doi.org/10.1080/13548506.2020.1732431

O'Brien, L. M. (2009, 2009/10/01/). The Neurocognitive Effects of Sleep Disruption in Children and Adolescents. *Child and Adolescent Psychiatric Clinics of North America*, *18*(4), 813-823. https://doi.org/https://doi.org/10.1016/j.chc.2009.04.008

O’Connor, B. C., Fabiano, G. A., Waschbusch, D. A., Belin, P. J., Gnagy, E. M., Pelham, W. E., Greiner, A. R., & Roemmich, J. N. (2014). Effects of a Summer Treatment Program on Functional Sports Outcomes in Young Children with ADHD. *J Abnorm Child Psychol*, *42*(6), 1005-1017. https://doi.org/10.1007/s10802-013-9830-0

Ogrodnik, M., Karsan, S., Malamis, B., Kwan, M., Fenesi, B., & Heisz, J. J. (2023, 2023/05/04). Exploring Barriers and Facilitators to Physical Activity in Adults with ADHD: A Qualitative Investigation. *Journal of Developmental and Physical Disabilities*. https://doi.org/10.1007/s10882-023-09908-6

Orangi, B. M., Rasoul, Y., Behrouz, G., Paul, L., & Amin, A. (2021). The Effect of Aerobic Exercise with Nonlinear Pedagogy on Anxiety, Depression, Motor Proficiency and Cognitive Ability of Boys with Attention Deficit Hyperactivity Disorder. *Journal of rehabilitation sciences and research*, *8*(3), 144-150. https://doi.org/10.30476/jrsr.2021.91068.1163

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, *372*, n71. https://doi.org/10.1136/bmj.n71

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. *J Atten Disord*, *21*(9), 783-795. https://doi.org/10.1177/1087054714533192

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. (2009). Fundamental Movement Skills in Children Diagnosed with Autism Spectrum Disorders and Attention Deficit Hyperactivity Disorder. *J Autism Dev Disord*, *39*(12), 1694-1705. https://doi.org/10.1007/s10803-009-0813-5

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. *J Atten Disord*, *23*(4), 384-397. https://doi.org/10.1177/1087054715569282

Papadopoulos, N., Rinehart, N. J., Bradshaw, J. L., Taffe, J., & McGinley, J. (2015). Is There a Link Between Motor Performance Variability and Social-Communicative Impairment in Children With ADHD-CT: A Kinematic Study Using an Upper Limb Fitts' Aiming Task. *Journal of Attention Disorders*, *19*(1), 72-77. https://doi.org/10.1177/1087054712454569

Papadopoulos, N., Stavropoulos, V., McGinley, J., Bellgrove, M., Tonge, B., Murphy, A., Cornish, K., & Rinehart, N. (2019). Moderating Effect of Motor Proficiency on the Relationship Between ADHD Symptoms and Sleep Problems in Children With Attention Deficit Hyperactivity Disorder-Combined Type. *Behavioral sleep medicine*, *17*(5), 646-656. https://doi.org/10.1080/15402002.2018.1443455

Park, S. (2014). Associations of physical activity with sleep satisfaction, perceived stress, and problematic Internet use in Korean adolescents. *BMC public health*, *14*(1), 1143-1143. https://doi.org/10.1186/1471-2458-14-1143

Piek, J. P., Pitcher, T. M., & Hay, D. A. (1999). Motor coordination and kinaesthesis in boys with attention deficithyperactivity disorder. *Dev Med Child Neurol*, *41*(3), 159-165. https://doi.org/10.1017/S0012162299000341

Pitcher, T. M., Piek, J. P., & Hay, D. A. (2003). Fine and gross motor ability in males with ADHD. *Developmental medicine and child neurology*, *45*(8), 525-535. https://doi.org/10.1017/S0012162203000975

Polanczyk, G., de Lima, M. S., Horta, B. L., Biederman, J., & Rohde, L. A. (2007). The Worldwide Prevalence of ADHD: A Systematic Review and Metaregression Analysis. *Am J Psychiatry*, *164*(6), 942-948. https://doi.org/10.1176/ajp.2007.164.6.942

Pontifex, M. B., Saliba, B. J., Raine, L. B., Picchietti, D. L., & Hillman, C. H. (2013, Mar). Exercise improves behavioral, neurocognitive, and scholastic performance in children with attention-deficit/hyperactivity disorder. *J Pediatr*, *162*(3), 543-551. https://doi.org/10.1016/j.jpeds.2012.08.036

