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Effects of physical activity and fitness on cognitive function, self-control, and resilience in young people with attention deficit hyperactivity disorder

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Abstract

This thesis is presented as a collection of four studies that examine the effects of physical activity on cognitive function, self-control, and resilience in young people with attention deficit/hyperactivity disorder (ADHD). Previous literature has highlighted beneficial effects of physical activity for cognition, self-control, and resilience in neurotypical young people. However, there is limited evidence regarding these effects in young people with ADHD; despite young people with ADHD typically displaying poorer cognition, self-control, and resilience than their neurotypical counterparts. Furthermore, acute physical activity interventions in young people with ADHD have predominantly only considered individual sports such as running or cycling, both of which are not commonly undertaken in this population and age-group. Furthermore, limited research has examined the effects of physical activity and physical fitness on self-control and resilience in this population; two psychological constructs key to young people's development. Furthermore, no research to date has investigated the qualitative preferences and perceptions of physical activity in young people with ADHD, their parents, and their teachers to gain a deeper insight into what a potential successful physical activity intervention might look like in this population. The current thesis aims to address these limitations and extend the literature base.

Study one was a meta-analysis of studies that have examined the acute effects of physical activity on cognitive function in young people with ADHD, considering key variables such as the duration and modality of physical activity, and study design. The meta-analysis highlighted that physical activity appears to have acute beneficial effects on cognition in young people with ADHD. Specifically, the study found a small overall benefit of acute physical activity on cognitive function in children and adolescents with ADHD (Standardised Mean Difference [SMD] = 0.18), with domain-specific benefits on cognitive flexibility (SMD = 0.21), attention (SMD = 0.20) and inhibitory control (SMD = 0.18); whilst no effect was observed for memory (SMD = 0.02). Furthermore, the optimal intervention duration was between 11-20 min (SMD = 0.23 vs. 0-10 min; SMD = 0.11, >20 min; SMD = 0.13) and modality-wise; running (SMD = 0.21) or 'other' types of physical activity (trampolining, exergaming and coordinative tasks; SMD = 0.39) were shown to improve cognitive function in this population, whilst cycling had no effect (SMD = 0.06).

Study two examined the associations between psychological constructs important in the development of young people with ADHD (cognitive function, trait self-

control, and trait resilience) and cardiorespiratory fitness and physical activity. The study identified positive associations between cardiorespiratory fitness and enhanced performance on tests of inhibitory control (r = -0.348; p = 0.01) and attention (simple Stroop IES r = -0.386; p = 0.004 and congruent Flanker task IES r = - 0.302; p = 0.026). There was also a tendency for a positive association between cardiorespiratory fitness and trait resilience (r = 0.253; p = 0.065). Furthermore, moderate-to-vigorous physical activity was positively associated with higher trait self-control (r = 0.370; p = 0.021). Thus, overall, study two demonstrates positive associations between physical activity/physical fitness and the important psychological constructs of cognitive function, self-control, and resilience in young people with ADHD.

These findings then guided the third study that aimed to identify the perceptions of physical activity to inform future physical activity intervention design from the perspective of young people with ADHD, their parents, and their teachers. The study found four common themes across the three key stakeholders which were; the need for reduced stopping and starting in interventions, ensuring activities are short, quick-paced and dynamic with clear instruction, reduced exposure to sensory situations that could lead to emotional dysregulation, and rethinking behaviour management and discipline methods in order to maintain enthusiasm and engagement without punishing young people for being unable to manage their ADHD symptoms (typically involving movement). Thus, concluding that a games-based physical activity was a potential modality of physical activity that met the criteria identified within the study findings.

Utilising these findings, study four examined the acute effects of a games-based physical activity session (30 min basketball-based activities) on cognitive function, state self-control, and state resilience in young people with ADHD. It was found that the 30-min basketball intervention did not acutely affect cognitive function performance (p = 0.109-0.971), self-control (p = 0.232) or resilience (p = 0.495) in young people with ADHD, compared to a resting control condition. Therefore, suggesting that an acute games-based physical activity intervention does not improve cognitive function, state self-control and state resilience in young people with ADHD.

Overall, the findings of this thesis demonstrate the importance of physical activity (and physical fitness) for young people with ADHD. Specifically, positive effects of physical activity on cognitive performance were demonstrated acutely via a meta-analysis in Chapter IV, and chronically in Chapter V; whilst the games-based intervention in Chapter VII did not show positive effects of physical activity acutely to enhance cognitive function. Similarly, Chapter V demonstrated a positive association

between physical activity and trait self-control, though the games-based intervention in Chapter VII did not influence state self-control in an acute setting. Finally, whilst there was a tendency for a positive association between physical fitness and trait resilience in Chapter V, the acute games-based intervention in Chapter VII did not affect state resilience. This thesis also assessed qualitative perceptions of physical activity interventions in young people with ADHD and other key stakeholders in Chapter VI, which was used to inform the games-based physical activity intervention in Chapter VII. Thus, whilst the intervention in Chapter VII did not acutely influence cognition, self-control or resilience in young people with ADHD, it is possible this was due to the limited 'dose' (i.e., a single session). Given that the intervention was developed with ecological validity in mind, future work should perhaps focus on the longer-term effects of such an intervention in this population.

Keywords: Physical Activity, Cardiorespiratory Fitness, Children, Adolescents, Cognitive Function, Executive Function, Self-Control, Resilience

List of Abbreviations

ADHD: Attention Deficit Hyperactivity Disorder

ANOVA: Analysis of variance

BMI: Body mass index

BSCS: Brief Self-Control Scale

CD-RISC: Connor-Davidson Resilience Scale

HR: Heart rate

MSFT: Multi-stage fitness test

NT: Neurotypical

PA: Physical activity

SD: Standard deviation

MVPA: Moderate-to-vigorous physical activity

VAS: Visual Analogue Scale

SMD: Standardised Mean Difference

CF: Cognitive function

ENMO: Euclidean Norm Minus One

DSM-5: Diagnostic and Statistical Manual of Mental Disorders

CSCRS: Child Self-Control Rating Scale

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Preface

Unless otherwise indicated by reference to published resources, the work presented in the present thesis is that of the author and has not been previously submitted for another degree to this or any other University.

Some of the work in this thesis has been published.

Published Papers

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Chapter I

Introduction

The Chief Medical Officers physical activity guidelines state "*if physical activity were a drug, we would refer to it as a miracle cure, due to the great many illnesses it can prevent and help treat*" (Department of Health and Social Care [DHSC], 2019a; Gibson-Moore, 2019). It seems necessary to begin this thesis with this statement. Physical activity has been known to not only prevent and treat illnesses, but it also aids in many other components of a high quality of life, through social, emotional and mental health benefits. Therefore, it is important to consider that we do not yet understand the full extent to which physical activity is able to manage, treat, and prevent illnesses, disabilities, and disorders. With the ever-increasing diagnoses in the UK of neurodevelopmental disorders (such as attention-deficit hyperactivity disorder, autism and oppositional defiance disorder), it is increasingly more valuable to identify different methods of management for these disorders. Physical activity is a method that has begun to be explored as a potential management technique for different neurodevelopmental disorders (Liu, Liang & Sit, 2024; Sung, Ku, Leung & MacDonald, 2022), however the research to date is still in its infancy and therefore specific physical activity interventions for the management and treatment of neurodevelopmental conditions are yet to be developed.

Young people aged 5 to 18 years are recommended to participate in at least 60 minutes of moderate-to-vigorous physical activity per day (DHSC, 2019a). Furthermore, they are recommended to engage in different types and intensities of physical activity across the week to aid the development of movement skills, muscular fitness and bone mineral density (DHSC, 2019a). Finally, young people are recommended to reduce the amount of time being sedentary (DHSC, 2019a). Despite these recommendations, it is startling that in the UK only 47% of young people meet the physical activity guidelines of 60 minutes per day, with approximately 30% participating in less than 30 minutes per day (Sport England, 2023).

More specifically, for the purpose of this thesis, data suggest that young people with a disability closely align with the data for neurotypical young people whereby approximately half (51 %) of young people with a disability meet the UK physical activity guidelines (Sport England, 2023). Physical activity has been shown to prevent the onset and reduce the risk of chronic diseases (Anderson & Durstine, 2019), therefore highlighting the vital role of physical activity for lifelong health and wellbeing. It has also been suggested that physical activity can reduce/attenuate ADHD symptoms (Zhang et al., 2025). Furthermore, hyperactivity and inattention can predict adult overweight and obesity levels, and inattention can be used to predict adult physical inactivity (Khalife et al., 2014). These findings may provide further explanation towards the high prevalence of obesity in young people with ADHD (~40%) compared to the general population (~27%) (Donnchadha, Bramham & Greene, 2023; Racicka et al., 2018). However, the data surrounding physical activity engagement and young people with ADHD remains inconclusive.

Despite the importance of physical activity for health and well-being, research is still very much in its infancy for outlining when physical activity can be used as a management tool for neurodevelopmental conditions. One such condition that has had increased focus within the media is ADHD. ADHD is one of the most prevalent neurodevelopmental disorders globally, with approximately 7% of young people aged 3 to 12 years, and 5.6% of adolescents aged 12 to 18 years (Salari et al., 2023) having a clinical diagnosis of the disorder. In recent years, the number of people receiving a formal diagnosis of ADHD has increased rapidly, with research suggesting increased awareness of, and information surrounding, ADHD, alongside improved treatment, as contributing factors in encouraging individuals to seek a clinical diagnosis (Burns, 2024).

ADHD is characterised by inattentive and hyperactive or impulsive behaviours that interfere with daily functioning and development (Rossi et al., 2023). However, ADHD is not a ‘homogenous’ condition, and individuals diagnosed with ADHD may display a wide range of symptoms. As such, ADHD is categorised into three different presentations:

inattentive presentation, hyperactive-impulsive presentation and combined presentation (American Psychiatric Association, 2013). Individuals with an inattentive presentation exhibit characteristics such as "*wandering off task, lacking persistence, having difficulty sustaining focus, and being disorganised and is not due to defiance or lack of comprehension*". Individuals with a hyperactivity-impulsive presentation are identified through "*excessive motor activity (such as a child running about) when it is not appropriate, or excessive fidgeting, tapping, or talkativeness*" and "*hasty actions that occur in the moment without forethought and that have high potential for harm to the individual"* (American Psychiatric Association, 2013, p. 61). A combined presentation is identified by an individual exhibiting both inattentive presentations and hyperactive-impulsive presentations. The characteristics highlighted above for each presentation (outlined in the DSM-5, 2013), are used to diagnose young people with ADHD. These presentations are identified through symptoms reported via parent and teacher reported questionnaires, and/or a health care professional's evaluation (ADHD UK, n.d.).

Currently, ADHD is managed through psychological interventions including behavioural therapies (behavioural therapy and cognitive behavioural therapy), cognitive training and neurofeedback, and mind and body-based interventions (Catalá-López et al., 2017). Other non-pharmacological treatment methods include complementary and alternative medicine such as dietary therapies. Dietary therapies are quite wide ranging, and include, consuming polyunsaturated fatty acids, minerals, vitamins, amino acids and herbal therapy (Catalá-López et al., 2017). Where non-pharmacological treatments are unsuccessful, pharmacological methods are used (broadly classified as stimulants, non-stimulants and anti-psychotics). The most common stimulants include; methylphenidate and amphetamine, and most common non-stimulants include; atomoxetine, and desipramine. Finally, antipsychotics or other unlicensed drugs are administered when all other methods are unsuccessful (Catalá-López et al., 2017). Pharmacological treatments are associated with a range of different side effects including sleep deprivation, mood swings, headaches, and loss of appetite (Toomey, Sox, Rusinak, & Finkelstein, 2012). With the condition affecting so many people globally, and current treatment methods

taking a more medicinal route, or utilising cognitive behavioural therapies, it is attractive to find alternative, cheaper methods of symptom and behaviour management, without some of the deleterious side effects of medication. Physical activity has begun to show some beneficial results, as a potential conjunctive treatment method alongside current management techniques (specifically for ADHD symptoms, cognitive functioning, social functioning, motor skills, behaviour and brain activity (Hoza, Martin, Pirog, & Shoulberg, 2016)).

Therefore, this thesis will focus on some of the potential benefits of physical activity for young people with ADHD, addressing the paucity of research in this area. More specifically, this thesis will examine the effects of physical activity and physical fitness on three different psychological constructs; namely, cognitive function, self-control, and resilience, in young people with ADHD. The three psychological constructs were selected for this thesis due to their relevance in day-to-day functioning in this population. Cognitive function is defined as a "*variety of different brain-mediated functions and processes*" of which give the brain ability to process, store, manipulate and use information from internal and external sources (Schmitt, Benton & Kallus, 2005, p. 460). Cognitive function is of particular importance in young people with ADHD because they commonly exhibit impaired performance on important cognitive domains such as executive function (Huang et al., 2016; Jakobson & Kikas, 2007; Marx et al., 2010), when compared to their neurotypical counterparts. Self-control is defined as "*the capacity for altering one's own responses, especially to bring them into line with standards such as ideals, values, morals, and social expectations, and to support the pursuit of long-term goals*" (Baumeister, Vohs & Tice, 2007, p. 351). Self-control has been suggested to be lower in young people with ADHD (Bunford, Evans & Wymbs, 2015) and is key to managing impulsive behaviours (Aguilar-Cárceles & Farrington, 2020; Hofmann et al., 2009), a key characteristic associated with ADHD. Finally, resilience has been defined as a "*dynamic process encompassing positive adaptation within the context of significant adversity*" (Luthar, Cicchetti, & Becker, 2000, p. 543). Considering the vast array of adversities typically experienced by young people with ADHD due to the nature of the condition (e.g.,

not completing schoolwork, suspension from school, poor grades), resilience plays an important role in the daily living of young people with ADHD (Martin, 2014).

Currently, research investigating the effects of physical activity on cognitive function in young people with ADHD is still in its infancy, however what has been identified to date suggests that children with ADHD benefit from physical activity with enhanced executive functioning (Welsch et al., 2021). Furthermore, the current literature base lacks high quality randomised controlled trials (Dastamooz et al., 2023), and the frequency, intensity, duration and type of physical activity that would be most effective in the management of ADHD in young people are not known. Research investigating the effects of physical activity on self-control and resilience in young people with ADHD is even more limited, with research to date only highlighting that more time spent exercising positively correlates with self-control (Bowling et al., 2017), and that physical activity is positively associated with resilience in young people with ADHD (Liang, Qiu & Sit, 2023).

The limited research in children and adolescents with ADHD and physical activity has tended to focus on the effects of activity on mood (Cornelius, Fedewa, & Ahn, 2017) and ADHD symptoms and behaviours (Hoza, Martin, Pirog, & Shoulberg, 2016). As highlighted above, cognitive function, self-control, and resilience are all key features in the daily functioning of young people with ADHD and contribute to the symptomatology, and management, of ADHD in young people (Burnette, Babij, Oddo & Knouse, 2020; Dvorsky & Langberg, 2016). Therefore, this thesis aims to examine the effects of physical activity with regard to these key psychological constructs. This thesis aims to identify physical activity intervention strategies that are most effective in this population; first through a meta-analytical review of the current literature, then a cross-sectional examination to understand whether there are associations between the aforementioned psychological constructs and physical activity, thirdly undertaking stakeholder engagement to facilitate intervention design, and finally testing the efficacy of an intervention (designed based upon the findings of the earlier experimental work).

Following this introduction, this thesis is organised into seven further chapters, as follows:

- Chapter II is a literature review that will define the key concepts that form the foundations of this thesis, as well as key terms that are fundamental to understanding the importance of this thesis. Furthermore, the literature review will outline the current literature within this area, highlighting gaps, strengths and limitations of the current research base.
- Chapter III is a general methods section that will highlight common methodologies utilised throughout the experimental chapters, and the reasons behind these decisions.
- The thesis is then split into four experimental chapters. Chapter IV examines the acute effects of physical activity on cognitive function in children and adolescents with ADHD through a systematic review and meta-analysis. Chapter V then investigates the associations of physical activity and cardiorespiratory fitness with cognitive function, self-control, and resilience in young people with ADHD. Chapter VI delves into a qualitative examination of how physical activity affects young people with ADHD from the perspectives of children with ADHD, their parents, and their teachers. Finally, chapter VII explores the acute effects of a games-based physical activity intervention on cognitive function, self-control, and resilience in young people with ADHD.
- The thesis will then conclude with a general discussion (chapter VIII) highlighting key themes that arise throughout the thesis, strengths and limitations of the work presented, practical applications, and finally ending with a reflection.

Chapter II

Review of the Literature

2.1. Overview of the review of the literature

Definitions and explanations of the key concepts that are fundamental to the thesis are explained in section 2.2, including ‘attention deficit hyperactivity disorder’, ‘physical activity, exercise, and physical fitness’, ‘adolescents’, ‘cognitive function’, ‘resilience’, and ‘self-control’. Section 2.3 to 2.5 highlight the cross-sectional, acute, and chronic effects of physical activity on cognitive function, self-control, and resilience in neurotypical young people and young people with attention deficit hyperactivity disorder (ADHD). Finally, section 2.6 highlights qualitative research methods, and reviews literature regarding perceptions of physical activity in neurotypical young people, and young people with ADHD.

2.2. Key definitions and concepts

2.2.1. Attention deficit hyperactivity disorder

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder affecting approximately 7% of young people aged 3 to 12 years, and 5.6% of adolescents aged 12 to 18 years globally (Salari et al., 2023). The sex differences in ADHD have been highlighted throughout the literature with a much higher prevalence in males than females (Ramtekkar, Reiersen, Todorov, & Todd, 2010), with a commonly reported community prevalence ratio of 3 to 1 (Sayal, Prasad, Daley, Ford, Coghill, 2018). However, the true magnitude of the sex differences has been questioned given it has been suggested that females are more likely to display normative behaviours to mask symptoms (Mowlem, Rosenqvist, Martin, Lichenstein, Asherson, & Larsson, 2019).

ADHD has been categorised into three different presentations; combined presentation, predominantly inattentive presentation, and predominantly hyperactive-impulsive presentation (DSM-5, 2013). Symptoms differ between ADHD types with inattentive ADHD being characterised by lack of attention, inability to complete tasks,

disorganised nature, and forgetfulness. Hyperactivity-impulsivity ADHD presentation is shown through fidgeting, with individuals often being described as “on the go”, talking excessively and interrupting people (DSM-5, 2013). Finally, a combined presentation is recognised when an individual meets the criteria for both inattentive, and hyperactive-impulsive presentations. For an ADHD diagnosis, a child must meet six (or more) of the symptoms described in the DSM-5 for either inattentive, hyperactive-impulsive, or both. Within this, the symptoms must be presented in more than one situation (e.g., at home, and at school), must have persisted for a minimum of 6 months, and have been present before the age of 12 years (DSM-5, 2013).

The aetiology of ADHD is still not fully understood. However, research to date has highlighted several environmental factors that have been identified as ADHD risk factors, including maternal smoking, prematurity, family adversity, and exposure to toxins (Akutagava-Martins, Salatino-Oliveira, Kieling, Rohde, & Hutz, 2013; Thapar, Cooper, Eyre, & Langley, 2013). Additional to these risk factors, ADHD has been suggested to have a genetic component, however it is often a mixture of environmental and genetic factors that amplify or modify ADHD risk (Thapar et al., 2013), as these do not work independently of each other (Nigg, Nikolas, & Burt, 2010).

ADHD is initially managed through non-pharmacological treatments such as non-invasive brain stimulation (Drechsler, Brem, Brandeis, Grünblatt, Berger, & Walitza, 2020), psychological interventions including behavioural therapies (i.e. behavioural therapy and cognitive behavioural therapy), cognitive training and neurofeedback (Catalá-López et al., 2017), child or parent training (Östberg & Rydell, 2011; Webster-Stratton, Reid & Beauchaine, 2011), and dietary supplements (Goode et al., 2018; Serrano-Troncoso, Guidi, & Alda-Diez, 2013). Other non-pharmacological treatments include mind and body-based interventions, herbal therapy, and consuming polyunsaturated fatty acids, minerals, vitamins and amino acids (Catalá-López et al., 2017). Where non-pharmacological treatments are unsuccessful, then pharmacological treatments including medication are sought (Felt, Biermann, Christner, Kochhar, & Harrison, 2014). The most common

stimulants for ADHD management include methylphenidate and amphetamines, whilst the most common non-stimulants include atomoxetine and desipramine. A final resort for ADHD management is the prescription of antipsychotics or other unlicensed drugs (e.g., Adderall, Daytrana and Vyvanse; Bates, 2009) when all other management methods are unsuccessful (Catalá-López et al., 2017). There are multiple limitations surrounding both non-pharmacological and pharmacological treatments which limit adherence. For example, non-pharmacological treatments often lack in efficacy (Guo, Assumpcao, & Hu, 2022), and pharmacological treatments have many side effects, such as sleep deprivation, mood swings, headaches, and loss of appetite, that often result in discontinuation of the medicines (Toomey, Sox, Rusinak, & Finkelstein, 2012) and a feeling of lost identity (Travell & Visser, 2006).