Rigoli, D., Kane, R. T., Mancini, V., Thornton, A., Licari, M., Hands, B., McIntyre, F., & Piek, J. (2017). The relationship between motor proficiency and mental health outcomes in young adults: A test of the Environmental Stress Hypothesis. *Human Movement Science*, *53*, 16-23. https://doi.org/10.1016/j.humov.2016.09.004

Rigoli, D., Piek, J. P., Kane, R., & Oosterlaan, J. (2012). An examination of the relationship between motor coordination and executive functions in adolescents. *Developmental Medicine & Child Neurology*, *54*(11), 1025-1031. https://doi.org/10.1111/j.1469-8749.2012.04403.x

Rosenthal, E. A., Broos, H. C., Timpano, K. R., & Johnson, S. L. (2024). Does Emotion-Related Impulsivity Relate to Specific ADHD Symptom Dimensions, and Do the Effects Generalize Across Comorbid Internalizing and Externalizing Syndromes? *Journal of Attention Disorders*, *28*(2), 178-188.

Rowland, A. S., Skipper, B. J., Umbach, D. M., Rabiner, D. L., Campbell, R. A., Naftel, A. J., & Sandler, D. P. (2015). The Prevalence of ADHD in a Population-Based Sample. *Journal of Attention Disorders*, *19*(9), 741-754. https://doi.org/10.1177/1087054713513799

Sadeh, A., Sharkey, K. M., & Carskadon, M. A. (1994). Activity-based sleep-wake identification: An empirical test of methodological issues. *Sleep (New York, N.Y.)*, *17*(3), 201-207. https://doi.org/10.1093/sleep/17.3.201

Sayal, K., Prasad, V., Daley, D., Ford, T., & Coghill, D. (2018). ADHD in children and young people: prevalence, care pathways, and service provision. *The Lancet Psychiatry*, *5*(2), 175-186. https://doi.org/10.1016/S2215-0366(17)30167-0

Schatz, N. K., Fabiano, G. A., Cunningham, C. E., dosReis, S., Waschbusch, D. A., Jerome, S., Lupas, K., & Morris, K. L. (2015, 2015/12/01). Systematic Review of Patients' and Parents' Preferences for ADHD Treatment Options and Processes of Care. *The Patient - Patient-Centered Outcomes Research*, *8*(6), 483-497. https://doi.org/10.1007/s40271-015-0112-5

Sciberras, E., Fulton, M., Efron, D., Oberklaid, F., & Hiscock, H. (2011, 2011/10/01/). Managing sleep problems in school aged children with ADHD: A pilot randomised controlled trial. *Sleep Medicine*, *12*(9), 932-935. https://doi.org/https://doi.org/10.1016/j.sleep.2011.02.006

Scott, N., Blair, P. S., Emond, A. M., Fleming, P. J., Humphreys, J. S., Henderson, J., & Gringras, P. (2013). Sleep patterns in children with ADHD: a population-based cohort study from birth to 11 years. *Journal of sleep research*, *22*(2), 121-128.

Seo, J. C., Jon, D. I., Shim, S. H., Sung, H. M., Woo, Y. S., Hong, J., Park, S. Y., Seo, J. S., & Bahk, W. M. (2022, Feb 28). Prevalence and Comorbidities of Attention Deficit Hyperactivity Disorder Among Adults and Children/Adolescents in Korea. *Clin Psychopharmacol Neurosci*, *20*(1), 126-134. https://doi.org/10.9758/cpn.2022.20.1.126

Sherrington, C., Moseley, A. M., Herbert, R. D., Elkins, M. R., & Maher, C. G. (2010). Ten years of evidence to guide physiotherapy interventions: Physiotherapy Evidence

Database (PEDro). *Br J Sports Med*, *44*(12), 836-837. https://doi.org/10.1136/bjsm.2009.066357

Sibley, B., & Etnier, J. (2003, 08/01). The Relationship between Physical Activity and Cognition in Children: A Meta-Analysis. *Pediatric Exercise Science, 15*, 243-256. https://doi.org/10.1515/ijsl.2000.143.183

Silva, L. A. D., Doyenart, R., Henrique Salvan, P., Rodrigues, W., Felipe Lopes, J., Gomes, K., Thirupathi, A., Pinho, R. A. D., & Silveira, P. C. (2019). Swimming training improves mental health parameters, cognition and motor coordination in children with Attention Deficit Hyperactivity Disorder. *Int J Environ Health Res*, 1.