2.2.2. Physical activity, exercise, and physical fitness

Physical activity has previously been defined as "*any bodily movement produced by skeletal muscles that results in energy expenditure*" (Caspersen, Powell, & Christenson, 1985). A more recent definition by Piggin (2020, p. 1) states "*physical activity involves people moving, acting, and performing within culturally specific spaces and contexts, and influenced by a unique array of interests, emotions, ideas, instructions and relationships".* Physical activity is described as multi-dimensional and is usually categorised by frequency, intensity, modality, and duration (Thivel, Tremblay, Genin, Panahi, Rivière, & Duclos, 2018). In neurotypical young people, physical activity has been shown to elicit beneficial effects physiologically (such as preventing cardiovascular disease, type 2 diabetes, and mental health disorders such as depression; Miles, 2007) (Eather, Ridley, & Leahy, 2020), cognitively (Drollette & Hillman, 2020), and for mental health (Biddle & Vergeer, 2020). The evidence currently suggests the greatest health benefits are when inactive individuals become more physically active (Warburton, & Bredin, 2016), and many of the benefits of physical activity are dependent on health conditions (Gledhill, 2001). The overall relationship between physical activity and general health status is still relatively poorly understood (Warburton & Bredin, 2018) and there has

also been evidence that physical activity is not beneficial for the aforementioned health conditions (Temporelli, 2021), thus it is important to highlight and consider that the evidence remains inconclusive.

The UK Chief Medical Officer guidelines for physical activity advise young people (aged 5 to 18 years) to engage in 60 min of moderate to vigorous physical activity on average a day, whilst minimising sedentary time (Gibson-Moore, 2019). In addition to this, young people are also encouraged to incorporate three days of muscle and bone strengthening activities (Chaput et al. 2020). With guidelines on physical activity engagement, it is surprising to find only 47% of young people met the UK government physical activity guidelines of 60 minutes per day with ~30% of young people only participating in up to 30 minutes per day (Sport England, 2023). With low participation and raised emphasis on the importance of physical activity for public health, it is important to understand the most effective way to engage young people in physical activity to elicit the aforementioned benefits. Furthermore, the physical activity guidelines are generalised for young people, with no specific guidance for young people with neurodevelopmental disorders such as ADHD, however a slightly higher percentage of young people with a disability (~51%) meet the UK physical activity guidelines of 60 minutes on average of moderate to vigorous physical activity per day (Sport England, 2023).

Although the terms physical activity and exercise are often used interchangeably, exercise is considered a sub-category of physical activity (Caspersen et al. 1985; Dasso, 2018). Exercise can be defined as "*physical activity that is planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective*" (Caspersen et al. 1985, p.126). Thus, exercise is a subset of physical activity where the primary aim is to improve fitness through planned and structured activities, whereas physical activity is linked to the movements people perform and the energy expenditure achieved through those movements (Caspersen et al. 1985). Within this thesis acute physical activity was defined as a single bout of physical activity lasting between 10 to 60 minutes (Liu et al., 2020). Chronic physical activity

interventions were defined as repeated bouts of physical activity over a set period of time (short- or long-term, e.g., weeks or months) (Sellami et al., 2018).

Another concept related to physical activity is physical fitness. Physical fitness can be defined as the skills and attributes that an individual possesses or achieves relating to their ability to perform physical activity (Caspersen et al., 1985). Being described as physically fit is defined as "*the ability to carry out daily tasks with vigour and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits and to meet unforeseen* emergencies" (Caspersen et al. 1985, p.128). There are key measurable components of physical fitness that can be split into two categories: health-related and skill-related component of fitness. There are a number of health-related components; cardiorespiratory endurance, muscular endurance, muscular strength, body composition, and flexibility (Caspersen et al. 1985), and skill-related components; agility, balance, coordination, power, speed, and reaction time (Corbin, Pangrazi, & Franks, 2000) that contribute to physical fitness.

2.2.3. Cognitive function

Although there is no universally agreed definition of cognitive function, one of the most common definitions defines cognitive function as a "*variety of different brain-mediated functions and processes*" (Schmitt, Benton, & Kallus, 2005). There are six main domains within cognitive function namely, executive function, memory, attention, perception, psychomotor and language (Schmitt et al. 2005) (Fig 2.1). These six domains can further be split into smaller domains, for example, memory can be categorised into short-term and long-term memory. Despite the ability to split the main domains into sub-domains, it is key to remember that these domains are often interlinked and reliant on each other (Schmitt et al. 2005). For example, in order to switch between tasks (cognitive flexibility; a sub-domain of executive function), attention and perception must be effectively used in order to process and correctly respond to the information and subsequently shift between tasks.

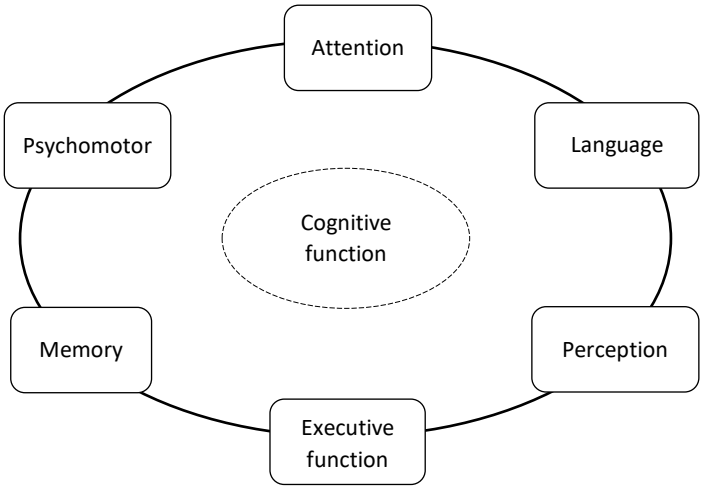


Figure 2.1. A basic schematic depicting the six domains of cognitive functioning (adapted from Schmitt et al. 2005)

Executive function (Fig 2.2) has been described as the most important domain of cognitive function for academic achievement (Best, Miller, & Naglieri, 2011; Willoughby, Wylie, & Little, 2019), compliance, emotion regulation, and social compliance (Carlson, Zelazo, & Faja, 2013). Commonly, executive function encapsulates three sub-domains: inhibitory control, working memory and cognitive flexibility (Diamond, 2013; Diamond, 2020; Doebel, 2020). It is important to understand that executive function develops throughout the lifetime, with significant improvements from the ages of 5 to 11 years (Diamond, 2013). The splitting of cognitive function into different domains and sub-domains, allow the assessment of cognition to be better examined and assessed.

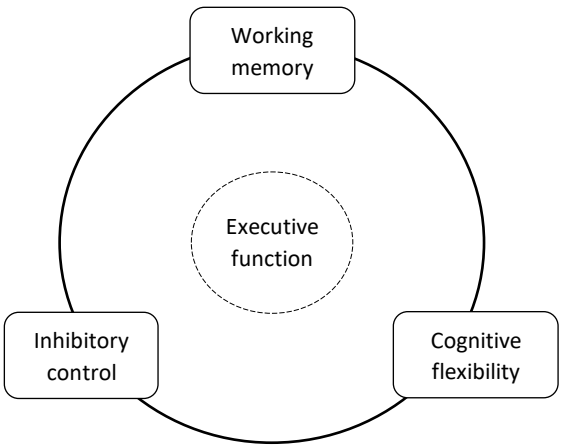


Figure 2.2. A basic schematic depicting the three domains of executive functioning.

Neuropsychological tests, commonly computer based, have been designed to assess each domain of cognition (Table 2.1). Key advantages of computer administered tests are the ability to measure speed and response consistency (Howieson, 2019); this allows for the careful prevention and consideration of potential speed-accuracy trade-offs (Schmitt, Benton, & Kallus, 2005). Due to the vast variety of cognitive tasks that can be used, it is difficult to interpret and compare cognitive improvements between studies.

Table 2.1. Cognitive domains and example cognitive task

Cognitive domain	Cognitive sub-domain	Example cognitive task
Executive function	Inhibitory control	Stroop Task
		Flanker Task
	Cognitive flexibility	Wisconsin Card Sorting Task (WCST)
	Working memory	Verbal Fluency
		Self-Ordered Pointing Test
Memory		Wechsler Memory Scale
		Colour Span Backwards Task
Attention		Conners continuous performance test
		Comprehensive Trail Making Test
Perception		Visual Object and Space Perception Battery (VOSP)
		Facial Recognition Test (FRT)
Psychomotor		Finger Tapping Test
Language		Expressive Vocabulary Test (EVT)

Note. Neuropsychological tests from Strauss, Sherman, and Spreen (2006).

In research with young people with ADHD, the same cognitive tests appear to be used as in neurotypical research. For example, working memory has been assessed using the digit span task and the Corsi block tapping test in research with both neurotypical (Andersson, 2010; Siquara, Lima & Abreu, 2018) and neurodiverse participants (Klingberg et al., 2005; Sleiman & Khanji, 2021; Wells et al., 2018; Ziereis & Jansen, 2015). Furthermore, executive function has been measured using the Flanker task (Benzing, Chang, & Schmidt, 2018; Liang, Qiu, Wang, & Sit, 2022; Pontifex et al., 2013), the Stroop test (Bigelow et al., 2021; Chang et al., 2012; Piepmeier et al., 2015), the Wisconsin Card Sorting test (Nejati & Derakhshan, 2021) and the Go/No-Go test

(Gawrilow et al., 2016; Nejati & Derakhshan, 2021). The effectiveness of these tests for measuring cognition between those with and without ADHD has not yet been examined.

2.2.4. Self-control

The overarching definition of self-control is "*the capacity for altering one's own responses, especially to bring them into line with standards such as ideals, values, morals, and social expectations, and to support the pursuit of long-term goals"* (Baumeister, Vohs, & Tice, 2007). Self-control, also referred to as self-regulation, is split into two domains: trait self-control and state self-control. Trait self-control refers to the innate ability to control actions and supress impulsive and recurrent responses to situations and environments (tag) and is closely related to self-discipline, which is defined as one's ability to work towards long-term goals and not give in to temptations (Hagger et al. 2021). Typically, trait self-control is measured through the Brief Self-Control Scale ([BSCS]; Tangney, Baumeister, & Boone, 2004) that asks questions surrounding ability to resist temptations, thought processes surrounding reactions to situations, and their perception of their own self-discipline. The BSCS has been used in research with adults (Pfeffer & Strobach, 2017; Pfeffer & Strobach, 2018), and in young people (Duckworth & Seligman, 2005; Finkenauer, Engels, & Baumeister, 2005; Ng-Knight et al. 2016), to a limited extent with individuals with ADHD (Uygur & Bahar, 2023; Saura-Garre et al., 2022). While, research investigating self-control in young people is limited, some child specific self-control scales have been developed, such as the 'Children's Perceived Self-Control Scale' by Humphrey (1982) and the 'Child Self-Control Rating Scale' ([CSCRS], Rohrbeck, Azar, & Wagner, 1991). Although the CSCRS has been used in self-control research with young people (Kuhnle, Hofer, & Kilian, 2012), a validated self-control scale for children is yet to be developed.

The present thesis examines self-control both in relation to trait self-control, outlined above, and state self-control. State self-control differs to trait self-control in that it refers to an individual's capability to utilise self-control more at some times than others (Gailliot, Gitter, Baker & Baumeister, 2012). State self-control has been described to

resemble a muscle with a limited supply of energy (Gailliot et al., 2012; Muraven & Baumeister, 2000). Another analogy to describe state self-control refers to self-control as a glass of water, of which over the day, self-control (the water) is utilised in different situations and is therefore gradually diminished. This concept is defined in the Strength Model of self-control (Baumeister, Vohs, & Tice, 2007) identifying self-control as a limited resource. Different contexts outlined in the Strength self-control model include *"controlling thoughts, managing emotions, overcoming unwanted impulses, fixing attention, guiding behaviour and making many choices"*. A second key model of state self-control is the Shifting Priorities Model (Inzlicht & Scheichel, 2012). The Shifting Priorities Model suggests that following self-control exertion, an individual experiences a shift in motivation, attention, and emotion of which results in a reduced ability to utilise self-control successfully in subsequent situations (Inzlicht & Schmeichel, 2012; Inzlitch, Schmeichel & Macrae, 2014). Young people with ADHD face many challenges day-to-day (e.g., managing emotions, overriding impulses, and maintaining inattention), which utilise one's self-control resource. With state self-control being described as a limited resource, or as a priority of which once used, an individual is unable to utilise in subsequent situations, it is possible that self-control in young people with ADHD is reduced (Bunford, Evans, & Wymbs, 2015).

With self-control being suggested to be reduced in young people with ADHD, (Bunford, Evans & Wymbs, 2015), a possible explanation for this is emotional dysregulation (Bunford, Evans, & Wymbs, 2015). Emotional dysregulation can be defined as "*patterns of emotional experience and expression that interfere with goal-directed activity"* (Thompson, 2019). In other words, emotional dysregulation refers to the ability of an individual to manage the speed of escalation, de-escalation, and intensity of an emotion (Bunford et al. 2015). An example of how the use of self-control in young people with ADHD can lead to positive or negative outcomes is presented in Fig 2.3.

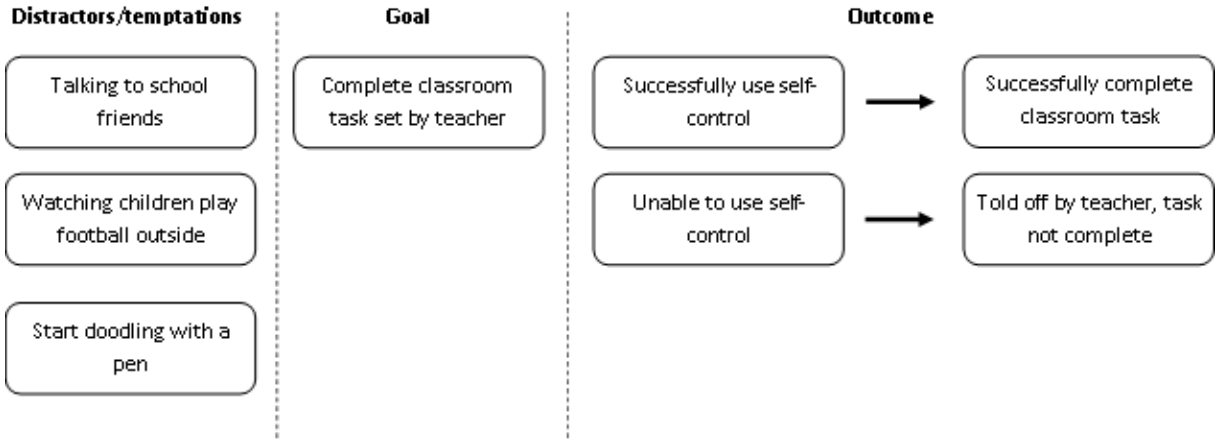


Figure 2.3. Schematic showing how self-control results in different outcomes for a child with ADHD

2.2.5. Resilience

Over the past thirty years, numerous definitions of resilience have been proposed in the psychology research literature based on alternative conceptualisations of resilience as a process or a trait (see, for a review, Fletcher & Sarkar, 2013). To illustrate, psychological resilience has been defined as a "*dynamic process encompassing positive adaptation within the context of significant adversity*" (Luthar, Cicchetti, & Becker, 2000, p. 543) and "*the personal qualities that enables one to thrive in the face of adversity*" (Connor & Davidson, 2003, p.76). The process conceptualisation of resilience recognises that it is a capacity that develops over time in the context of person-environment interactions (Egeland, Carlson, & Stroufe, 1993). When resilience is conceived as a trait, it has been suggested that it represents a constellation of characteristics that enable individuals to adapt to the circumstances they encounter. In the context of young people, greater psychological resilience to adversities during childhood has been found to result in healthier overall well-being in young adulthood (Nishimi et al. 2022), highlighting the importance of resilience for development in later life.

It is commonly recognised that young people with ADHD face a number of adversities such as academic difficulties, difficulty maintaining peer relationships, (Gardner & Gerdes, 2015), parent-child relationship issues (Lifford, Harold, & Thapar, 2008), and comorbidities (e.g., anxiety, autism, conduct disorder), all of which can affect

an individual's psychological resilience (Modesto-Lowe, Yelunina, & Hanjan, 2011). There are a range of different factors that can influence the resilience of young people with ADHD (see, for a review, Black et al., 2024, see also Dvorsky & Langberg, 2016; Mastoras et al., 2018; Regalla, Segenreich, Guilherme & Mattos, 2019). These include socioeconomic status and intelligence levels (Regalla et al., 2019), genetic factors (contributing up to 75% of ADHD-related behaviours), neural factors (delayed development of cortical maturation and cortical grey matter thickness in children and adolescents with ADHD compared to controls), child factors (those with behavioural and sociodemographic advantages have the best long-term ADHD management), parental factors (supportive and positive parenting techniques), peer factors (interaction with peers to facilitate social affiliation, conflict resolution and empathy) and pharmacological treatments (medications improve social functioning and mental health) (Modesto-Lowe et al. 2011). Furthermore, other potential factors in neurotypical people, include different psychological factors/characteristics including self-efficacy and state anxiety (Etherton et al., 2022). In line with the trait conceptualisation of resilience, these factors are often referred to as promotive and protective factors in the psychological resilience literature (Dvorsky & Langberg, 2016; Fullerton, Zhang, & Kleitman, 2021).

In addition to psychological resilience, social resilience has been discussed within the ADHD population and can be defined as "*the capacity to develop and exhibit social competence despite life stressors and behavioural challenges*" (Jia, Mikami, & Normand, 2021, p. 840). In terms of social stressors and challenges encountered in young people with ADHD, the family environment has been highlighted as a potential factor impacting social resilience (Jia et al., 2021). Some studies have revealed that parental involvement and family cohesion could impact family environments and subsequently impact social resilience in young people with ADHD (Black et al., 2024; Duh-Leong, Fuller & Brown, 2020; Dvorsky & Lanberg, 2016; ; Kawabata, Tseng, & Gau, 2012; Mastoras, Saklofske, Schwean, & Climie, 2018; Ray, Evans, & Langberg, 2017).

Aside from the promotive and protective factors associated with influencing resilience in young people with ADHD, in terms of levels of resilience, 50-53% of children with ADHD in a sample of 108 children with ADHD were found to have high(er) levels of resilience (via parent and teacher self-report), which was found to be on a par with a comorbidity matched neurotypical sample (Chan et al. 2022). Notwithstanding these figures, a high percentage of children in this population (~47-50%) exhibited low(er) levels of resilience, and questions still remain regarding individual, family, and social aspects that promote resilience in young people with ADHD (Chan et al. 2022). In terms of the measurement of resilience, in line with the trait conceptualisation, resilience is commonly assessed quantitatively via questionnaires such as the Connor-Davidson Resilience Scale ([CD-RISC]; Connor & Davidson, 2003; Campbell-Sills & Stein, 2007). The 10-item CD-RISC questionnaire includes statements such as: "*I am able to adapt to change*", "*I tend to bounce back after illness or hardship*", "*I am not easily discouraged by failure*", and "*I can handle unpleasant feelings*" (Campbell-sills & Stein, 2007). The CD-RISC 10 is one of the most common reliable and valid resilience measures (Windle et al., 2011) and has been used in a wide variety of research (Durish, Yates, & Brooks, 2018; Fullerton et al. 2021) including with children and young people with ADHD (Black et al., 2024; She, Yang, Lau, & Lau, 2020).

2.3. Relationships of physical activity and physical fitness with cognitive function in neurotypical young people and young people with ADHD

The following section of the literature review will consider the acute and chronic relationships of physical activity and physical fitness with cognitive function in young people. There will be a focus on young people with ADHD, however each section will start with a brief overview of the evidence in neurotypical young people. The studies assessing the chronic effects of physical activity and physical fitness are primarily cross-sectional in nature, whilst the studies assessing the acute effects of single bouts of physical activity tend to be intervention-based studies.

2.3.1. Physical activity and cognitive function: Cross-sectional studies

2.3.1.1. Neurotypical young people

Recent meta-analyses suggest that there are positive associations between physical activity and cognitive function in neurotypical young people (Bidzan-Bluma & Lipowska, 2018; Donnelly et al. 2016; Sibley & Etnier, 2003). Findings, however, remain inconsistent (Singh et al. 2018). This could be due to variability in the research methodology or outcome measures (Donnelly et al. 2016). The current literature has primarily focused on the associations of physical activity on academic achievements, suggesting that chronic physical activity (such as physical education interventions, circuit training, aerobic training, and self-reported physical activity participation) has a medium positive effect on academic achievement (including achievement on verbal and maths tests, grade point averages, and standardised test scores) in children and adolescent, whereas acute physical activity has no effect on academic achievement in this population (Barbosa et al. 2020). Specifically, increased time spent doing physical activity appears to be positively associated with mathematics and reading (small to medium effects) with the greatest effects on geography (Barbosa et al. 2020).

Research investigating the associations between physical activity and cognitive function in neurotypical young people has focused on many different cognitive domains which makes it challenging to compare between research studies. Currently, the research has identified that physical activity is positively associated with on-task attention (Kubesch et al., 2009; Syväoja et al., 2014) and planning (Pirrie & Lodewyk, 2012). A meta-analysis by Bidzan-Bluma and Lipowska (2018) also found that physical activity was positively associated with changes to brain structures, resulting in improved working memory, and cognitive flexibility. A further potential issue surrounding the methodology of research investigating the associations between physical activity and cognitive function or academic achievement, is linked to the measurement of physical activity, making it difficult to compare research methodologies. Due to feasibility and access to materials (Corder et al. 2009), physical activity is often measured via subjective self-report measures (Donnelly et al. 2016) such as the International Physical Activity Questionnaire ([IPA-Q] Aggio et al. 2016) or physical activity diaries. Such self-report measures have a number of limitations,

including variance in question interpretation and self-report bias (over- and under-estimating) (Marasso et al., 2021). Even though it is difficult to compare and contrast the research, the weight of evidence suggests a positive association between habitual physical activity and cognitive function in neurotypical young people.

2.3.1.2. Young people with ADHD

The association between physical activity and cognition in young people with ADHD is under-represented in the current literature, with only two studies to date having examined this association (Gapin & Etnier, 2010; Liang et al., 2022), see Table 2.2. Research by Gapin and Etnier (2010) used both accelerometers and a physical activity diary log to measure the association between physical activity levels and executive function performance in eighteen children aged 8 to 12 with ADHD. The results revealed that physical activity was positively associated with executive function (specifically; planning) in children diagnosed with ADHD (Gapin & Etnier, 2010). The most recent research investigating the associations between physical activity and cognition by Liang et al., (2022) found a positive association between physical activity and working memory (measured via The Tower of London task). However, a negative association was found between cognitive flexibility (measured through the trail making test) and physical activity, with sleep latent suggested to be a mediating factor affecting the cross-sectional associations; thus suggesting the associations with physical activity may be different for different cognitive domains.

It is clear to see that more research is required to investigate the promising relationship between physical activity and cognitive function in young people with ADHD, with a focus on using both subjective (such as physical activity diaries, and physical activity questionnaires or interviews) and device measured (such as accelerometers or pedometers) methods to assess perceptions and actual physical activity levels in this population across a broader range of domains of cognitive function.

2.3.2. Physical fitness and cognitive function: Cross-sectional studies

2.3.2.1. Neurotypical young people

There is a growing body of literature in neurotypical young people suggesting a beneficial role of physical fitness on executive function performance (Buck, Hillman, & Castelli, 2008; Chaddock et al., 2010), attention (Hillman, Castelli, & Buck, 2005) and memory (Chaddock, Hillman, Buck & Cohen, 2011). In cross-sectional research, aerobic fitness is commonly assessed using the multi-stage fitness test (Ramsbottom et al., 1988) or the Andersen-Test (Andersen, Andersen, Andersen, & Anderssen, 2008). The current literature shows a positive association between physical fitness and different cognitive domains in neurotypical children (Wick, Kriemler, & Granacher, 2022) and adolescents (Mora-Gonzalez et al., 2019; Westfall et al., 2018).

2.3.2.2. Young people with ADHD

In young people with ADHD, the associations between physical fitness and cognitive function have only been examined by one research article (see Table 2.3). Research by Tsai, Hung, Tsai, Chang, Huang, & Hung (2017) was the first and only to examine this relationship. Tsai et al. (2017) investigated the associations between the top 40% (high-fit) and bottom 40% (low-fit) of 80 participants aged 8 to 12 years with ADHD, with different physical fitness components (flexibility, muscular endurance, muscular power, aerobic capacity, and body composition). It was found that greater fitness (specifically muscular endurance, muscular power, aerobic capacity, and body composition) was associated with enhanced inhibitory control in young people with ADHD. With such limited research within this population, it is key for future research to extend this research by investigating additional cognitive domains, and cardiorespiratory fitness outcomes.

Table 2.2. Associations between physical activity and cognitive function in young people with ADHD

Authors (year) and *Country*	Participant details	Physical activity measures	Cognitive function measures	Main findings
Gapin & Etnier (2010) *USA*	N = 18 10.61 ± 1.50 y ADHD-H/I = 5 ADHD-I = 2 ADHD-C = 8	Free living physical activity (accelerometer) Daily PA log	Inhibitory control – Conners' Continuous Performance Test (CPT-II) Planning – Tower of London Working memory – Digit Span Processing speed – Children's colour Trails Test 1 and 2 (CCTT 1 & 2)	Moderate to vigorous physical activity positively associated with performance on Tower of London (planning) Other cognitive outcomes were increased although was non-significant
Liang et al., (2022) *China*	N = 56 8.82 ± 1.49 y	Free living physical activity (ActiGraph)	Inhibitory control - Flanker task Working memory and planning – Tower of London Cognitive flexibility – Trail Making Test	Working memory was positively associated with moderate-to-vigorous physical activity. Cognitive flexibility was negatively associated with moderate to vigorous physical activity.

Note. NT = neurotypical, ADHD-C = combined presentation, ADHD-I = inattentive presentation, ADHD-HI = hyperactive impulsive presentation

2.3.3. Acute physical activity interventions and cognitive function

2.3.3.1. Neurotypical young people

A review highlighted the beneficial effect of acute physical activity interventions on cognitive functioning in young people (Hillman, Logan, & Shigeta, 2019). Specifically, there are effects of acute physical activity on different cognitive function domains. Working memory (Budde et al., 2010; Pesce, Crova, Cereatti, Casella, & Bellucci, 2009) and attention (Chen et al., 2014; Kubesch et al., 2009; Gallotta et al., 2015) have been shown to be enhanced following acute submaximal physical. Additionally, executive function has also been shown to be improved following games-based physical activity interventions (Cooper et al., 2018), cycling (Ellemberg & St-Louis-Deschênes, 2010; Park & Etnier, 2019), and exergaming (Benzing et al., 2019). Although the effects of chronic physical activity interventions have been investigated more thoroughly, it is still important to assess the acute physical activity benefits on cognition as these effects are likely to contribute to long-term benefits. A recent review by Pontifex et al. (2019) highlighted the key focus of acute moderate-to-vigorous physical activity interventions on cognition and subsequently suggested that there is a requirement for a more focused approach on specific cognitive domains, populations, and mechanisms affecting the relationship.

Table 2.3. Associations between physical fitness and cognitive function in young people with ADHD

Authors (year) and *Country*	Participant details	Physical fitness measures	Cognitive function measures	Main findings
Tsai et al. (2017) *Taiwan*	N = 80 8 to 12 y	Flexibility = sit-and-reach Muscular endurance = curl-ups Muscular power = standing long jump Aerobic capacity = 800m run Body composition = body mass index-BMI	Inhibitory control – Flanker task	Higher muscular endurance, muscular power, and aerobic capacity and lower body composition was associated with better performance on the Flanker task

2.3.3.2. Young people with ADHD

As previously highlighted, there is a relationship between physical activity and physical fitness with cognitive function in young people with ADHD. With this knowledge, it is important to assess how an implemented single bout of physical activity effects the cognitive function (and subsequently behaviour and symptom management) in children and adolescents with ADHD. Encouraging work has indeed reported a direct benefit of acute physical activity behaviour in children and adolescents with ADHD (Chan, Jang, & Ho, 2022). Impulsive behaviour and inhibitory control have been directly linked in young people with ADHD (Ames & White, 2011) and may suggest why behaviour has often been interlinked with cognition and assessed independently with physical activity interventions.

There have been a number of different acute physical activity interventions implemented in young people with ADHD examining the effects of a single bout of physical activity on different cognitive domains (see Table 2.4.). Executive function has arguably been the domain of cognition investigated in the greatest depth. This is likely due to the aforementioned poorer executive function displayed by young people with ADHD (Glozman & Shevchenko, 2014). Research investigating the effects of acute physical activity on executive function in children and adolescents with ADHD include that by Benzing, Chang and Schmidt (2018), who showed 15-min of moderate intensity exergaming elicited greater performance on inhibition and switching on the Flanker task and Colour Span Backwards task (measured via enhanced response times). Additional acute physical activity interventions that evoked beneficial effects on executive function in young people with ADHD include running (Chang, Liu, Yu & Lee, 2012; Pontifex et al. 2013; Miklós, Komáromy, Futó, & Balázs, 2020; Yu et al., 2020), cycling (Piepmeier et al. 2015; Ludyga et al. 2017; Ludyga et al. 2020) and trampolining (Gawrilow et al., 2016).

The cognitive domain of attention was also examined, research by Medina et al. (2010) found specific improvements in response time on the Conner's Continuous Performance Test following physical activity. However, when considering the cognitive domain of working memory, one study did not find any improvement following 30-minutes

of seated cycling on a desk-bike compared to 30-minutes of seated rest (Ruiter, Görlich, Loyens, Wong, & Paas, 2022).

2.3.4. Chronic physical activity interventions and cognitive function

2.3.4.1. Neurotypical young people

It has been shown that chronic physical activity interventions are promising in improving multiple aspects of cognitive function, with a highlighted improvement on executive functioning and inhibitory control (Xue, Yang, & Huang, 2019) in neurotypical children and adolescents. Some of the research remains inconsistent, for example Watson et al. (2017) reviewed the literature investigating classroom-based physical activity interventions and found that the effects on cognitive function were inconsistent. It was suggested that this could be due to quality of measures used and type of cognitive function domain assessed, limiting the conclusions that can be drawn (Watson et al. 2017). However, a large proportion of the literature shows beneficial effects of chronic physical activity on multiple aspects of cognition in neurotypical young people (Álvarez-Bueno et al. 2017).

2.3.4.2. Young people with ADHD

A recent review by Welsch et al. (2021) identified 13 studies that used chronic physical activity interventions for young people with ADHD. The literature surrounding chronic physical activity and cognition in young people with ADHD is still in its infancy, with much of the literature having been conducted in the last 10 years (see table 2.5.). One of the earliest research articles by Ahmed and Mohamed (2011), investigated the effects of a progressive aerobic moderate-intensity physical activity program spread over 10 weeks. This study found improvements in academic and classroom behaviour, attention, and motor skills following the physical activity condition, with no significant improvements in the resting control group (Ahmed & Mohamed, 2011). Similarly, Verret, Guay, Berthiaume, Gardiner, and Béliveau, (2012) employed a progressive aerobic physical activity program over 10-weeks with a focus on aerobic, muscular, and motor

Table 2.4. Acute physical activity interventions on cognitive function in young people with ADHD

Authors (year) and *Country*	Participant details	Physical activity measure	Control	Cognitive function measures	Main findings
Pontifex et al. (2013) *USA*	N = 20 ADHD 9.3 ± 0.3 y; ADHD-C 9.5 ± 0.3 y; ADHD-I 9.6 ± 0.9 y; ADHD-HI N = 20 NT 9.8 ± 0.1 y	Treadmill running (65%-75% HR_{max}) 20 min	Seated reading 20 min	Inhibitory control – Flanker task	Both young people with ADHD and neurotypical young people exhibited greater accuracy and processing on the Flanker task post-exercise
Chang et al. (2012) *Taiwan*	N = 40 10.43 ± 0.90 ADHD-C = 21 ADHD-I = 14 ADHD-HI = 5	Treadmill running (50%-70% HRR) 30 min	Video-watching 30 min	Inhibitory control - Stroop test Cognitive flexibility – Wisconsin Card Sorting Test (WCST)	Improved performance (accuracy) on Stroop colour-word condition Less errors on WCST
Chuang et al. (2015) *Taiwan*	N = 19 9.42 ± 1.38 ADHD-C = 7 ADHD-HI = 12	Treadmill running (60% HRR) 30 min	Video-watching 30 min	Inhibitory control – Go/No Go paradigm	Improvements in response time following physical activity
Ludyga et al. (2017) *Switzerland*	N = 16 ADHD 12.8 ± 1.8 NT = 18 13.5 ± 1.3	Cycling at moderate intensity (65-70% $HR_{max)}$ Coordinative exercises-object control skills and bilateral coordination skills	Video-watching 20 min	Inhibitory control – Flanker task	Decreased response time on congruent and incongruent Flanker task following physical activity

Authors (year) and *Country*	Participant details	Physical activity measure	Control	Cognitive function measures	Main findings
Piepmeier et al. (2015) *USA*	N = 14 ADHD 10.14 ± 1.96 y ADHD-C = 2 ADHD-I = 6 ADHD-HI = 2 N = 18 NT 11.22 ± 2.43 y	Cycling on cycle-ergometer (40-60 RMP/ RPE 5-7) 30 min	Video-watching 30 min	Inhibitory control - Stroop test Inhibitory control – Tower of London Cognitive flexibility – Trail Making Test	Improvements in processing speed and inhibitory control via Stroop test following physical activity. No effects on performance on Tower of London or Trail Making Test
Medina et al. (2010) *Brazil*	N = 25 M = 9.33 ± 2.87 NM = 9.75 ± 2.38	Treadmill activity 10 x 2min effort (target HR 165 – 169 beats·min^{-1})	1 min stretching session	Attention – Conner's continuous performance test- II	Physical activity elicited benefits in reaction time on the CCPT-II in both M and NM ADHD groups
Benzing et al. (2018) *Switzerland*	N = 46 10.48 ± 1.38	Exergaming task 15 min	Video-watching 15 min	Inhibitory control – Flanker task Visual working memory – Colour span backwards	Improvements in response time in inhibition and switching following physical activity
Gawrilow et al. (2016) *Germany*	N = 47 10.47 ± 1.49	Trampolining jumping 5 min	Colouring 5 min	Inhibitory control – Go/ No Go paradigm	Greater successful response inhibition in the physical activity condition with fewer errors

Authors (year) and *Country*	Participant details	Physical activity measure	Control	Cognitive function measures	Main findings
Bigelow et al. (2021) *Canada*	N = 16 11.38 ± 1.5	Cycling on a cycle-ergometer (65%-85% HR_{max}) 10 min	Mindfulness meditation 10 min Reading 10 min	Inhibitory control – Stroop test Working memory - Leiter 3 reverse memory scale Cognitive flexibility – Trail making test	Mindfulness meditation elicited greater improvements on executive function than acute physical activity
Ruiter et al., (2022) *Netherlands*	N = 18 15.62 ± 2.20 y	Cycling on a desk bike 30 min	Seated-rest	Working memory – Wechsler Intelligence Scale for Children	No statistically significant improvement on working memory

Note. M = medicated, NM = non-medicated, NT = neurotypical young people, ADHD-C = combined presentation, ADHD-I = Inattentive presentation, ADHD-HI = Hyperactive-impulsive presentation

skills exercises. It was found that the experimental group had lower response times on visual research tests and sustained attention following the physical activity program, along with greater parent and teacher reported behavioural scores in the experimental group compared to the control condition (Verret et al. 2012). Other studies have used progressive or varied aerobic physical activity programs to examine the effects of physical activity on cognition in young people with ADHD, finding benefits on working memory (Ziereis & Jansen, 2015), inhibitory control (Memarmoghaddam et al. 2016) and cognitive flexibility (Liang et al. 2022).

A number of studies have also been conducted specifically examining aquatic exercise. For example, Chang et al., (2012) conducted an 8-week aquatic moderate intensity physical activity program that revealed that children with ADHD had a substantial improvement in accuracy on the NoGo stimulus, an aspect of the Go/NoGo task that assesses inhibitory control, compared to the waiting-list control. Hattabi et al., (2022) also found improved inhibitory control scores following a 12-week aquatic physical activity programme. More recently, Da Silva et al. (2020), similarly used aquatic exercises to assess cognition and found improvements in cognitive flexibility and selective attention following the physical activity intervention. Although these aquatic studies revealed cognitive benefits across different domains of cognitive function, it is important to highlight the lack of intensity measurement, making it extremely difficult to identify the optimal intensity to elicit benefits. Finally, utilising a different activity mode, a study on 40 young people with ADHD investigated the effects of an 18-month Taekwondo intervention on inhibitory control measured via the Stroop task and visual attention measured via the Ruff 2 and 7 test (Kadri et al. 2019). Kadri et al (2019) found significant improvements in all aspects of both the cognitive tests, suggesting taekwondo is a potential beneficial intervention to elicit improvements in inhibitory control and attention in young people with ADHD.

Table 2.5. Chronic physical activity interventions on cognitive function in young people with ADHD

Authors (year) and *Country*	Intervention Group		Control Group		PA Intervention					
	n	Mean age (SD)	n	Mean age (SD)	PA	Duration	Intensity	Control condition	CF domains	Main findings
Ziereis & Jansen (2015) *Germany*	EG1 = 13 EG2 = 14	9.2 ± 1.3y 9.6 ± 1.6y	16	9.5 ± 1.4y	Mixed PA: Ball games	1 x 60 min per week; 12-weeks	N/A	Waiting list	Verbal and visual-spatial working memory Inhibitory control	Mixed ball games improved working memory performance (Index scores, digit span forwards and digit span backwards).
Benzing & Schmidt (2019) *Switzerland*	28	10.46 ± 1.30y	23	10.39 ± 1.44y	Exergaming	3 x 30 min per week; 8-weeks	N/A	Waiting list	Inhibitory control Working memory	Exergaming improved executive function specifically inhibition and switching (reaction times)
Pan et al. (2019) *Taiwan*	15	9.08 ± 1.43y	15 ADHD 30 NT	8.90 ± 1.66y 9.14 ± 1.54y	Table tennis programme	2 x 70 min per week; 12-weeks	N/A	Not stated	Attention Inhibitory control Cognitive flexibility	Inhibitory control (measured by the Stroop colour-word test) was significantly improved following the 12-week physical activity intervention
Chang et al. (2014) *Taiwan*	14	8.19 ± 7.65y	13	8.78 ± 8.33y	Aquatic exercise	2 x 90 min per week; 8-weeks	Moderate-intensity	Waiting list	Inhibitory control	Accuracy on the Go/Nogo test was significantly improved following 8-weeks of aquatic exercise
Chou & Huang (2017) *Taiwan*	24	10.71 ± 1.00y	25	10.30 ± 1.07y	Yoga	2 x 40 min per week; 8 weeks	Moderate (50-60% HR_{max})	Normal life without physical activity program	Perception Attention	Attention was improved following 8-weeks of yoga in young people with ADHD

Authors (year) and *Country*	Intervention Group		Control Group		PA Intervention					
	n	Mean age (SD)	n	Mean age (SD)	PA	Duration	Intensity	Control condition	CF domains	Main findings
Verret et al. (2012) *Canada*	10	9.1 ± 1.1y	8	9.1 ± 1.1y	Progressive aerobic, muscular, and motor skills exercises (e.g., basketball, football)	3 x 45 min per week; 10 weeks	Moderate-vigorous intensity	No stated	Attention Response inhibition	Improved attention and improved information processing following intervention.
Da Silva et al. (2020) *Brazil*	10	12 ± 2y	10	12 ± 1y	Aquatic exercise	2 x 45 min per week; 8 weeks	Not stated	Not stated	Cognitive flexibility Attention	Improved cognitive flexibility and selective attention in young people with ADHD.
Ahmed & Mohamed (2011) *Saudi Arabia*	42	13.9 ± 1.6y	42	13.8 ± 1.7y	Aerobic exercises	3 x 45 min per week; 10 weeks	Moderate intensity	No exercise programme	Attention (via behaviour rating scale)	Improved attention following aerobic exercise.
Memarmoghaddam et al. (2016) *Iran*	19	8.31 ± 1.29y	17	8.29 ± 1.31y	Goal-directed exercise;10 min training station;15 min running on a treadmill;15 min ball games	3 x 90 min per week; 8 weeks	Not stated	Not stated	Inhibitory control Attention	Inhibitory control was improved following physical activity intervention, however attention was not improved.

Authors (year) and *Country*	Intervention Group		Control Group		PA Intervention					
	n	Mean age (SD)	n	Mean age (SD)	PA	Duration	Intensity	Control condition	CF domains	Main findings
Kadri et al. (2019) *Tunisia*	20	14.5 ± 3.5y	20	14.2 ±3y	Taekwondo intervention	2 x 50 min per week; 1.5 years	Not stated	Physical activities such as handball in P.E. lessons at school	Inhibitory control Sustained attention	Selective attention was improved (measured on the Stroop test) following the Taekwondo intervention.
Hattabi et al., (2022) *Tunisia*	N = 20	9.95 ± 1.31y	20	9.75 ± 1.33	Aquatic exercises	3 x 90 min per week; 12 weeks	50-70% maximum HR	Not stated	Inhibitory control	Inhibitory control was significantly improved following a 12-week aquatic exercise intervention.

Note. EG1 = exercise group 1, EG2 = exercise group 2, NT = neurotypical

2.3.5. Moderating variables in both acute and chronic physical activity interventions

There have been suggested to be multiple moderating factors that could potentially influence the effects of physical activity on cognitive function (Pesce, 2009; Williams et al. 2019). These effects have been discussed in a review paper by Williams et al (2019) in neurotypical children and adolescents, highlighting three exercise characteristics potentially affecting this relationship (intensity, duration, and modality), along with five personal/participant characteristics (age, physical activity levels, physical fitness, cognitive ability, and weight status).