Skounti, M., Philalithis, A., & Galanakis, E. (2007, 2007/02/01). Variations in prevalence of attention deficit hyperactivity disorder worldwide. *European Journal of Pediatrics, 166*(2), 117-123. https://doi.org/10.1007/s00431-006-0299-5

Smith, A. L., Hoza, B., Linnea, K., McQuade, J. D., Tomb, M., Vaughn, A. J., Shoulberg, E. K., & Hook, H. (2013). Pilot physical activity intervention reduces severity of ADHD symptoms in young children. *Journal of Attention Disorders, 17*(1), 70-82.

Snitselaar, M. A., Smits, M. G., Heijden, K. B. v. d., & Spijker, J. (2017). Sleep and circadian rhythmicity in adult ADHD and the effect of stimulants: A review of the current literature. *Journal of Attention Disorders, 21*(1), 14-26. https://doi.org/10.1177/1087054713479663

Soorya, L. V., & Halpern, D. (2009). Psychosocial interventions for motor coordination, executive functions, and socialization deficits in ADHD and ASD. *Primary Psychiatry, 16*(1), 48-54. http://search.ebscohost.com/login.aspx?direct=true&db=psyh&AN=2009-02056-002&site=ehost-live&scope=site
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Spierer, D. K., Hagins, M., Rundle, A., & Pappas, E. (2011, 2011/04/01). A comparison of energy expenditure estimates from the Actiheart and Actical physical activity monitors during low intensity activities, walking, and jogging. *European Journal of Applied Physiology, 111*(4), 659-667. https://doi.org/10.1007/s00421-010-1672-7

Sprich, S. E., Safren, S. A., Finkelstein, D., Remmert, J. E., & Hammerness, P. (2016). A randomized controlled trial of cognitive behavioral therapy for ADHD in medication-treated adolescents. *J Child Psychol Psychiatry, 57*(11), 1218-1226. https://doi.org/10.1111/jcpp.12549

Stein, M. A., Weiss, M., & Hlavaty, L. (2012, 2012/07/01). ADHD Treatments, Sleep, and Sleep Problems: Complex Associations. *Neurotherapeutics, 9*(3), 509-517. https://doi.org/10.1007/s13311-012-0130-0

Stodden, D. F., Goodway, J. D., Langendorfer, S. J., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008, 2008/05/01). A Developmental Perspective on the Role of Motor Skill Competence in Physical Activity: An Emergent Relationship. *Quest*, *60*(2), 290-306. https://doi.org/10.1080/00336297.2008.10483582

Stone, M. R., Stevens, D., & Faulkner, G. E. J. (2012). Maintaining recommended sleep throughout the week is associated with increased physical activity in children. *Preventive medicine, 56*(2), 112-117. https://doi.org/10.1016/j.ypmed.2012.11.015

Sung, V., Hiscock, H., Sciberras, E., & Efron, D. (2008). Sleep Problems in Children With Attention-Deficit/Hyperactivity Disorder: Prevalence and the Effect on the Child and Family. *Arch Pediatr Adolesc Med, 162*(4), 336-342. https://doi.org/10.1001/archpedi.162.4.336

Tandon, P. S., Sasser, T., Gonzalez, E. S., Whitlock, K. B., Christakis, D. A., & Stein, M. A. (2019). Physical activity, screen time, and sleep in children with ADHD. *J PHYS ACT HEALTH, 16*(6), 416-422. https://doi.org/10.1123/jpah.2018-0215

Tatsumi, Y., Mohri, I., Shimizu, S., Tachibana, M., Ohno, Y., & Taniike, M. (2015). Daytime physical activity and sleep in pre-schoolers with developmental disorders. *J Paediatr Child Health, 51*(4), 396-402. https://doi.org/10.1111/jpc.12725

Thomas, R., Sanders, S., Doust, J., Beller, E., & Glasziou, P. (2015). Prevalence of Attention-Deficit/Hyperactivity Disorder: A Systematic Review and Meta-analysis. *Pediatrics, 135*(4), e994-e1001. https://doi.org/10.1542/peds.2014-3482

Tietze, A. L., Zernikow, B., Michel, E., & Blankenburg, M. (2014). Sleep disturbances in children, adolescents, and young adults with severe psychomotor impairment: impact on parental quality of life and sleep. *Developmental Medicine & Child Neurology, 56*(12), 1187-1193.