2.3.5.1. Duration

In neurotypical young people, Williams et al (2019) concluded from their review of the literature that physical activity greater than 20 minutes in duration has the potential to elicit beneficial effects on all domains of cognition. In terms of physical activity duration in young people with ADHD, there has been limited research. Craft (1983) investigated the effects of 1 min, 5 min, and 10 min of cycling on an ergometer at a maintained physical work capacity of 170 beats.min^{-1}. Craft (1983) found no significant effect of physical activity duration on cognition; however, this could be due to the short durations of physical activity which may not be sufficient to elicit cognitive benefits (Grassman et al., 2017). Craft (1983) is the only study to date to examine different durations of physical activity and cognitive function in young people with ADHD. Other research has shown effects of longer durations of a single bout of physical activity (Chang et al. 2012; Chuang et al. 2015; Ludyga et al. 2020), however, the ‘optimum’ duration is yet to be understood.

2.3.5.2. Intensity

Intensity has also been suggested to moderate the effects of acute physical activity on cognition, with Williams et al. (2019) highlighting the limited research investigating this effect in neurotypical young people. High-intensity physical activity has been suggested to affect some parts of attention (Russo, Castagnoli, Babini, & Ceciliani, 2020). Comparatively, a study investigating differences between passive, moderate

intensity and vigorous intensity physical activity breaks in school found moderate intensity breaks evoked the greatest benefits on selective attention (Janssen et al. 2014). Within ADHD research, different physical activity intensities are yet to be examined, and therefore no conclusions can be made regarding the physical activity intensity most beneficial for cognitive performance in this population.

2.3.5.3. Modality

Finally, modality of physical activity has been highlighted as a key moderating factor affecting the physical activity-cognition relationship (Williams et al. 2019). In neurotypical young people there has been an increased focus on cognitively engaging exercises such as coordinative exercise, however results are still inconclusive as to whether this elicits beneficial effects on aspects of cognition (Schmidt, Egger & Conzelmann, 2015; Ishihara, Sugasawa, Matsuda & Mizuno, 2017), or not (Gallotta et al. 2014). In young people with ADHD, a range of different modalities of physical activity have been used. Coordinative physical activity interventions have also been explored in this population and have yielded promising results (Ludyga et al. 2017), however with the limited research, further research is required to confirm whether cognitively engaging activity is more beneficial than other modalities of physical activity.

2.3.6. Mechanisms underpinning the effects of physical activity, physical fitness, and exercise on cognitive function

There has been a growing body of research investigating the underlying mechanisms underpinning the effects of physical activity, physical fitness, exercise and cognitive functioning. Cerebral blood flow (Endres et al., 2003; Swain et al., 2003), brain-derived neurotrophic factor (BDNF) (Piepmeier & Etnier, 2015; Vaynman, Ying, & Gomez-Pinilla, 2004) and cerebral structure (Chaddock, Pontifex, Hillman & Kramer, 2011) have been linked to physical fitness and physical activity (Marmeleira, 2013). Furthermore, in adults, research has found relationships between neural activation and physical activity (Ekkekakis et al., 2005; Petruzzello & Tate, 1997).

The cerebral blood flow hypothesis suggests that physical activity increases oxygen and glucose transport to the brain which in turn improves brain function (Renke, Marcinkowska, Kujach & Winklewski, 2022). Controversially, research has suggested that during physical activity there is actually a reduced cerebral blood flow, and any cognitive improvements are due to cerebral neural activation rather than cerebral perfusion (Ogoh et al., 2014). Thus, without more specific research to identify exactly whether it is cerebral perfusion, or neural activation that is a consequence of physical activity, the evidence remains unreliable and unclear; however, what is known is that physical activity appears to elicit improvements in brain functioning and cognition.

BDNF has been shown to be key in cognitive performance and brain adaptations (Cirulli et al., 2004; Horch et al., 1999; Mu et al., 1999). Much of the literature examining the effects of BDNF on cognition has been conducted on animals and thus the replicability in humans has only more recently been examined. However, the literature linking physical activity and BDNF levels has been extensively researched showing higher levels of physical activity are associated with higher BDNF (Walsh & Tschakovsky, 2018), with much of this literature linked to additional cognitive benefits (Dinoff, Herrmann, Swardfager & Lanctôt, 2017; Walsh et al., 2020).

2.4. The effects of physical activity and physical fitness on self-control in young people with ADHD

2.4.1. Physical activity and self-control: Cross-sectional studies

Self-control and exercise behaviours have been shown to be related in neurotypical young people with associations between high self-control, increased fruit and vegetable intake, and reduced sedentary time (Wills et al. 2008; Junger & van Kampen, 2010). On the other hand, low self-control is associated with increased saturated fat intake, and lower amounts of time spent participating in vigorous physical activity (Wills et al. 2008). High self-control, in respect to physical activity self-regulation (the ability to plan and take action on participating in physical activity), has been shown to be associated with greater physical activity involvement in physically active adolescents (Gerber et al. 2015).

In young males, a linear association between self-control and self-reported physical activity, aerobic fitness, and muscular fitness was found, indicating that higher self-control scores were associated with better performance on the fitness test (12-minute Cooper run) (Kinnunen et al. 2012). This was the first study to examine the associations between physical fitness and self-control. More recently, a cross-sectional study found high levels of trait self-control is associated with higher physical fitness in adolescents (Boat et al. 2022), further supporting that self-control is associated with healthy behaviours.

In young people with ADHD, the literature is still somewhat limited, however, physical education duration and frequency has been positively associated with teacher reported self-control (Barnard-Brak, Davis, Sulak & Brak, 2011) (see table 2.6). Whereby, those children with high self-control participated in greater teacher-reported physical activity. Therefore, there is a gap in the literature that investigates associations between self-control and physical activity in young people with ADHD, specifically there is a lack of studies using device measured physical activity methodology (such as accelerometers).

2.4.2. Acute and chronic physical activity interventions and self-control

Physical activity has been used to assess improvements in self-control over two months in young adults (Oaten, & Cheng, 2006). It was found that a 2-month physical activity intervention (3-4 cardiovascular exercise sessions per week) improved good choice behaviours associated with self-control, such as healthy eating, reduced impulse spending and increased time spent on academic work (Oaten & Cheng, 2006). Physical activity has also been used in a 2-year intervention to ‘train’ and improve self-control in young people during physical education lessons at school (Pesce, Lakes, Stodden, & Marchetti, 2021). The intervention consisted of games (requiring self-control) that employed ‘red-light’ style activities with instruction to ‘stop’ and ‘go’ at different points. Results revealed that those who participated in the self-control physical activity intervention had lower levels of quick-temperedness and disruptiveness compared to the control condition, further highlighting these beneficial effects (Pesce et al. 2021). Other

Table 2.6. Associations between physical activity and physical fitness with self-control in young people with ADHD

Authors (year) *and Country*	Participant details	Physical activity measures	Self-control measures	Main findings
Barnard-Brak et al. (2011) *USA*	N = 17565	Teacher reported physical activity based on physical education lessons – time per week and duration per lesson	Self-control composite – questionnaire completed by teachers on how well a student is able to control their behaviours	Positive association between teacher reported self-control and physical activity across 6 years in children as well as lower levels of ADHD symptoms

research has suggested a bidirectional relationship between physical activity and cognition suggesting that greater self-control results in increased adherence and participation in physical activity (Crescioni et al. 2011; Dishman, Jackson, & Bray, 2014; Stadler, Oettingen, & Gollwitzer, 2009).

In young people aged 7-8 years with intellectual disabilities, a structured physical activity program to develop psychosocial behaviours was successful in improving emotional self-control following 8-weeks of motor skills such as, jumping, balance, sensory control, agility, and upper body strengthening (Choi & Cheung, 2016). Furthermore, studies have also found that physical activity improves self-control aspects of social skills in young people with autism and intellectual disabilities (Zhao, & Chen, 2018; Yilmaz, & Soyer, 2018) as well as a unique mind-body exercise program with a focus on relaxation (Chan, Sze, Siu, Lau, & Cheung, 2013). Shachar et al. (2016) conducted a physical activity program, whereby participants attended afterschool sport activities five times a week for an academic year to assess self-control and aggressive behaviours in young people who demonstrate observed aggressive behaviours in school. Shachar et al. (2016) found that self-control skills were improved following the physical activity program, and suggested these skills were improved after reduced hostile thoughts, and changes in positive and negative emotions. In girls, changes in self-control skills were directly linked to changes in physical aggression, whereas in boys, these changes in self-control were linked indirectly to changes in physical aggression through changes in their positive and negative emotions (Shachar et al. 2016). Reactive aggression has been associated with ADHD in young people as this type of aggression is linked to impulsive behaviours, a subtype of ADHD (Retz & Rösler, 2009). With this evidenced association between behavioural self-control (e.g., managing aggression and hostile thoughts) and physical activity participation, it could be that similar findings could be found within young people with ADHD; however, this association has only been examined by one study to date (see table 2.7). Bowling et al. (2017) investigated the effects of cyber-cycling (an exergame) on behavioural self-control (via a self-regulation score) in 103 young people (aged 7 to 16 years) with ADHD and autism. An inverse linear relationship was found,

whereby increased time spent exercising positively correlated with decreased minutes spent in disciplinary time, measured via self-regulation score (Bowling et al. 2017). The results show that even a short duration of moderate intensity exercise can elicit beneficial behavioural outcomes and self-control scores in young people with ADHD. Further research is still required to examine this association, however the study by Bowling et al. (2017) shows promising findings.

2.5. The effects of physical activity and physical fitness on resilience in young people with ADHD

The following section of the literature review will consider the acute and chronic effects of physical activity and physical fitness on resilience in young people. Although there will be a focus on young people with ADHD, the section will start with an overview of the evidence in neurotypical young people. Overall, there is limited research investigating the effects of physical activity on resilience. This section will be split into cross-sectional research and research investigating acute and chronic physical activity interventions.

2.5.1. Physical activity, physical fitness, and resilience: Cross-sectional studies

In neurotypical young people, physical activity has been associated with high(er) psychological resilience (Ho et al. 2015; Moljord et al. 2014). Ho et al. (2015), found a positive association between physical activity levels (measured via self-report questionnaires), and psychological resilience (measured through the CD-RISC) in adolescents aged 12 to 14 years. The positive association between physical activity and resilience was associated with mental well-being, whereby those that were more physically active had better mental wellbeing and resilience, compared to their sedentary peers (Ho et al. 2015). Furthermore, muscle-strengthening exercise has been associated with greater levels of self-reported resilience in young people aged 10 to 17 years (Zhang, Jiang, Zhang, & Chi, 2022).

Table 2.7. Acute and chronic physical activity interventions on self-control in young people with ADHD

Authors (year)	n	Study design	PA	Duration	Intensity	Control condition	Self-control measurement	Main findings
Bowling et al. (2017) *USA*	N= 103 11.8 y ADHD diagnosis: 46 (57.5%)	Crossover group-randomized controlled trail (RCT)	Cyber-cycling exergaming on stationary bicycles	2 x 30-40 min; 7 weeks	Monitored however no set intensity	No structured aerobic activity (10-week washout period between conditions)	Behavioural self-regulation score (teacher completed) Disciplinary time out of class	Cyber-cycling improved self-regulation and classroom functioning in children with ADHD

Note. RCT = Randomised controlled trial.

In young people with ADHD, the literature is limited, however one study has examined the relationship between moderate to vigorous physical activity and resilience in this population (see table 2.8). Liang et al., (2023), investigated the associations between daily physical activity (measured via wrist-worn accelerometers) and self-reported resilience in children with ADHD. The results revealed that moderate to vigorous physical activity was positively associated with resilience, highlighting that increased physical activity levels were associated with higher self-reported resilience.

2.5.2. Acute and chronic physical activity interventions and resilience

Although physical activity as an intervention to improve resilience in young people with ADHD is yet to be examined, potential interventions have been discussed that could impact resilience in this population (Mackenzie, 2018), however these are yet to be implemented. To the best of our knowledge, only one study has examined building resilience in children with ADHD (Niu et al. 2021). In a case study, with a child with ADHD, a dialogic reading, and guided reading intervention was administered to promote resilience (Niu et al. 2021). Improvements were found in affect control, positive thinking, and goal planning, in addition to recognising coping strategies and experiences of when the child had to utilise resilience (Niu et al. 2021).

In neurotypical young people populations, a recent review by Andermo et al (2020) investigated school related physical activity intervention on mental health, with a sub-focus on resilience. Although the research is still limited, Andermo et al (2020) identified four studies investigating the effects of physical activity on resilience in neurotypical young people (Khalsa et al. 2012; Moore, Woodcock, & Dudley, 2019; Noggle et al. 2012; Yook, Kang, & Park, 2015). Three out of the four intervention studies used yoga as their mode of physical activity (Khalsa et al. 2012; Noggle et al. 2012), with one additionally incorporating a new sport into the program (Yook et al., 2015). The two studies using only yoga as their physical activity intervention found good internal consistency within intervention groups but no significant increase following the physical activity intervention in children ages 16.8 ± 0.6 years (Khalsa et al. 2012) or adolescents aged 17.2 ± 0.7 years

(Noggle et al. 2012). With the addition of sporting components alongside yoga, Yook et al. (2015) found an increase in self-reported resilience following the intervention compared to a control condition. Finally, Moore et al (2019) conducted a martial arts-based intervention over 10-weeks and found that following the physical activity intervention, participants resilience score was significantly improved, compared to the control condition, who found a decreased resilience score. It is clear to see that the evidence is still inconclusive, however, the modality of physical activity may be a predictive factor in eliciting benefits on resilience outcomes. Furthermore, a 20-week afterschool triathlon training intervention conducted in girls aged 11 to 14 years, found improvements in self-reported (via interview) resilience levels, better attitudes, and academic achievement (Gatz & Kelly, 2018). The research in neurotypical young people whereby physical activity is used to improve resilience shows some promising findings, and in order to understand this relationship further, research needs to implement different modalities, durations, and intensities of physical activity in wider populations (e.g., ADHD), to successfully understand the extent at which physical activity could aid resilience.

2.6. Qualitative research investigating effects of physical activity on young people with ADHD

This section of the thesis discusses qualitative research methods used within young people with ADHD and summarises the findings investigating the association between physical activity, physical fitness, and ADHD in children and adolescents. This section will begin discussing qualitative research methods (focus groups and interviews) used with young people and will then discuss findings of qualitative research looking at physical activity in young people with ADHD.

2.6.1. Qualitative research methods in young people

Focus groups have previously been shown to be an effective method of qualitative research in young people, enabling researchers to gain the perspectives of young people regarding a variety of different topics (Gibson, 2007; Gibson, 2012).

Table 2.8. Associations between physical activity and physical fitness with resilience in young people with ADHD

Authors (year) and *Country*	n	Study design	PA	Resilience measurement	Main findings
Liang, Qiu, & Sit, (2023) *China*	N= 85 8.41 y ADHD-C = 31 ADHD-I = 45 ADHD-HI = 9	Cross-sectional	Accelerometer worn for at least 4 days (3 weekdays and 1 weekend day)	Connor Davidson Resilience Scale (CD-RISC-25)	Moderate to vigorous physical activity is positively associated with resilience in young people with ADHD

Note. ADHD-C = combined presentation, ADHD-I = Inattentive presentation, ADHD-HI = Hyperactive-impulsive presentation

Planning is important for the success of focus groups with a well-developed interview guide prepared to encourage open, lively discussion (Gibson, 2007). In doing so, certain considerations need to be taken to conduct successful focus groups. First and foremost, it is important to consider the location and setting of focus groups, with many discussed benefits of conducting focus groups in naturally occurring settings that allow for group discussion of sometimes difficult topics (Brown, 2015). For young people, school seems to be an attractive location and has been proven to be successful at creating a safe peer environment in similar aged participants (van den Berg et al., 2018). Potential barriers to consider; include the initial issue of gaining entry to schools, retrieving parental consent and logistical difficulties such as scheduling (Horowitz et al. 2003; Mayeux & Kraft, 2017). Furthermore, for the purpose of conducting focus groups with children with ADHD, this is of particular importance with added safeguarding concerns. Building on this, group composition is another important factor to consider. For the running of successful focus groups, participant groups should share similar characteristics and should be acquainted with each other (Bagnoli & Clark, 2010). With children with ADHD often having comorbidities such as autism, typically inhibiting social interactions (Grzadzinski et al., 2011), therefore, by acquainting participants prior to the focus groups, this may reduce some of the potential challenges faced when interviewing young people with ADHD.

In order to get fruitful answers to questions, the moderator/interviewer need to be carefully selected to create the most effective environment and setting. The moderator must be skilled, approachable, patient, and friendly to create such a relaxed environment (Gibson, 2007; Morgan et al., 2002). Several steps have been outlined by Morrison (2013) To ease children's interviews, these include; adopting a sensitive but good-humoured nature to show participants they are in a supported climate. The researchers should also have a friendly disposition to portray a friendly, non-threatening persona. Next, interviews should reassure participants in that their responses would only be listened to by the researcher, and finally, interviewers should ensure they are attentive whilst participants are discussing ideas to ensure participants know their ideas and opinions are of value (Morrsion, 2013).

2.6.2. Qualitative research methods in young people with ADHD

Although focus groups have become a popular and successful interviewing method in young people (Abdelghaffar et al., 2019; Chalkley et al., 2020; Jago et al., 2009), the qualitative research in young people with ADHD is limited. Previously, interviews have been conducted with young people with ADHD (McDougal et al., 2023), however, focus groups are underused in this population. Harvey et al (2014) conducted a mixed method study using 'scrapbook interviews' as one of their data collection methods. The method, conducted with young people with ADHD, encouraged the children to talk about their physical activity experiences using photographs taken by the participants to guide the discussions. Due to the limited research and the variety of qualitative methods on offer, it is difficult to identify what method is the most appropriate or successful to implement in qualitative research with young people with ADHD. Furthermore, much of the current qualitative research has been conducted with parents of children with ADHD, further restricting the ability to assess which qualitative methods work best for children with ADHD.

2.6.3 Interviews with parents and teachers

When developing a successful intervention, it is important to consider and value stakeholders' opinions and ideas to create a holistic and feasible intervention (O'Cathain et al., 2019; Koorts et al., 2018). Previous literature has employed different methods to gain perspectives of different stakeholders including focus groups (Abdelghaffar et al., 2019) and interviews (Travell & Visser, 2006). Interviews with young people with ADHD and their parents has been employed previously to gain insights from different perspectives (Travell & Visser, 2006). Furthermore, interviews have also been conducted to gain perceptions of teachers of students with ADHD in a range of different scenarios (Lawrence, Estrada & McCormick, 2017; McDougal et a., 2023; Wilson et al., 2023). With literature highlighting the importance of gaining different perspectives in developing successful interventions, it is important to consider perspectives holistically to develop a physical activity intervention in young people with ADHD.

2.7 The present thesis

In drawing this review to a close, the literature review has outlined the current evidence base examining the relationship between physical activity and physical fitness, with cognitive function, self-control, and resilience, both acutely and chronically, in young people with ADHD. Moreover, this review has highlighted the importance of qualitative research for developing successful physical activity interventions in young people with ADHD.

Overall, the evidence suggests that acute and chronic physical activity interventions improve cognitive function in young people with ADHD. However, there are several variables that may moderate the effects of physical activity on cognition in this population such as modality, duration, and frequency: with the optimum dose of physical activity yet to be established. Furthermore, the review highlights the lack of research investigating the effects of physical activity on self-control and resilience in young people with ADHD, both of which are key variables in the daily functioning of this population.

Therefore, the aims for the studies presented within this thesis are:

- To investigate the effects of acute physical activity interventions, compared to resting condition, on cognitive function in children and adolescents with ADHD. Specifically, the effects will be examined across different moderating factors including domains of cognition, mode of physical activity, type of study design, duration of physical activity, and timing of administration of cognitive function tests post physical activity (Chapter IV).
- To examine the associations between physical activity and cardiorespiratory fitness with cognitive function, self-control, and resilience in young people with ADHD (Chapter V).
- To explore the perceived effects of physical activity on ADHD symptoms and behaviours in young people with ADHD, and to address what an intervention needs to look like in order to elicit benefits and be practically viable on young people's ADHD symptoms and behaviours through

interviews with key stakeholders (children with ADHD, their parents and their teachers) (Chapter VI).

- To investigate the effects of an acute games-based physical activity intervention on cognitive function, self-control, resilience and mood in young people with ADHD (Chapter VII).

Chapter III

General Methods

3.1. Introduction

This chapter provides an overview of the common methodologies and procedures employed in the studies presented within this thesis (primarily chapters V and VII; the methods of chapters IV and VI are discussed in their own chapters); and is comprised of two subsequent sections. The first section (section 3.2.) explains the procedures for participant recruitment, and the collection of participant assent and parent/guardian/caregiver consent. The second section (section 3.3.) outlines the main experimental measurements utilised.

3.2. Participant recruitment

Following ethical approval from Nottingham Trent University's Human Invasive Ethics Committee, primary and secondary state and private (Special Educational Needs; SEN) schools in the East Midlands were approached and invited to participate in the studies. The headteacher and special educational needs coordinator (SENCo) were contacted and provided with information about the study aims, participant inclusion criteria, school requirements/commitments and experimental procedures. Participant packs including a participant information sheet (see appendix A.1, A.2, A.3, A.4 and A.5 for participant information sheets for each of the Chapters), parental/guardian/caregiver consent (see appendix B for example), and a health screen (appendix C), were delivered to the schools to distribute to eligible and potential participants. The schools often attached their own invitation letter to the participant packs to explain the schools reasoning for participating. Parents/guardians/caregivers interested in their child's participation returned the completed consent form and health screen. Child assent was then completed during familiarisation. Once participant packs were returned, a lead investigator checked that the forms had been completed, signed, and that there were no health conditions that may restrict participation in the studies, or potentially confound

study outcomes. Participants with a clinical diagnosis of ADHD, and those on the pathway to an ADHD diagnosis were recruited to participate. It was decided to include young people on the pathway to an ADHD diagnosis, due to the reported long wait times associated with gaining an ADHD diagnosis and challenges associated with such wait times (Edbrooke-Childs & Deighton, 2020; Roughan & Stafford, 2019). Being on the pathway to an ADHD diagnosis was defined as actively seeking a clinical diagnosis either through their doctor's surgery or through a private medical surgery.

For the purposes of this thesis, information regarding current pharmacological treatments (i.e. medications) taken by participants were noted. However, participants were not asked to stop taking their medication and were recommended to continue with their usual treatment routines. This approach was taken for two main reasons: firstly, on ethical grounds it was not deemed necessary to ask participants to deviate from their prescribed medication routine for the purposes of taking part in the studies; secondly, this approach also maintained the ecological validity of the examination of the use of physical activity as a treatment alongside current pharmacological interventions (given this is the way that physical activity will be 'experienced' by these young people in everyday life). Furthermore, to the best of our knowledge, there appears to be no guidance regarding recommendations as to whether children should cease use of medication whilst participating in research of this nature. For example, whilst some studies ask children to stop taking their medication on the day of experimental trials (Geladé et al., 2017; Geladé et al., 2018; Lufi & Parish-Plass, 2011; Verret et al., 2012), other studies ask children to continue with their standard medication use (Benzing, Chang & Schmidt, 2018; Gawrilow et al., 2016; Pan et al., 2017).

3.3. Experimental measures

This section contains experimental measures that are common to one or more experimental chapter of this thesis. Where measures were only utilised in a single study of the thesis, details are included in the relevant experimental chapter.

3.3.1. Physical fitness

The multi-stage fitness test (MSFT) is used throughout this thesis as a measure of cardiorespiratory fitness. The MSFT involves participants undertaking progressive 20 m shuttle runs until exhaustion, or until the participants fails to keep in-time with the audio that dictates the running speed. With a starting pace of 7.5 $km.h^{-1}$, the speed increased by 1 $km.h^{-1}$ from level 1 to level 2 and increased by 0.5 $km.h^{-1}$ for every minute/level completed thereafter (Ramsbottom et al., 1988). The MSFT were completed in groups of 3-8 participants. During the test, participants were paced by a member of the research team familiar with the test, and additional researchers provided verbal encouragement to encourage maximal effort. The test was terminated when participants failed to keep up with the pace of the test on three consecutive occasions, or the point of volitional exhaustion. Distance covered was used as the criterion measure, in accordance with previous research in young people (Boat et al., 2022; Williams et al., 2022; Dring et al., 2019). Where possible, all MSFT were completed inside in a sports hall to standardise the delivery, however on one occasion, the test was competed outside on the tennis courts (due to the lack of a suitable indoor space being available in the school).

3.3.2 Physical activity

Free-living physical activity was measured using Actigraph GT3X+ triaxial accelerometers (Actigraph, Pensacola, FL, USA). To ensure the correct fitting of the accelerometer, a member of the research team fitted each participant with the accelerometer on the right hip (on an elasticated waist band) during experimental sessions. Participants were instructed to wear the accelerometer for 7 d (24 $h \cdot d^{-1}$), with the only exception being any activities that were water-based (e.g., showering or swimming). Accelerometers were initialised to capture data at 100 Hz.

Accelerometer data were downloaded using ActiLife v6.13.4 and saved in a raw format (GT3X). The raw files were processed in RStudio (RStudio 4.2, 2022.07.2+576), using the open-source *GGIR* package (for a detailed explanation of the steps involved, see Migueles et al., 2019). The “Euclidean Norm Minus One” (ENMO) was calculated using 5 s epochs and expressed in *mg*. Data were removed if the post calibration error

was greater than 0.01 *g* (van Hees et al., 2014; Williams et al., 2023), there were less than 3 days (1 weekend day) of wear time (with at least 10 hours of wear time per day). Cut points were set at 0-64 *g* (sedentary), 64-143 *g* (light), 143-465 *g* (moderate), and > 465 *g* (vigorous) (Hilderbrand, van Hees, Hansen, & Ekelund, 2014; Hilderbrand, Hansen, van Hees, & Ekelund, 2017). Total volume of physical activity per day was expressed as average acceleration (ENMO, *mg*), and the intensity gradient was selected as the metric to describe the intensity of physical activity (intensity distribution of acceleration across the time period) (Buchan, McLellan, Donnelly & Arthur, 2019; for further information about the intensity gradient see Rowlands et al., 2018). To reflect the decrease of time spent in higher intensity physical activity, the intensity gradient is always negative; and a less negative intensity gradient reflects a higher proportion of time spent in high intensity activities. Rowlands et al (2018) proposed the new metric to avoid error associated with using physical behaviour outcomes (i.e. MVPA and inactive time) and therefore provides a more detailed picture of an individual's physical activity profile.

ENMO was selected to analyse the accelerometer data over the traditional count-based cut-points, since ENMO provides a standardised metric (Rowlands et al., 2016), allowing comparison of data regardless of study protocols and accelerometer model (Rowlands et al., 2016). In addition to this, previous literature has highlighted the ability of ENMO to explain the variance in total energy expenditure compared to cut-based approaches (Migueles et al., 2019). In addition to this, research comparing ENMO and traditional count-based cut-points showed that ENMO is more accurate (75% accuracy) compared to traditionally used cut-points (70.8% accuracy; Montoye et al., 2020). Finally, ENMO has been shown to closer align with physical activity intensity during laboratory-based measures (Van Loo et al., 2017), of which has been used more recently and regularly in paediatric research to analyse physical activity data (Williams et al., 2023).

3.3.3. Cognitive function tests

The battery of cognitive function tests consisted of a Stroop test, Sternberg paradigm, and a Flanker task. The battery of tests lasted approximately 15 minutes and

was administered via a laptop computer (Lenovo ThinkPad; Lenovo). Before starting each test, instructions were presented on the laptop screen as well as verbally by a member of the research team. The research team guided the participants through an example of each test on a projector to ensure the participants fully understood each task. Each test level began with three to six practice stimuli for which the data were disregarded; this served to re-familiarise the participants with the test and negate any potential learning effects. In groups of 4 to 10 participants, participants were asked to complete the tasks in silence wearing noise cancelling headphones, however due to some sensory issues, noise cancelling headphones were not used. Instead, in order to maintain consistent delivery, the cognitive tests were conducted in small groups in quiet spaces to reduce the risk of distraction. The information about completing the cognitive tests were supplied by researchers trained in the use of the cognitive tests and the same information were given on each testing session. Response time (ms) of correct responses and proportion of correct responses (%) were recorded and subsequently used to calculate an inverse efficiency score (IES; Statsenko et al., 2020). The IES was calculated (reaction time (ms) / accuracy (proportion correct)) and has been used in previous research to provide a single cognitive outcome that combines both response times and accuracy (Bedard et al., 2021); thus, negating the possibility of speed-accuracy trade-offs affecting study outcomes (Statsenko et al., 2020; Heitz, 2014). For ease of interpretation, a lower IES indicates improved performance on the cognitive task.

3.3.3.1. Stroop task

The Stroop test (Stroop, 1935) measures attention and the inhibitory control aspect of executive function. The test consists of two levels of difficulty: congruent and incongruent. During both conditions a test word (always a colour) appears in the centre of the screen with a distractor word and a target word either side. For the congruent (simple) condition, the words are written in white ink and the participant must select (using the left and right arrow keys) the word that matches the central word. For the incongruent (difficult) condition, the test word appears in the centre of the screen with a target word

and distractor word either side. The congruent level consisted of 20 stimuli, and the incongruent level 40 stimuli. Using the arrow keys, the participant must select the colour the word is written in, rather than the word itself (e.g., if the word is blue but is written in green ink, the correct answer would be green; see figure 3.1 for screenshot of the Stroop task). The responses remained on the screen until a response was made, and the inter-stimulus interval was 1 s. The Stroop test (Stroop, 1935) has been used in multiple studies with neurotypical young people (Cooper et al., 2016; Gilbert et al., 2023) and young people with ADHD (Assef, Capovilla & Capovilla, 2014; Bigelow et al., 2021; Piepmeier et al., 2015). Digital versions of the Stroop test have become more popular due to advancements in technology; however, researchers are still sceptical and uncertain on the reliability of computerised versions compared to the traditional paper-based version of the Stroop test (Penner et al., 2012). The computerised Stroop test has been found to be reliable in neurotypical young people aged five to 13 years (Basu, 2023); with reliability having been shown to be greater in young people aged five to eight years (α=0.74) compared to eight to 13 years (α=0.58) (Basu, 2023). The test-retest reliability has been found to be high in adolescents and thus can be used in this aged population (Cooper et al., 2015). Furthermore, in individuals aged 10 to 85 years with neuropsychiatric disorders (including children and adolescents with ADHD) the computerised Stroop test has been found to have moderate test-retest reliability (r = 0.74) compared to the conventional method (r = 0.64) further supporting its use within the population in this thesis (Gualtieri & Johnson, 2006).



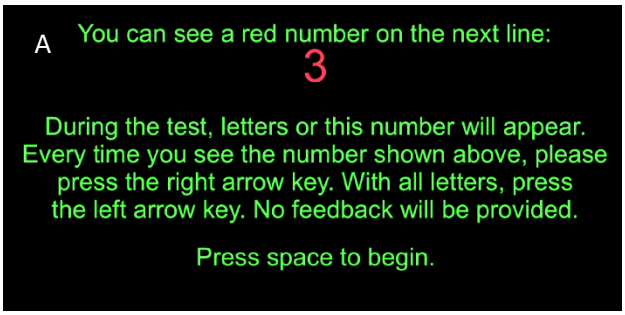


Figure 3.1A: Stroop test congruent level**. Figure 3.1B:** Stroop test incongruent level

3.3.3.2. Sternberg Paradigm

The Sternberg paradigm (Sternberg, 1969) task measures the working memory component of cognitive function. During the Sternberg task, participants are shown a

series of items, which the participant must remember. The items then disappear off the screen and single items will appear on the screen; the participant must indicate using the right arrow key if the letter that appears is one of their 'target' items or a distractor item by pressing the left arrow key. The tasks get progressively more difficult by increasing the number of items the participant must remember. The first level starts with one item (always the number '3') as their target item, then progressing to three items (randomly generated letters) and finally ending with five items (randomly generated letters). The one-item level contained 16 stimuli, whilst the three and five item levels each contained 32 stimuli. The responses remained on the screen until a response was made, and the inter-stimulus interval was 1 s. See figure 3.2 for screenshots of the three levels of the Sternberg paradigm. The use of the Sternberg paradigm with young people with ADHD is relatively limited (Roman-Urrestarazu et al., 2016; Walters et al., 2024). However, the test-retest reliability for the Sternberg Paradigm has been shown to have high reliability within an adolescent population (Cooper, Bandelow, Morris, & Nevill, 2015).



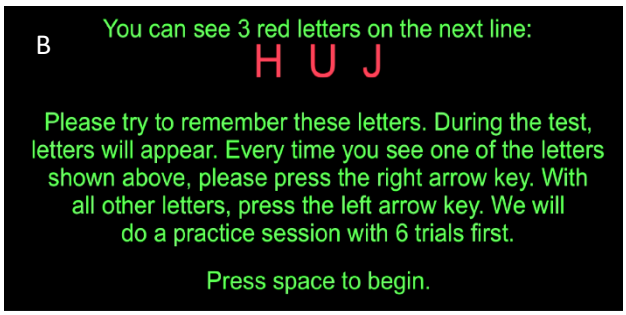




Figure 3.2A: One item of the Sternberg Paradigm. **Figure 3.2B**: Three item level of the Sternberg Paradigm.

Figure 3.2C: Five item level of the Sternberg Paradigm.

3.3.3.3. Flanker task

The Flanker task (Erikson & Erikson, 1974) is a measure of attention and executive function, specifically the inhibitory control aspect of executive function. The Flanker task involves two test levels (congruent and incongruent). For the congruent level there are 5 directional arrows displayed on the screen (all pointing either left or right). Participants must select the direction of the central arrow using the left and right arrow key (e.g., <<<<< the correct answer would be <). For the incongruent level, the central arrow would be facing in the opposite direction to the other four arrows, and the participant will have to select the direction of the central arrow (e.g., <<><<, the correct answer would be >). Each level contained 30 stimuli. The responses remained on the screen until a response was made, and the inter-stimulus interval was 1 s. See figure 3.3. for screenshots of the Flanker task. There has been an increased use of computerised cognitive tests due to convenience and improved technology which has led to many questions between traditional cognitive tests methodology and modern computerised methods. The Flanker test has been found to be consistent in reliability between the two methods in young adults (Lee & Pitt, 2024). Furthermore, research in children and adolescents has further supported the use of the Flanker test through test-retest reliability highlighting high internal consistency (Meyer, Bress & Proudfit, 2014). These findings are further supported in young people with ASD (autism spectrum disorder) showing moderate reliability of the Flanker task in young people with neurodevelopmental disorders (Cremone-Caira et al., 2020), although these findings have not yet been investigated in young people with ADHD.

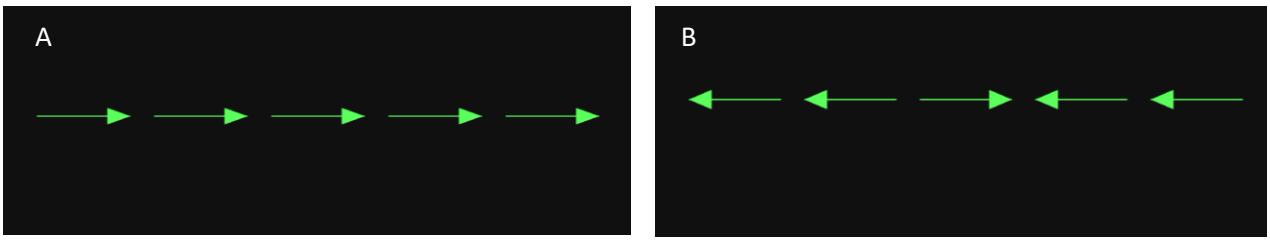


Figure 3.3A: Congruent level of the Flanker task. **Figure 3.3B:** Incongruent level of the Flanker task.

3.3.4. Questionnaires

3.3.4.1. Brief self-control scale

Participants self-control was examined using the Brief Self-Control Scale (BSCS; Tangney, Beaumeister, & Boone, 2004) which is a measure of trait self-control. This 13-item questionnaire provides a 5-point Likert-type scale ranging from one (indicating not very much) to five (indicating very much); in response to statements such as “I have a hard time breaking bad habits”. The Brief Self-Control Scale has been proven to be a successful tool for assessing self-control in young people (Boat et al., 2022; Rodríguez-Menchón, Morales, Orgilés, & Espada, 2022; Turliuc & Pojoga, 2018). Self-control score is calculated by sum of all items, however 9 questions are reverse scored during data analysis (i.e., if the participant scored 1 for a reverse question, a score of 5 for that question would be their final score for the sum calculation). For ease of interpretation, a higher score on the BSCS indicates higher self-control. See appendix D for full questionnaire. Due to state self-control being measured in Chapter VII, the Brief Self-Control scale was adapted for this chapter (see appendix E for adapted questionnaire). Items were reworded to address participants state control as opposed to their trait self-control (e.g., item 1 ‘*I am good at resisting* temptation’, were changed to ‘*I feel like I can resist a* temptation’). This was deemed to be the most appropriate method due to there being limited alternative measures of state self-control suitable for children and adolescents.

3.3.4.2. CD-RISC

The 10-item Connor-Davidson Resilience Scale (CD-RISC; Campbell-Sills & Stein, 2007; Connor & Davidson, 2003) provides a self-report measure of the psychological trait of resilience (see appendix F). For each item (e.g., “I am able to adapt when changes occur”) participants are provided with a 5-point Likert-type scale, with ranging from 0 to 4 (0 indicating not true at all, 4 indicated true nearly all the time), with higher scores indicating higher resilience. CD-RISC received one of the best psychometric ratings (Windle et al., 2011) and has excellent reliability and validity when investigating resilience in adolescents (Durish, Yeates, & Brooks, 2018; She, Yang, Lau & Lau, 2020) and in

sport/exercise contexts (Gonzalez et al., 2016). Resilience was calculated by a total sum of scores of all items on the questionnaire, with higher scores on the CD-RISC indicating higher resilience. Process resilience was examined in Chapter VII, using an adaptation of the CD-RISC whereby questions were reworded to address 'state'/process resilience (e.g., question 1 '*I am able to change the way I behave when new things happen'* were changed to '*I feel like I could change the way I behave if new things were going to happen).* This was deemed to be the most appropriate method due to there being no alternative measure of process resilience in young people (see appendix G for adapted questionnaire).

3.3.4.3. International Physical Activity Questionnaire – Children version

The International Physical Activity Questionnaire for Children (IPAQ-c) is a reliable and valid measure of self-reported physical activity levels across 7 days (Aggio et al., 2016). The IPAQ-c gathers information about physical activity levels in children's spare time, PE lessons and extra-curricular activities (see appendix H). Question 1 was removed from the IPAQ-c due to the cultural variance of sports included. A sum score of 1 indicated low physical activity, whereas a sum score of 5 indicated high physical activity. The IPAQ-c has been shown to be a good measure of physical activity in young people when used in conjunction with objectively measured physical activity (Marasso, Lupo, Collura, Rainoldi, & Brustio, 2021), and a similar version has been utilised in young people with ADHD (Baniasadi, 2024; Gallego-Méndez et al., 2020).

3.3.4.4. SNAP questionnaire

The SNAP-IV rating scale (Swanson et al., 2001) was used to measure ADHD symptoms and behaviours (see appendix I). The SNAP-IV includes 18 items to measure inattentive symptoms and hyperactive-impulsive symptoms. Ratings for each item are given on a 4-point scale: 'not at all', 'just a little', 'quite a bit', or 'very much'. Items scored 'not at all' are given a score of zero, 'just a little' is given a score of one, items scored 'quite a bit' are given a score of two, and 'very much' are given a score of three. Questions one to nine were categorised under 'inattentive presentation'; if average scores ≥ 1.78 if

rated by parents and ≥ 2.56 if rated by teachers, the child is considered to display the inattentive ADHD subtype. Questions 10-18 were categorised as 'hyperactive/impulsive presentation'; if average scores were ≥ 1.44 if rated by parents, and ≥ 1.78 if rated by teachers, the child is considered to display the hyperactive ADHD subtype. Combined presentation is presumed if average scores on questions both parts of the questionnaire were ≥ 1.67 if rated by parents, and ≥ 2.00 if rated by teachers (see table 3.1). Scores suggested participants may be more closely aligned to a specific ADHD presentation, however a full diagnostic assessment would be needed to establish this more reliably.

Table 3.1. Breakdown of scores to show presumed ADHD diagnosis (Swanson et al., 2001; Swanson et al., 2012).

Presumed ADHD presentation	Parents	Teachers
Inattentive (questions 1-9)	≥ 1.78	≥ 2.56
Hyperactive/impulsive (questions 10-18)	≥ 1.44	≥ 1.78
Combined (average score across all questions)	≥ 1.67	≥ 2.00

Chapter IV

Acute effects of physical activity on cognitive function in children and adolescents with attention-deficit/hyperactivity disorder: A systematic review and meta-analysis

4.1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) has been suggested to be the third most common neurodevelopmental disorder in children and adolescents (Polanczyk, Salum, Sugaya, Caye, & Rohde, 2015). ADHD is estimated to have a prevalence of 3%–7% in children and adolescents globally (Diagnostic and Statistical Manual of Mental Disorders; APA, 2013; Sayal, Prasad, Daley, Ford, & Coghill, 2018) and is more prevalent in boys, with a commonly reported 3:1 ratio compared to girls (Arnett, Pennington, Willcutt, DeFries, & Olson, 2015; Wittchen et al., 2011). ADHD symptoms are often recognisable from early childhood (APA, 2013); however, ADHD is most commonly diagnosed at the age of 12 years in boys, and aged 16 years in girls (Danielson et al., 2018). ADHD has three sub-groups; predominantly inattentive, predominantly hyperactive/impulsive or a combined presentation (DSM-5, 2013). The diagnosis of ADHD involves the individual meeting six or more of the DSM-5 criteria, where all symptoms must have been present prior to 12 years of age; and the individual must have shown symptoms in at least two settings, for instance at school and at home (DSM-5, 2013). Recognisable symptoms and behaviours associated with the disorder include, but are not limited to, the inability to maintain attention, frequent fidgeting, lack of patience, and an inability to follow instructions or organise tasks and activities (APA, 2013; DSM-5, 2013).