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

Torabi, F., Farahani, A., Safakish, S., Ramezankhani, A., & Dehghan, F. (2018). Evaluation of motor proficiency and adiponectin in adolescent students with attention deficit hyperactivity disorder after high-intensity intermittent training. *PSYCHIAT RES, 261*, 40-44. https://doi.org/10.1016/j.psychres.2017.12.053

Tsai, M.-H., Hsu, J.-F., & Huang, Y.-S. (2016). Sleep Problems in Children with Attention Deficit/Hyperactivity Disorder: Current Status of Knowledge and Appropriate Management. *Curr Psychiatry Rep, 18*(8), 1-9. https://doi.org/10.1007/s11920-016-0711-4

Tse, A. C. Y., Lee, P. H., Zhang, J., & Lai, E. W. H. (2018). Study protocol for a randomised controlled trial examining the association between physical activity and sleep quality in children with autism spectrum disorder based on the melatonin-mediated mechanism model. *BMJ Open, 8*(4), e020944. https://doi.org/10.1136/bmjopen-2017-020944

Tse, C. Y. A., Lee, H. P., Chan, K. S. K., Edgar, V. B., Wilkinson-Smith, A., & Lai, W. H. E. (2019). Examining the impact of physical activity on sleep quality and executive functions in children with autism spectrum disorder: A randomized controlled trial. *Autism, 23*(7), 1699-1710. https://doi.org/10.1177/1362361318823910

Tseng, M. H., Henderson, A., Chow, S. M. K., & Yao, G. (2004). Relationship between motor proficiency, attention, impulse, and activity in children with ADHD. *Dev Med Child Neurol*, *46*(6), 381-388. https://doi.org/10.1017/S0012162204000623

Ulrich, D. (2000). *The test of gross motor development*. TX: Prod-Ed.

Van der Heijden, K. B., Smits, M. G., Van Someren, E. J. W., Ridderinkhof, K. R., & Gunning, W. B. (2007, 2007/02/01/). Effect of Melatonin on Sleep, Behavior, and Cognition in ADHD and Chronic Sleep-Onset Insomnia. *Journal of the American Academy of Child & Adolescent Psychiatry*, *46*(2), 233-241. https://doi.org/https://doi.org/10.1097/01.chi.0000246055.76167.0d

van der Heijden, K. B., Stoffelsen, R. J., Popma, A., & Swaab, H. (2018). Sleep, chronotype, and sleep hygiene in children with attention-deficit/hyperactivity disorder, autism spectrum disorder, and controls. *Eur Child Adolesc Psychiatry*, *27*(1), 99-111. https://doi.org/10.1007/s00787-017-1025-8

Van Der Stigchel, S., Rommelse, N. N. J., Deijen, J. B., Geldof, C. J. A., Witlox, J., Oosterlaan, J., Sergeant, J. A., & Theeuwes, J. (2007). Oculomotor capture in ADHD. *COGN NEUROPSYCHOL*, *24*(5), 535-549. https://doi.org/10.1080/02643290701523546

Verret, C., Guay, M.-C., Berthiaume, C., Gardiner, P., & Béliveau, L. (2012). A Physical Activity Program Improves Behavior and Cognitive Functions in Children With ADHD: An Exploratory Study. *J Atten Disord*, *16*(1), 71-80. https://doi.org/10.1177/1087054710379735

Vysniauske, R., Verburgh, L., Oosterlaan, J., & Molendijk, M. L. (2020). The Effects of Physical Exercise on Functional Outcomes in the Treatment of ADHD: A Meta-Analysis. *J Atten Disord*, *24*(5), 644-654. https://doi.org/10.1177/1087054715627489

Wachob, D., & Lorenzi, D. G. (2015). Brief Report: Influence of Physical Activity on Sleep Quality in Children with Autism. *Journal of autism and developmental disorders*, *45*(8), 2641-2646. https://doi.org/10.1007/s10803-015-2424-7

Wajszilber, D., Santiseban, J. A., & Gruber, R. (2018). Sleep disorders in patients with ADHD: impact and management challenges. *Nat Sci Sleep*, *10*, 453-480. https://doi.org/10.2147/nss.S163074

Wang, F., & Boros, S. (2021, 2021/01/02). The effect of physical activity on sleep quality: a systematic review. *European Journal of Physiotherapy*, *23*(1), 11-18. https://doi.org/10.1080/21679169.2019.1623314

Warburton, E. R. D., & Bredin, S. D. S. (2017). Health benefits of physical activity: a systematic review of current systematic reviews. *Current Opinion in Cardiology*, *32*(5), 541-556. https://doi.org/10.1097/HCO.0000000000000437

Weiss, M. D., & Salpekar, J. (2010). Sleep problems in the child with attention-deficit hyperactivity disorder: defining aetiology and appropriate treatments. *CNS Drugs, 24*(10), 811.