These ADHD symptoms and behaviours are often associated with lower academic performance (Silva et al., 2020) and impaired cognitive functioning (Claesdotter, Cervin, Åkerlund, Råstam, & Lindvall, 2018) in children, which may in turn affect their future academic achievements (Arnold, Hodgkins, Kahle, Madhoo, & Kewley, 2020). This is unsurprising given that cognitive function is comprised of a multitude of domains which are all key to academic success (Jacob & Parkinson, 2015; Pascual, Muñoz, & Robres,

2019). These domains include memory, attention, perception, executive function (working memory, inhibitory control, and cognitive flexibility), psychomotor, and language (Harvey, 2019; Schmitt, Benton, & Kallus, 2005). Executive function, which is comprised of high-order cognitive processes and skills contributing to inhibitory control, cognitive flexibility, and working memory (Ahmed & Miller, 2011; Best & Miller, 2010; Carlson, Moses, & Claxton, 2004), has been shown to be the domain of cognitive function most commonly affected by ADHD, although ADHD is a condition with a great deal of heterogeneity (Kofler et al., 2019; Martel, Nikolas, & Nigg, 2007; Schoemaker et al., 2012). This is of particular interest given that executive function is also suggested to be the most important cognitive domain for academic achievement (Best, Miller, & Naglieri, 2011).

In children and adolescents, ADHD is typically initially treated with non-pharmacological treatments such as diet or lifestyle management (Chaplin, 2018), parent training programmes, and psychoeducation (NHS, 2018). There is, however, a lack of evidence of the efficacy of such non-pharmacological interventions (Sonuga-Berg et al., 2016). Where these initial treatments are not successful in managing ADHD, medications such as methylphenidate, lisdexamfetamine, and dexamphetamine are commonly prescribed (NHS, 2018). Adherence to such medication is often dependent on ADHD severity and willingness to take the medication, alongside parental perceptions of medication use (Charach & Fernandez, 2013). Although medication helps to control ADHD symptoms and has demonstrated improvements in cognitive function in children and adolescents with ADHD (Yildiz, Sismanlar, Memik, Karakaya, & Agaoglu, 2011), ADHD medication has several negative side effects which may contribute to poor adherence; including sleep problems, mood disturbances, weight loss and headaches (Catalá-López et al., 2017; Toomey, Sox, Rusinak, & Finkelstein, 2012; Yildiz et al., 2011). With regards to non-pharmacological lifestyle management, physical activity has been suggested to be a potential intervention for the management of ADHD symptoms and behaviours (Gapin & Etnier, 2014; Vysniauske, Verburgh, Oosterlaan, & Molendijk, 2020; Welsch et al., 2021); yet physical activity is not commonly used by healthcare providers as an additional or alternative ADHD management technique.

Recently, systematic reviews have concluded that there are positive effects of both acute (single-bouts of physical activity) and chronic (physical activity conducted multiple times a week, over an extended period of time) physical activity interventions on cognitive function in children and adolescents with ADHD (Cornelius, Fedewa, & Ahn, 2017; Grassmann, Alves, Santos-Galduróz, & Galduróz, 2017; Liang, Wong, Sum & Sit, 2021; Neudecker, Mewes, Reimers, & Woll, 2019; Suarez-Manzano, Ruiz-Ariza, Torre-Cruz, & Martínez-López, 2018). In regard to the chronic effects of physical activity, one study concluded that 5–20 weeks of 30–90 min (per week) of moderate to vigorous exercise demonstrates a chronic positive effect on overall cognition and behaviour in children and adolescents (Suarez-Manzano et al., 2018). The most recent systematic review and meta-analysis by Welsch et al. (2021) primarily focused on the effect of chronic exercise interventions on executive functioning domains in children and adolescents with ADHD. It was found that chronic exercise interventions showed beneficial effects for the domains of inhibitory control, cognitive flexibility, and working memory in children and adolescents with ADHD compared to a control condition with no treatment. Therefore, overall, the findings of Welsch et al. (2021) tentatively provide evidence that chronic exercise interventions are beneficial across cognitive domains in children and adolescents with ADHD.

A number of recent reviews have shown that acute bouts of physical activity have a small but positive effect on subsequent cognitive function in neurotypical children and adolescents (Chang, Labban, Gapin, & Etnier, 2012; Donnelly et al., 2016; Williams, Hatch, & Cooper, 2019). These effects have been demonstrated across a range of domains of cognition, including attention (Altenburg, Chinapaw, & Singh, 2016; Park & Etnier, 2019), working memory (Koutsandréou, Wegner, Niemann & Budde, 2015) and executive function (Verburgh, Königs, Scherder, & Oosterlaan, 2014). Therefore, it is logical that acute bouts of physical activity could be a potential intervention to improve cognitive function in children and adolescents with ADHD.

There are suggestions from the literature in neurotypical young people, and from narrative reviews in children and adolescents with ADHD, that the key moderating

variables in the physical activity cognition relationship are characteristics of the physical activity task (e.g., duration and modality) and the timing of cognitive tests post physical activity (Erickson et al., 2019; Pesce, 2009; Williams et al., 2019). Specifically, the proposed physical activity-cognition framework by Williams et al. (2019) suggested that both physical activity characteristics (duration, intensity and modality) and issues regarding the measurement of the cognitive variables (domains measured, and timing of the tests) will influence the acute effects of physical activity on subsequent cognition in young people. Additionally, participant characteristics, such as age, physical fitness, and cognitive ability, were also suggested to influence this relationship (Williams et al., 2019). Furthermore, Pesce (2009) discussed the effects of individual and task constraints on the physical activity-cognition relationship, highlighting how individual constraints such as physical fitness, motor coordination skills, cognitive expertise, age, and gender; alongside task constraints including exercise intensity, duration and complexity, cognitive task complexity and time relation between physical activity and cognitive task, influence this relationship.

Specifically, Chang et al. (2015) investigated the impact of exercise duration on subsequent cognition in neurotypical young adults (20–22 years). The findings suggest that 20 min of moderate-vigorous physical activity results in faster Stroop performance reaction time; compared to a resting, 10 min or 40 min physical activity condition. Furthermore, in neurotypical adolescents, Hatch et al. (2021) investigated the effects of 30 min exercise, 60 min exercise and a resting control condition on thirty-eight adolescents, highlighting the greatest cognitive benefits following 30 min of high-intensity intermittent running, compared to 60 min and the resting control. Although Chang et al. (2015) and Hatch et al. (2021) provided evidence of the importance of duration, perhaps it is a combination of task constraints that contributes to the beneficial effects of physical activity on cognition. This suggestion is supported by evidence of improved executive function after 30-minutes of open-skill physical activity (badminton), compared to closed-skill physical activity (running) (Hung, Tseng, Chao, Hung, & Wang, 2018); identifying modality of physical activity to be a key moderator of the physical activity-cognition relationship.

Finally, the timing of the completion of cognitive tests following physical activity has also been shown to play an important role in determining post-activity cognitive effects, whereby the greatest beneficial effects were found when the tests were completed 11–20 min following physical activity (Chang, Liu, Yu, & Lee, 2012). Therefore, it is clear that key moderating variables such as characteristics of the physical activity (e.g., duration, modality), and the timing of cognitive tests following physical activity should be considered and assessed in future research examining the effects of physical activity on cognition. Moreover, these effects are yet to be fully examined in ADHD populations, with no synthesis or meta-analysis having pooled the available data from individual studies to address these important questions.

Whilst a review by Cornelius et al. (2017) began to highlight the importance of these potential moderators in children and adolescents with ADHD, due to the lack of research when the previous review was conducted, only the moderator of modality of physical activity was found to affect cognitive function performance, whereby aerobic physical activity such as running and cycling elicited greater improvements on subsequent cognition compared to non-aerobic activities. Furthermore, these moderators have not yet been examined meta-analytically in young people with ADHD. It is therefore important to reassess the effects of these moderating factors on cognition in children and adolescents with ADHD.

Whilst much of the literature has focused on the chronic effects of physical activity interventions on cognitive function in children and adolescents with ADHD, less emphasis has been placed on the acute effects of a single-bout of physical activity on subsequent cognition in this population; and, in particular, how the aforementioned moderating variables (such as the intensity, duration and modality of the activity) influence these effects. The effects of acute physical activity interventions do however have significant importance for healthcare practitioners and educationalists working within this population; and the potential practical utility of a single-bout of physical activity to enhance cognition and behaviour in children and adolescents with ADHD is yet to be fully addressed.

Overall, it appears that the existing systematic reviews investigating the effects of acute physical activity interventions on cognitive function do not use a meta-analytical approach. Therefore, there is currently limited knowledge regarding the size of the effect of acute physical activity on cognition in children and adolescents with ADHD. Furthermore, with recent increased attention within the research literature towards the effects of acute physical activity interventions on children and adolescents with ADHD, it is important to provide an up-to-date review of the literature, whilst adopting a meta-analytical approach to provide insight regarding the size of the effect. Furthermore, the effect of key moderating variables (such as the intensity, duration, and modality of physical activity) should be meta-analytically examined, in order to provide practical recommendations for practitioners. Enhancing the understanding regarding the effects of acute physical activity interventions could also inform the chronic, longer-term effects; given that acute bouts of physical activity are likely to contribute to, and accumulate to, any chronic adaptations. Therefore, understanding the acute effects may provide mechanistic insight regarding the chronic effects.

In conclusion, whilst it appears that chronic physical activity interventions are beneficial for cognition in children and adolescents with ADHD, the evidence regarding the acute effects of a single-bout of physical activity are poorly understood. Therefore, the primary aim of chapter one; a systematic review and meta-analysis, was to investigate the effects of acute physical activity interventions, compared to a resting condition, on cognitive function in children and adolescents aged 5–18 years with ADHD. A secondary aim was to examine the effects across moderating factors; domains of cognition, mode of physical activity, type of study design, duration of physical activity, and timing of administration of cognitive function tests post physical activity.

4.2. Method

This meta-analysis followed the recommendations provided by the preferred reporting items for systematic reviews and meta-analyses (PRISMA-P) checklist (Moher et al., 2015).

4.2.1. Search Process

A comprehensive electronic literature search of three databases of literature (PubMed, ProQuest & Web of Science) was simultaneously conducted (see figure 4.1.). The primary search terms were as follows: (1) “attention deficit hyperactivity disorder” (“ADHD” or “attention deficit disorder” or “ADD” or “impulsivity” or “hyperactivity”), (2) “young people” (“children” or “adolescents” or “juvenile” or “minors” or “pubescent”), (3) “physical activity” (“exercise” or “acute exercise” or “sport” or “single bout exercise” or “aerobic”) and (4) “cognitive function” (“cognition” or “executive function” or “inhibitory control” or “working memory” or “attention” or “cognitive flexibility”). The search was restricted to studies conducted with human participants, written in English and those published until July 2021. A manual search was additionally conducted, and reference lists of selected articles were screened for relevant articles which were not found during the initial search. Once the search was complete, duplicates were removed, and titles and abstracts were screened for relevance. Full texts were then screened following the inclusion criteria (see Figure 4.1 for a more detailed record of the search process).

The literature search resulted in 246 article titles and abstracts being reviewed, 31 full-text articles being screened, of which 14 articles were included in the systematic review and meta-analysis. Reasons for exclusion of the 17 studies removed after full-text screening are described in Figure 4.1. The screening process was conducted by two investigators and any discrepancies were resolved by consulting a third investigator.

4.2.2. Inclusion Criteria

The decision to include articles in the final sample was based on the following criteria: (a) the study must have investigated the effects of an acute physical activity (single-bout) intervention on cognition in children and adolescents with ADHD; (b) participants must be children and/or adolescents aged 5-18 years; (c) participants must have a diagnosis of ADHD by a psychiatric physician or meet the criteria outlined in validated rating scales (e.g., DSM-5); (d) the studies must report cognitive function test results either ‘pre’ intervention or have a comparison group (e.g. resting control group); and (e) the studies must have measured at least one cognitive function outcome (see Table 4.3 for included studies).

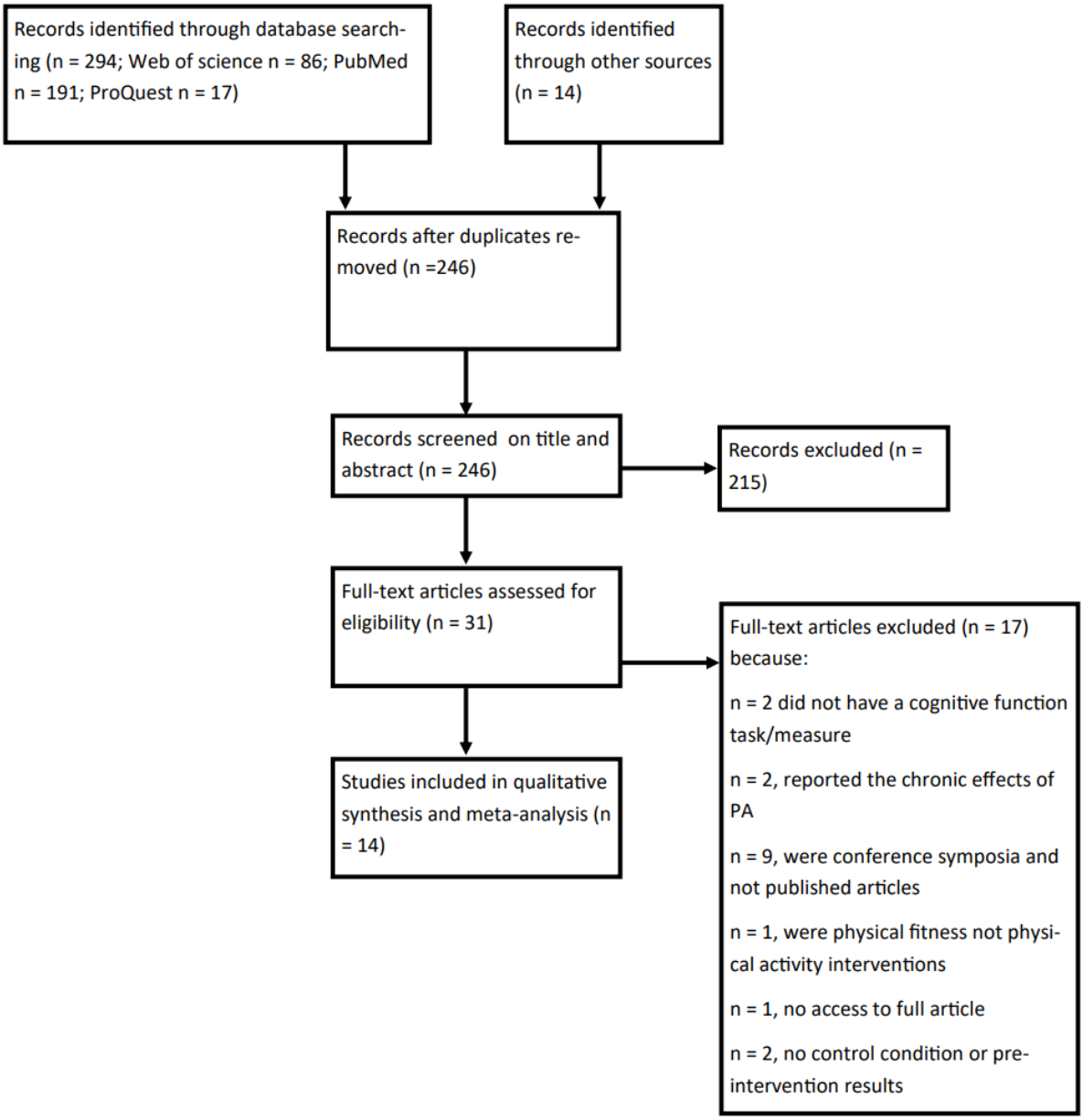


Figure 4.1. PRISMA flow chart outlining search strategy for systematic review and meta-analysis.

4.2.3. Data Extraction and Management

The data were extracted independently by the lead author. Key demographic participant information (e.g., number, sex, age, comorbidity, and medication use), study characteristics (e.g., number of experimental sessions, familiarisation trials, study design, physical activity intervention intensity and duration and control condition duration) and cognitive function characteristics (e.g., cognitive function tests, cognitive function domains and the means ± SD for both intervention and control conditions) were

collated. Once all data were extracted, four authors discussed the results of the included studies where there was a lack of clarity or understanding of the reported results.

Corresponding authors of studies with missing data from the published articles (Miklós et al., 2020; Piepmeier et al., 2015) were contacted to request missing means and standard deviations for the cognitive function tests to facilitate inclusion in the meta-analysis.

4.2.4. Data Synthesis

Where studies contained multiple physical activity conditions (e.g., medicated group and a non-medicated group, or multiple durations of physical activity) compared to a control condition, the physical activity conditions were combined to create a single pairwise comparison group, as recommended in the Cochrane Handbook (Higgins et al., 2019). Most of the studies included in the meta-analysis used multiple cognitive function tests with a number of outcome measures (e.g., reaction time and error rate). Therefore, each measure was inputted separately (due to the variety of units reported for each measure) and a standardised mean difference (SMD) effect size was calculated (see table 4.1 for details on outcome measures assessed). Where a control condition was absent in one study (Craft, 1983), the pre-intervention results were used as a control; providing a pre-post comparison and allowing inclusion in the meta-analysis.

4.2.5. Meta-Analysis

The meta-analysis was conducted using Review Manager software (RevMan, 5.4.1, The Cochrane Collaboration, 2020). The initial meta-analysis included measures across all cognitive function domains (Figure 4.1). Subsequently, a separate sub-analysis was conducted for each cognitive domain measured by the included studies, namely cognitive flexibility, attention, memory, and inhibitory control (Figure 4.3). A further sub-analysis was conducted to examine the effect of physical activity duration, categorised as ≤ 10 min, 11-20 min and > 20 min. A third sub-analysis was also conducted to investigate the study design, which was coded as within-subject design or between-subject design; one study was not included in this sub-analysis due to the use of a mixed study design (Mahon et al., 2013). A fourth sub-analysis was conducted for the

mode of physical activity, categorised as ‘running’, ‘cycling’, and ‘other’. The group named ‘other’ grouped any alternative physical activity that was not running or cycling and included trampolining, exergaming, and coordinative tasks. One study was included in two groups due to the use of two different physical activity interventions (Ludyga et al., 2017). Finally, a sub-group analysis was conducted looking at the timing of completion of the cognitive function tests post-intervention. Nine out of the 14 studies included in the meta-analysis reported timing post-intervention and were therefore included in the sub-group analysis. One study (Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013) stated that the timing of their post-physical activity cognitive measurements were based on a target heart rate rather than specific timing; this study was therefore not included in this sub-group analysis. The groups were categorised as ‘immediately post-intervention’, ‘2–10 min post-intervention’ and ‘> 10 min post intervention’.

The results from the meta-analyses are reported as standardised mean difference (SMD) using a random effect model, due to the studies assessing the same outcome (e.g., cognitive domain) but using different tests (e.g., Stroop test and Flanker) and outcome measures (e.g., response time and accuracy); in line with recommendations (Cochrane Handbook, Version 6.2, 2021). Effect sizes were interpreted as per convention (≤ 0.2 small effect, ≤ 0.5 medium effect, ≤ 0.8 large effect) (Cochrane Handbook, Version6.2, 2021). Statistical significance was accepted as $p < 0.05$. Heterogeneity was recognised as small (0-44%), moderate (40-60%), substantial (50-90%) and considerable (75-100%), in line with recommendations (Cochrane Handbook, Version 6.2, 2021).

4.2.6. Risk of bias

The studies were assessed for their quality using the Cochrane Collaboration’s tool to assess Risk of Bias (Higgins, Savović, Page, & Sterne., 2019). The revised tool for risk of bias (RoB 2) was used to assess risk of bias in the included studies. Each study was carefully assessed, and a risk-of-bias judgement was made by following the suggested algorithm for each domain assessed. As per recommendations, the domain ‘S’ (signalling) which assessed the risk of bias arising from period and carryover effects, was only completed for the crossover studies (Sterne et al., 2019).

Table 4.1. Supplementary table showing cognitive function task, measures, outcome measures, and cognitive function domains assessed in the included studies.

Study	N Effect sizes	Cognitive function task	Measure	Outcome measure	Cognitive function domains assessed
Mahon et al, (2013)	3	Conners continuous performance test 2	Errors of omission	Accuracy	Attention
			Errors of commission	Accuracy	Attention
			Response time	Reaction time	Attention
Benzing et al, (2018)	4	Flanker	Response time (congruent)	Reaction time	Attention
			Response time inhibition	Reaction time	Inhibitory control
			Response time switching	Reaction time	Cognitive flexibility
		Colour span backwards	Sum of correct responses	Accuracy	Visual working memory
Miklos et al, (2020)	14	KiTAP	Median of reaction time	Reaction Time	Attention
			Total omissions	Accuracy	Cognitive flexibility
			Omissions with distractor	Accuracy	Cognitive flexibility
			Total error	Accuracy	Cognitive flexibility
			Errors with distractor	Accuracy	Cognitive flexibility
			Errors without distractor	Accuracy	Cognitive flexibility
			Median of reaction time	Reaction time	Attention
			Total omissions	Accuracy	Attention
			Total error	Accuracy	Attention
			Median of reaction time	Reaction time	Cognitive flexibility
			Total error	Accuracy	Cognitive flexibility
		Go/ No Go task	Median of reaction time	Reaction time	Attention
			Total error	Accuracy	Inhibitory control
Ludyga et al, (2017)	2	Flanker task	Response time (congruent)	Reaction time	Attention
			Response time (incongruent)	Reaction time	Inhibitory control

Study	N Effect sizes	Cognitive function task	Measure	Outcome measure	Cognitive function domains assessed
Chang et al, (2012)	4	Stroop test	Response time (word)	Reaction time	Attention
			Response time (colour)	Reaction time	Attention
			Response time (colour-word)	Reaction time	Inhibitory control
		Wisconsin card sorting task	Total correct	Accuracy	Cognitive flexibility
Craft (1983)	3	Weshsler intelligence scale for children – reversed digit span	Total correct	Accuracy	Memory
		WISC-R coding B	Total correct	Accuracy	Memory
		The Illinois test for psycholinguistic abilities – visual sequential memory	Total correct	Accuracy	Visual sequential memory
Chuang et al, (2015)	4	Go/ No Go task	Commission rate	Accuracy	Inhibitory control
			Reaction time	Reaction time	Attention
			Hit rate	Accuracy	Inhibitory control
			Omission rate	Accuracy	Inhibitory control
Medina et al, (2010)	3	Conners continuous performance test 2	Response time	Reaction time	Attention
			Errors of commission	Accuracy	Attention
			Errors of omission	Accuracy	Attention
Pontifex et al, (2013)	2	Flanker task	Response accuracy (total correct)	Accuracy	Inhibitory control
			Post error response time	Reaction time	Inhibitory control
Hung et al, (2016)	4	Task switching paradigm	Response time (global switching)	Reaction time	Cognitive flexibility
			Accuracy (global switch)	Accuracy	Cognitive flexibility
Gawrilow et al, (2016)	2	Go/ No Go task	Error rate	Accuracy	Inhibitory control
			Successful responses	Accuracy	Inhibitory control

Study	N Effect sizes	Cognitive function task	Measure	Outcome measure	Cognitive function domains assessed
Ludyga et al, (2020)	4	Alternate uses task	Category	Accuracy	Cognitive flexibility
			Fluency (correct responses)	Accuracy	Cognitive flexibility
			Originality	Accuracy	Cognitive flexibility
			Elaboration	Accuracy	Cognitive flexibility
Piepmeier et al, (2015)	5	Stroop test	Response time (word)	Reaction time	Attention
			Response time (colour)	Reaction time	Attention
			Response time (colour word)	Reaction time	Inhibitory control
		Tower of London	Total moves	Accuracy	Inhibitory control
		Trail making test	Response time	Reaction time	Cognitive flexibility
Bigelow et al, (2021)	4	Stroop test	Proportion correct	Accuracy	Inhibitory control
			Total errors	Accuracy	Inhibitory control
		Reverse memory subscale	Number complete	Accuracy	Working memory
		Trail making test	Response time	Reaction time	Cognitive flexibility

4.3. Results

4.3.1. Description of Included Studies

A total of 14 studies and 58 effect sizes were included in the meta-analysis. The number of participants with ADHD in the studies ranged from 14 to 100 (11% of the total sample population were female), with a total participant sample size of 446 across all of the included studies. The participant's ages ranged from six years to 16 years. Twelve out of the fourteen studies reported the number of participants on medication, with 66% of all participants in the included studies regularly taking medication (two studies did not state the number of participants using medication (Bigelow et al., 2021; Pontifex et al., 2013)). Medication was not chosen for a sub-group analysis due to the variability of medications and protocol for medication use for participation in studies (e.g., stop using medication 24 h before intervention).

Of the included studies, 12 directly measured the intensity of physical activity to confirm a moderate to vigorous intensity whilst two studies (Gawrilow et al., 2016; Medina et al., 2010) stated that they used moderate to vigorous physical activity but did not directly measure this (physical activity intensity for each study is outlined in Table 4.3). Physical activity duration varied from 1 min to 30 min (mean ± SD: 19 ± 10 min). Of the physical activity interventions, six of the studies used physical activity on a cycle ergometer (Bigelow et al., 2021; Craft, 1983; Ludyga et al., 2017; Ludyga et al., 2020; Mahon et al., 2013; Piepmeier et al., 2015), with one study also using a coordinative task (Ludyga et al., 2017), and five studies used a treadmill to complete either continuous or interval running (Chang et al., 2012; Chuang et al., 2015; Hung et al., 2016; Medina et al., 2010; Pontifex et al., 2013). Miklós et al. (2020) used running as their physical activity condition but did not state whether they used a treadmill. One study used trampolining as their physical activity condition (Gawrilow et al., 2016), and the final study used exergaming (Benzing et al., 2018) (see table 4.3 for an overview of the included studies).

4.3.2. Risk of bias

The results from the risk of bias revealed that five studies were low risk across all of the domains (Table 4.2). All of the included studies showed low risk across the domains of missing data, measurement of the outcomes and selection of the reported results. The randomization process category resulted in one study having a high risk (Medina et al., 2010) and eight having some concerns (Table 4.2). Overall, the risk of bias assessment revealed that there were some concerns for at least one category for eight of the included studies; however, these were deemed to be low risk in the overall judgement. Although one study was high risk in one domain, the overall risk of bias judgement was decided to be 'some concerns' and would not substantially lower the confidence of the result.

Table 4.2. Risk of bias for included studies

Article	Domain 1: randomisation process	Domain S: Period and carry over effects	Domain 2: effect of assignment	Domain 3: missing data	Domain 4: Measurement of outcome	Domain 5: selection of reported result	Overall risk score
Craft (1983)	?	✓	✓	✓	✓	✓	✓
Medina et al., (2010)	×	?	✓	✓	✓	✓	?
Chang et al., (2012)	✓	NA	✓	✓	✓	✓	✓
Mahon et al., (2013)	?	✓	?	✓	✓	✓	✓
Pontifex et al., (2013)	?	✓	✓	✓	✓	✓	✓
Chuang et al., (2015)	?	✓	✓	✓	✓	✓	✓
Piepmeier et al., (2015)	✓	✓	✓	✓	✓	✓	✓
Gawrilow et al., (2016)	✓	NA	✓	✓	✓	✓	✓
Hung et al., (2016)	?	✓	✓	✓	✓	✓	✓
Ludyga et al., (2017)	?	✓	✓	✓	✓	✓	✓
Benzing et al., (2018)	✓	NA	✓	✓	✓	✓	✓
Ludyga et al., (2020)	✓	NA	✓	✓	✓	✓	✓
Miklós et al., (2020)	?	NA	✓	✓	✓	✓	✓
Bigelow et al., (2021)	?	✓	✓	✓	✓	✓	✓

Note. Domain S was completed for cross-over studies, low risk is indicated by a ✓, some concerns is indicated by a ?, and high risk is indicated by a ×.

Table 4.3. Overview of included studies

Study (year)	n participants with ADHD (females)	Study design	PA duration (min)	PA intervention (exercise intensity)	Control condition	Cognitive function test	Cognitive function domains measured	Number of effect sizes Total: 50
Craft (1983)	31	Within	1, 5, & 10	Cycling at 18-20 $Km \cdot h^{-1}$ (170 $beats.min^{-1}$	Resting/ 0 mins (pre-exercise)	Weschler Intelligence Scale for Children-revised digit span Weschler Intelligence Scale for Children – Revised - coding B Illinois test of psycholinguistic abilities	Memory Visual sequential memory	3
Medina et al., (2010)	25	Within	30	10 loaded efforts for 2 min with 1 min rest on treadmill (intensity not stated)	Stretching	Conners' continuous performance test II	Attention	3
Chang et al., (2012)	40 (3)	Between	30	Treadmill running (50-70% HRR)	Watched a running/ exercise-related video	Stroop Test Wisconsin Card Sorting Test	Inhibitory control Cognitive flexibility	4
Mahon et al., (2013)	22 (2)	Mixed	20	30 s cycling, followed by 30 s stationary rest (90% PWC)	Resting (pre-exercise)	Conners' continuous performance test II	Attention	3
Pontifex et al., (2013)	20 (6)	Within	20	Aerobic exercise on a treadmill (65-75% $HR_{max)}$	Seated reading	Eriksen Flanker Test	Inhibitory control	2
Chuang et al., (2015)	19 (3)	Within	30	Treadmill running (60% HRR)	Watched video	Go/ No Go test	Inhibitory control	4
Pepmeier et al., (2015)	14 (5)	Within	30	Continuous cycling (40-60 RPM/RPE between 5-7)	Watched Planet Earth documentary whilst sat on cycle-ergometer	Stroop test Tower of London Trail Making Test	Inhibitory control General executive function Cognitive flexibility	5
Gawrilow et al., (2016)	47	Between	5	Continuous bouncing on trampoline	Coloured in pictures that depicted activities	Go/ No Go task	Inhibitory control	2
Hung et al., (2016)	34 (1)	Within	30	Running on treadmill (5-70% HRR)	Watched video	Task Switching Paradigm	Cognitive flexibility	4
Ludyga et al., (2017)	16 (5)	Within	20	1. Cycling at moderate intensity (65-70% $HR_{max)}$ 2. Coordinative exercises-object control skills and bilateral coordination skills	Watched documentary about exercise behaviour in adults	Eriksen Flanker test	Inhibitory control	2

Study (year)	n participants with ADHD (females)	Study design	PA duration (min)	PA intervention (exercise intensity)	Control condition	Cognitive function test	Cognitive function domains measured	Number of effect sizes Total: 50
Benzing, Chang & Schmidt., (2018)	46 (8)	Between	15	Exergame called “Shape up” (55-90% HR_{max})	Watching documentary about mountain running	Eriksen Flanker test Colour span backwards test	Inhibitory control Visual working memory	4
Ludyga et al., (2020)	16 (5)	Within	20	Continuous cycling (65-75% HR_{max})	Watched documentary on exercise behaviour in adults	Alternate Uses task	Cognitive flexibility	4
Miklós et al., (2020)	100 (8)	Between	20	Interval running divided into 4 x 4 periods with 1 min slow walking breaks (60-80% HR_{max})	Watched cartoon video whilst seated	KiTAP Go/No Go test	Attention Cognitive flexibility Inhibitory control	14
Bigelow et al., (2021)	16 (5)	Within	10	Cycling on a cycle ergometer (65-85% HR_{max})	Reading magazines	Stroop test Leiter-3 Reverse Memory subscale	Inhibitory control Working memory Cognitive flexibility	4

Note. PA – physical activity; $km \cdot h^{-1}$ - Kilometres per hour; HRR - Heart Rate Reserve; HR_{max} - Maximum Heart Rate; PWC - Peak Working Capacity; RPE - Rating of Perceived Exertion, RPM - Revolutions Per Minute.

4.3.3. Meta-analysis

4.3.3.1. Overall effect

The overall effect suggested a statistically significant small effect favouring acute bouts of physical activity compared with a control condition, to improve cognitive function in young people with ADHD (SMD = 0.18; 95% CI [0.12,0.25]; $p < 0.01$). The test for heterogeneity indicated no significant heterogeneity across the effect sizes in the overall sample (Q (41.65), df = 13, I^2 = 68%) (Figure 4.2).

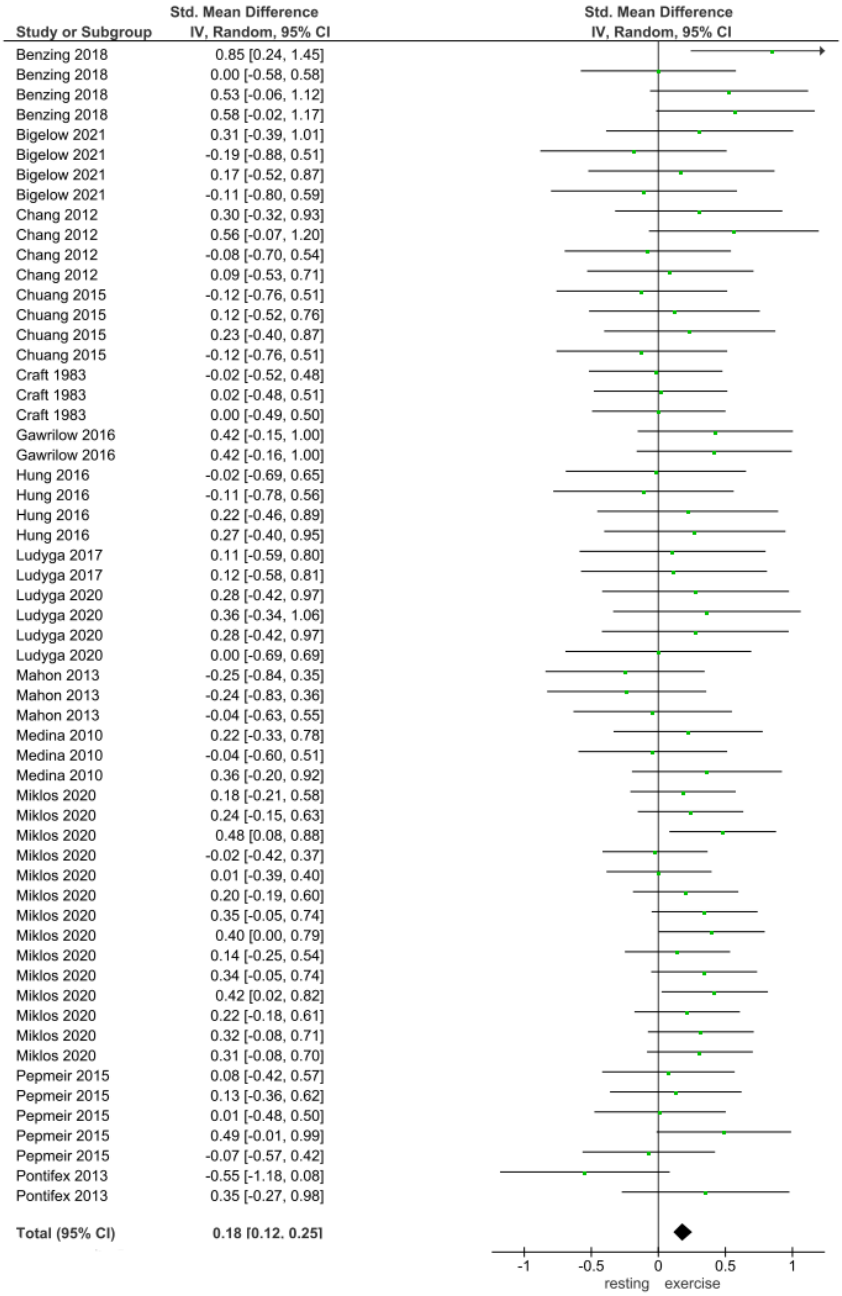


Figure 4.2. Forest plot showing overall effect size of included studies (SMD = 0.18; 95% CI [0.12,0.25]; p < 0.01; I^2=68%).

4.3.3.2. Sensitivity analysis

A sensitivity analysis was conducted by removing each effect size from the overall meta-analysis one at a time, and then returning them to the overall sample. The sensitivity analysis revealed a stable effect size, that ranged from SMD = 0.19 [0.12, 0.26], $p < 0.001$ to SMD = 0.18 [0.11, 0.24], $p < 0.001$ when each of the individual studies were removed.

4.3.3.3. Cognitive domains

The sub-group analysis of the cognitive domains (Figure 4.3) revealed that there was a statistically significant positive effect of acute physical activity on cognitive flexibility after an acute bout of physical activity compared to a control condition (SMD = 0.19, [0.07, 0.31], $p < 0.001$); and the test for heterogeneity showed moderate heterogeneity across the sample (Q(10.25), df = 6, $I^2 = 41\%$). Attention was revealed to have a statistically significant small effect following an acute bout of physical activity (SMD = 0.20, [0.08, 0.32], $p < 0.001$) with moderate to substantial heterogeneity (Q(16.04), df = 8, $I^2 = 50\%$). It was also shown that acute bouts of physical activity enhanced inhibitory control, with a statistically significant small effect (SMD = 0.21, [0.07, 0.34], $p = 0.02$); the test for heterogeneity showed moderate heterogeneity (Q(13.p14), df = 8, $I^2 = 39\%$). However, the sub-analysis revealed that memory was not enhanced in children and adolescents with ADHD following an acute bout of physical activity (SMD = 0.02, [−0.22, 0.26], $p = 0.87$); with no heterogeneity (Q(0.22), df = 2, $I^2 = 0\%$). The test for subgroup differences was non-significant for cognitive domains (Q(2.00), df = 3, $p = 0.57$, $I^2 = 0\%$).

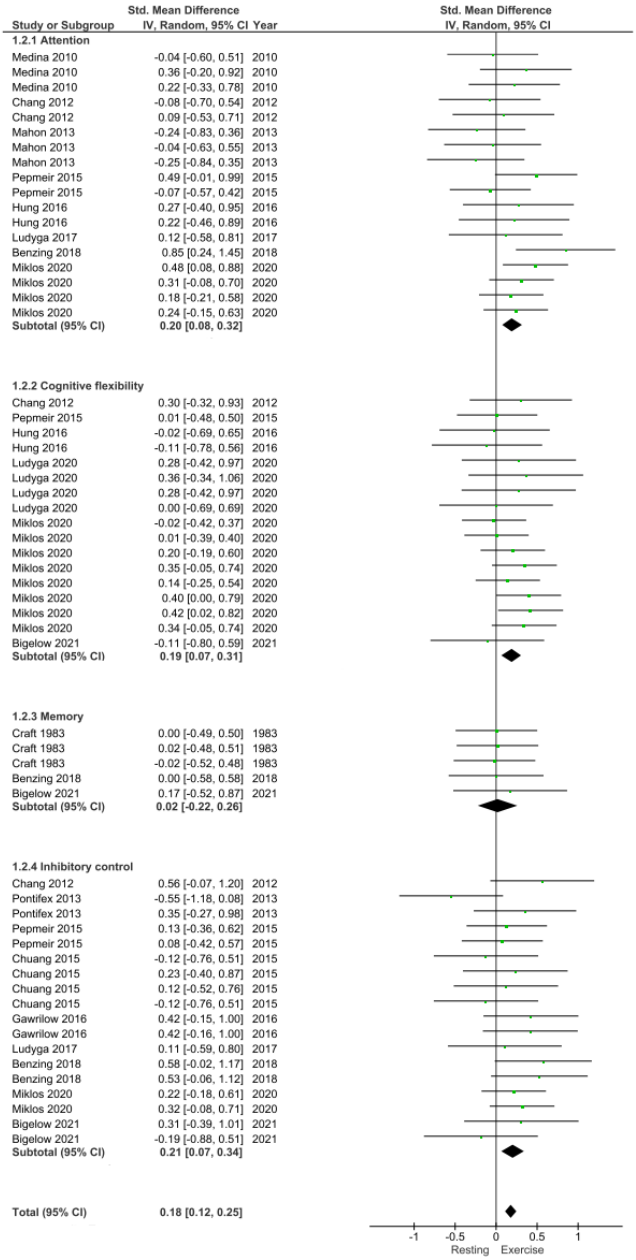


Figure 4.3. Forest plot showing sub-group analysis. Note. Attention (SMD=0.20, p=0.001; I^2=50%), cognitive flexibility (SMD=0.19, p=0.001; I^2=41%), inhibitory control (SMD=0.21, p=0.02, I^2=39%), memory (SMD=0.02, p=0.57, I^2=0%).

4.3.3.4. Physical activity intervention duration

Studies with physical activity interventions > 20 min revealed a statistically significant small effect on cognitive function (SMD = 0.13, [-0.00, 0.26], p = 0.05); with moderate to substantial heterogeneity ($Q(8.77)$, df = 4, I^2 = 54%). The sub-analysis also revealed that physical activity interventions 11 min to 20 min in duration showed a statistically significant small effect on cognitive function (SMD = 0.23, [0.14, 0.31], p < 0.01) with considerable heterogeneity (Q(26.55), df = 5, I^2 = 81%). Finally, studies which

used physical activity interventions ≤ 10 min in duration revealed no effect on cognition (SMD = 0.11, [-0.08, 0.30], p = 0.27) with moderate heterogeneity (Q(4.20), df = 2, I^2 = 52%) (Figure 4.4). The test for subgroup differences was non-significant for physical activity duration (Q(2.12), df = 2, p =0.35, I^2 = 6%).