Weiss, M. D., Wasdell, M. B., Bomben, M. M., Rea, K. J., & Freeman, R. D. (2006, 2006/05/01/). Sleep Hygiene and Melatonin Treatment for Children and Adolescents With ADHD and Initial Insomnia. *Journal of the American Academy of Child & Adolescent Psychiatry*, *45*(5), 512-519. https://doi.org/https://doi.org/10.1097/01 chi.0000205706.78818.ef

Welsch, L., Alliott, O., Kelly, P., Fawkner, S., Booth, J., & Niven, A. (2021). The effect of physical activity interventions on executive functions in children with ADHD: A systematic review and meta-analysis. *Mental health and physical activity, 20*, 100379. https://doi.org/10.1016/j.mhpa.2020.100379

Wiggins, L. D., Rice, C. E., Barger, B., Soke, G. N., Lee, L.-C., Moody, E., Edmondson-Pretzel, R., & Levy, S. E. (2019). DSM-5 criteria for autism spectrum disorder maximizes diagnostic sensitivity and specificity in preschool children. *Soc Psychiatry Psychiatr Epidemiol*, *54*(6), 693-701. https://doi.org/10.1007/s00127-019-01674-1

Wilens, T. E., & Spencer, T. J. (2010, 2010/09/01). Understanding Attention-Deficit/Hyperactivity Disorder from Childhood to Adulthood. *Postgraduate Medicine*, *122*(5), 97-109. https://doi.org/10.3810/pgm.2010.09.2206

Wrotniak, B. H., Epstein, L. H., Dorn, J. M., Jones, K. E., & Kondilis, V. A. (2006). The Relationship Between Motor Proficiency and Physical Activity in Children. *Pediatrics, 118*(6), e1758-e1765. https://doi.org/10.1542/peds.2006-0742

Wu, X., Tao, S., Zhang, Y., Zhang, S., & Tao, F. (2015). Low physical activity and high screen time can increase the risks of mental health problems and poor sleep quality among Chinese college students. *PLoS ONE*, *10*(3), e0119607-e0119607. https://doi.org/10.1371/journal.pone.0119607

Yazd, S. N. T., Ayatizadeh, F., Dehghan, F., Machado, S., & Wegner, M. (2015). Comparing the Effects of Drug Therapy, Perceptual Motor Training, and Both Combined on the Motor Skills of School-Aged Attention Deficit Hyperactivity Disorder Children. *CNS NEUROL DISORD-DR*, *14*(10), 1283-1291. https://doi.org/10.2174/1871527315666151111123501

Yin, H., Yang, D., Yang, L., & Wu, G. (2022, 2022-July-22). Relationship between sleep disorders and attention-deficit–hyperactivity disorder in children [Original Research]. *Frontiers in Pediatrics, 10*. https://doi.org/10.3389/fped.2022.919572

Yurumez, E., & Kilic, B. G. (2016). Relationship Between Sleep Problems and Quality of Life in Children With ADHD. *Journal of Attention Disorders, 20*(1), 34-40. https://doi.org/10.1177/1087054713479666

Zhao, X., Page, T. F., Altszuler, A. R., Pelham, W. E., Kipp, H., Gnagy, E. M., Coxe, S., Schatz, N. K., Merrill, B. M., & Macphee, F. L. (2019). Family burden of raising a child with ADHD. *Journal of Abnormal Child Psychology*, *47*, 1327-1338.

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

Zuckerman, K. E., Hill, A. P., Guion, K., Voltolina, L., & Fombonne, E. (2014). Overweight and Obesity: Prevalence and Correlates in a Large Clinical Sample of Children with Autism Spectrum Disorder. *J Autism Dev Disord, 44*(7), 1708-1719. https://doi.org/10.1007/s10803-014-2050-9