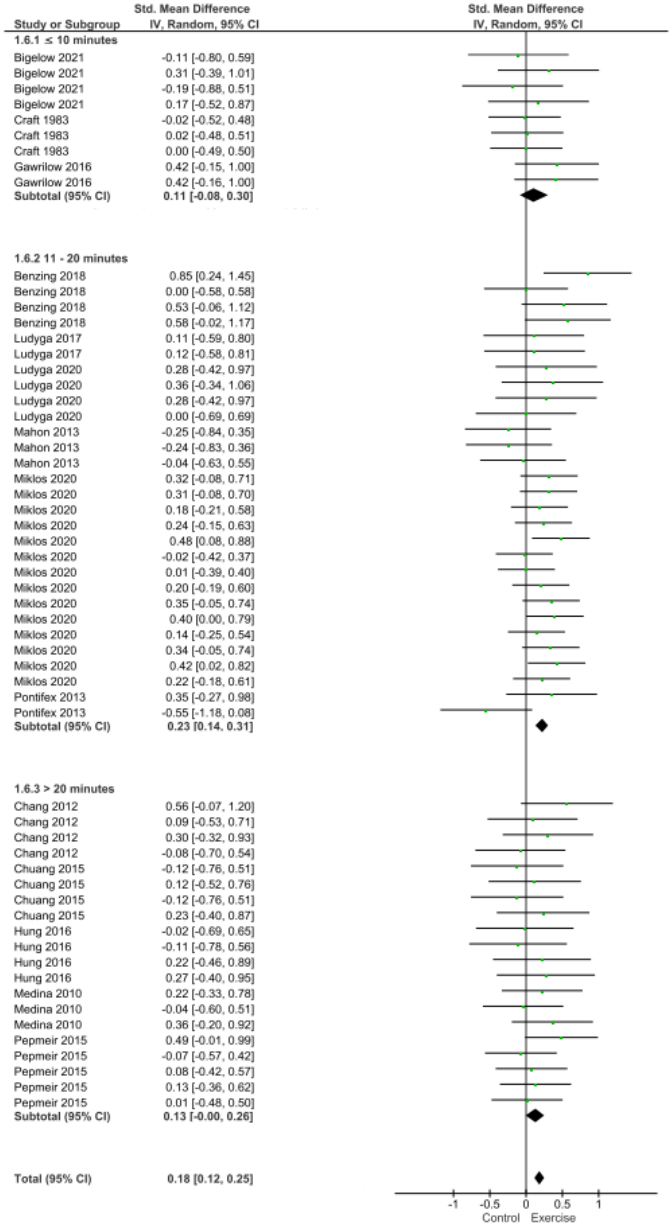


Figure 4.4. Forest plot showing sub-group analysis for physical activity duration. Note. ≤ 10 min (SMD=0.11, p=0.27, I^2=52%), 11-20 min (SMD=0.23, p<0.01; I^2=81%) and >20 min (SMD=0.13, p=0.05; I^2=54%).4.3.3.5.

4.3.3.5. Study design

The sub-analysis for study design (Figure 4.5) revealed a statistically significant small effect for between-subjects design after acute physical activity interventions on

subsequent cognitive function (SMD = 0.27 [0.18, 0.36], $p < 0.01$) and there was not shown to be significant heterogeneity ($Q(17.42)$, $df = 4$, $I^2 = 77\%$). The effect for studies with a within-subjects design was not significant (SMD = 0.08 [-0.04, 0.19], $p = 0.11$); the test for heterogeneity showed no significance ($Q(12.35)$, $df = 6$, $I^2 = 51\%$).

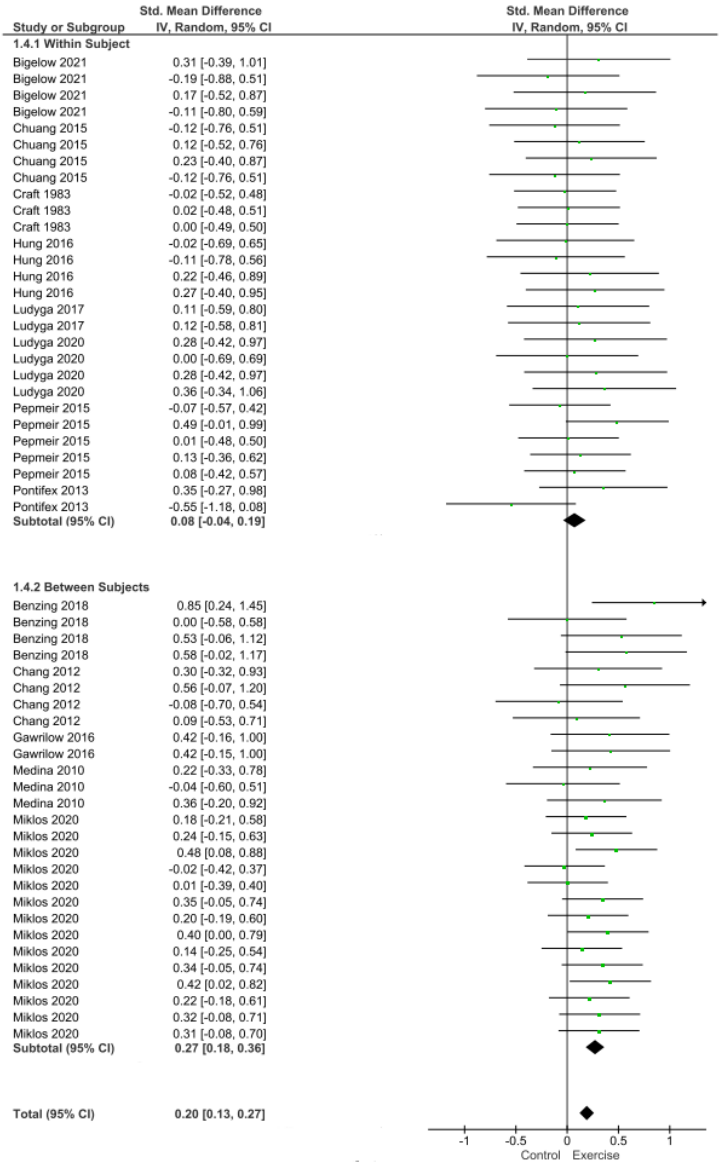


Figure 4.5. Forest plot showing sub-group analysis for study design. Note. Within subject designs (SMD = 0.08, p = 0.11; $I^2 = 51\%$) and between subject designs (SMD = 0.27, $p < 0.01$; $I^2 = 77\%$).

4.3.3.6. Modality of exercise

Finally, modality of physical activity was categorised into 'running' interventions, 'cycling' interventions and 'other'. Studies that used modes of physical activity interventions which were not running or cycling showed a statistically significant small effect on subsequent cognitive performance (SMD = 0.39 [0.18, 0.61], $p < 0.01$), and

showed substantial heterogeneity (Q (5.78), df = 2, I^2 = 65%). Running physical activity interventions also produced a statistically significant small effect on sequential cognitive function performance (SMD = 0.21 [0.12, 0.29], p < 0.01) and showed considerable heterogeneity (Q (20.27), df = 5, I^2 = 75%). The sub-analysis showed that cognitive performance was not enhanced following cycling interventions (SMD = 0.06 [-0.07, 0.19], p = 0.35) and revealed moderate heterogeneity (Q(8.30), df = 4, I^2 = 52%) (Figure 4.6). The test for subgroup differences revealed a statistically significant difference for physical activity modality (Q(7.38), df = 2, p = 0.02, I^2 = 73%).

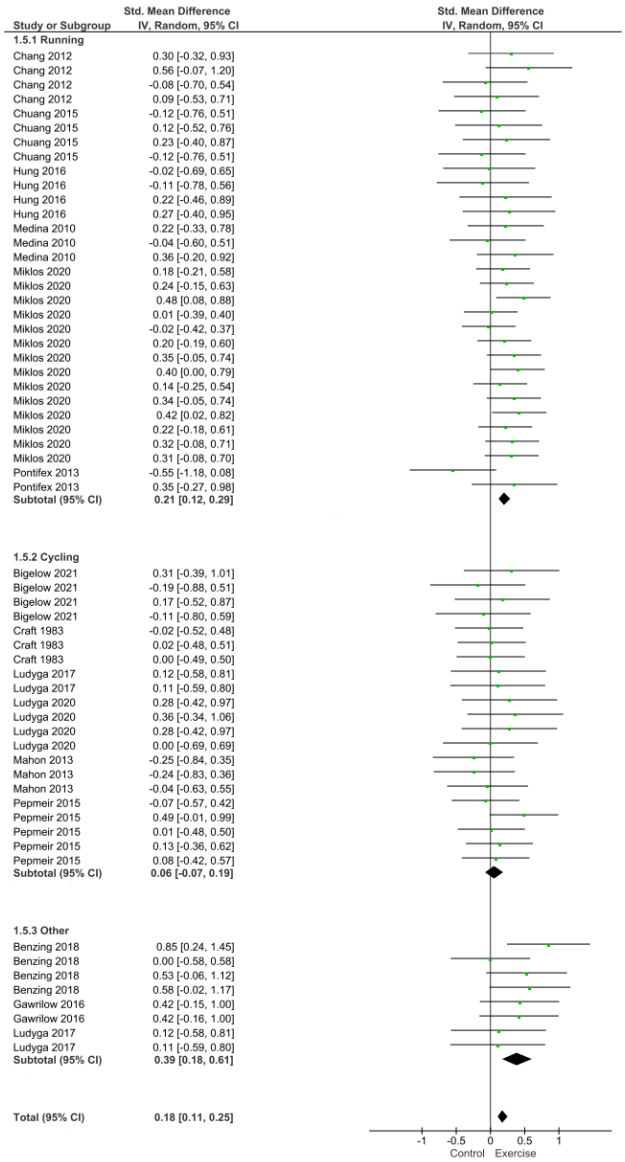


Figure 4.6. Forest plot showing sub-group analysis for modality of physical activity intervention. Note. Running interventions (SMD = 0.21, p < 0.01; I^2 = 75%), cycling interventions (SMD = 0.06, p = 0.35; I^2 = 52%), and 'other' physical activity interventions (SMD = 0.39, p < 0.01; I^2 = 65%).

4.3.3.7. Timing of cognitive function tasks post exercise

Finally, timing of completion of the cognitive function tests were categorised into 'immediately post-intervention', '2-10 min post-intervention' and '> 10 min post-intervention'. The results showed that studies which completed the cognitive function tasks 2-10 min post intervention had a statistically significant small effect on cognitive performance (SMD = 0.21, [0.12, 0.30], $p < 0.01$) with a substantial heterogeneity ($Q(13.32)$, $df = 2$, $I^2 = 86\%$). The sub-group analysis revealed that studies that completed the tests > 10 min post intervention showed small positive effect on cognition, although this effect was not statistically significant (SMD = 0.19, [-0.09, 0.47], $p = 0.19$) with no heterogeneity ($Q(0.74)$, $df = 1$, $I^2 = 0\%$). Finally, studies that completed the tasks immediately post intervention revealed a small effect on cognition, however this effect did not reach statistical significance (SMD = 0.17, [-0.01, 0.35], $p = 0.06$) but had a substantial heterogeneity ($Q(16.65)$, $df = 3$, $I^2 = 82\%$) (see figure 4.7). The results from the test for subgroup differences were non-significant for timing of cognitive function tasks post exercise ($Q(0.20)$, $df = 2$, $p = 0.91$, $I^2 = 0\%$).

4.4. Discussion

The main aim of this systematic review and meta-analysis was to examine the effects of acute physical activity interventions on cognitive function in children and adolescents with ADHD. Specifically, this meta-analysis examined key moderating variables in the acute effects of physical activity on cognition in children and adolescents with ADHD, including the cognitive function domain, the physical activity duration, study design, the modality of physical activity, and the timing of cognitive function tests following physical activity. Of the 14 studies which were included in the review and meta-analysis, the overall effect showed a small benefit of acute physical activity compared to a control condition on cognitive function in children and adolescents with ADHD (SMD = 0.18). The sub-analyses revealed that acute physical activity interventions were associated with statistically significant small beneficial effects on cognitive flexibility (SMD = 0.21), attention (SMD = 0.20) and inhibitory control (SMD = 0.18); however, memory (SMD =

0.02) was not shown to be enhanced. The analysis also revealed that cognition was

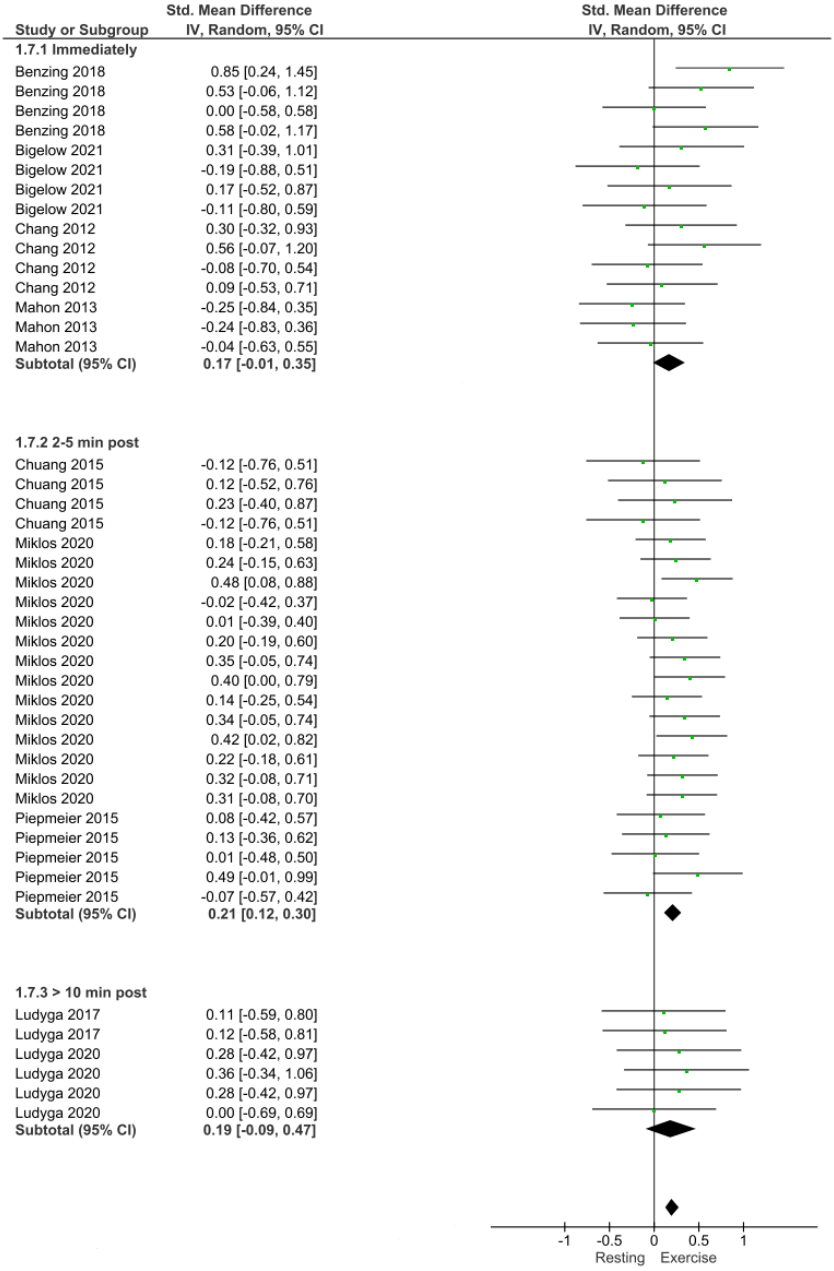


Figure 4.7. Forest plot showing sub-group analysis for timing of cognitive function test completion post-intervention. Note. Immediately post-interventions (SMD = 0.17, p = 0.06, I^2 = 82%), 2-5 min post-intervention (SMD = 0.21, p < 0.01; I^2 = 86%), and > 10 min post-intervention (SMD = 0.19, p = 0.19; I^2 = 0%).

improved following physical activity interventions 11–20 min (SMD = 0.23) and >20 min (SMD = 0.13) in duration, whereas interventions less than 10 min in duration had no significant benefit (SMD = 0.11). Whist studies with a between subject design demonstrated a positive effect on subsequent cognition (SMD = 0.28), those studies with a within subject design did not (SMD = 0.09). With regards to the modality of physical

activity, running (SMD = 0.21) and 'other' modes of physical activity including trampolining, exergaming, and coordinative tasks (SMD = 0.39) had beneficial effects on cognition, whilst cycling did not (SMD = 0.06). Finally, the positive effects of physical activity on cognition in children and adolescents with ADHD occur after a short delay of 2–10 minutes following the activity (SMD = 0.21); whilst small, non-statistically significant, effects were found when tests were completed immediately (SMD = 0.17) and >10 min post-intervention (SMD = 0.19). To our knowledge, this study is the first meta-analysis to investigate the effects of acute physical activity interventions on cognitive function in children and adolescents with ADHD with specific focus on key moderating variables (such as the duration and modality of activity) which influence the subsequent effects on cognition.

The present study found that, overall, acute physical activity interventions had a small beneficial effect on cognitive function in children and adolescents with ADHD (SMD = 0.18). The present meta-analysis is novel in examining the acute effects of physical activity on children and adolescents with ADHD; and builds on previous systematic reviews by adding meta-analytical results and insights. Previous reviews have investigated the combined effects of acute and chronic physical activity interventions in children and adolescents with ADHD; with one study examining both ADHD and autism (Tan, Pooley, & Speelman, 2016), and one solely focusing on chronic interventions (Welsch et al., 2021). Systematic reviews investigating the effects of acute physical activity interventions (ergometric cycling or treadmill running) on cognitive function (inhibitory control, memory and cognitive flexibility) in children and adolescents with ADHD (Grassmann et al., 2017) have also reported beneficial effects, and therefore support the findings of the present meta-analysis.

The results of the present study are the first to demonstrate the effectiveness of acute physical activity interventions on four individual cognitive domains, namely cognitive flexibility, inhibitory control, memory, and attention. It was found that cognitive flexibility (SMD = 0.21), attention (SMD = 0.20), and inhibitory control (SMD = 0.18) had a small significant improvement following acute physical activity. However, there were no effects

of acute physical activity on memory (SMD = 0.02). Silva et al. (2015) investigated the effects of an acute physical activity intervention on subsequent attention in children and adolescents with ADHD and found that both attention and impulse control were significantly improved after physical activity. It was suggested that this improvement was due to the release of serotonin, dopamine and norepinephrine which helps the participants remain focused and calm. The findings from Silva et al. (2015) support the present research and provide some evidence regarding the underpinning mechanisms for the acute effects of physical activity on attention in children and adolescents with ADHD.

Previous research has also found similar beneficial effects of a single bout of physical activity on inhibitory control in children and adolescents with ADHD, with specific increases in response accuracy (Yu et al., 2020). Specifically, these beneficial effects were reported 30 and 60 min post-physical activity (Yu et al., 2020). Finally, cognitive flexibility has been shown to improve following chronic physical activity interventions in children and adolescents with ADHD, with improvements in reaction times reported (Benzing & Schmidt, 2019). Although the research investigating the effects of acute physical activity on cognitive flexibility is relatively limited, evidence from the present meta-analysis and previous research exploring chronic interventions provides evidence that this important cognitive domain can be enhanced following physical activity (Welsch et al., 2021).

Memory was the only cognitive domain not found to be improved following acute physical activity (SMD = 0.02). This could be due to only a small number of studies investigating memory as a cognitive domain (3 studies, yielding 5 effect sizes). Although the present meta-analysis provides evidence of no overall effect of physical activity on memory in children and adolescents with ADHD, the study of Bigelow et al. (2021) found a small beneficial effect. The research by Bigelow et al. (2021) used a physical activity intervention lasting 10 min, a duration which the present meta-analysis revealed to be non-significant in producing a beneficial effect on cognition. It is therefore surprising that Bigelow et al. (2021) found a small beneficial effect on memory and could raise questions

about whether different durations of physical activity may have different effects on each domain of cognitive function; yet this has not been investigated to date.

Moderating variables that could potentially influence the effect of acute physical activity interventions on cognition in children and adolescents with ADHD were investigated in the present meta-analysis. The first of these variables was the duration of physical activity. The present study revealed that physical activity interventions ≤10 min in duration did not benefit cognition (SMD = 0.11) compared to studies which used interventions 11–20 min (SMD = 0.23) and >20 min (SMD = 0.13) in duration. This finding has been supported by a recent review in neurotypical children and adolescents where it was suggested that longer bouts of physical activity have a greater benefit on cognition compared to shorter durations (Williams et al., 2019). The dose-response relationship of physical activity duration and cognitive function is still relatively under-researched in children and adolescents with ADHD. The research by Craft (1983), included in the present review, was the only study to investigate different durations of acute physical activity, however it is suspected that the durations selected by Craft (1983) (1, 5 and 10 min) were too short to produce any significant benefit on cognition (Grassmann et al., 2017). Physical activity duration is thus a critical aspect of creating an effective intervention. The findings of the present study suggest that physical activity interventions >11 min in duration positively enhance subsequent cognition; an important novel finding with important implications for future intervention design.

Study design was also investigated, and it was found that studies which adopted a between subject study design demonstrated enhanced cognition following physical activity (SMD = 0.28), whereas those which used a within subject study design did not (SMD = 0.09). Although between subject designs reduce the risk of a demand effect (Charness, Gneezy, & Kuhn, 2012), it is still desired that the participants are randomly allocated to each condition. Randomization was conducted in all studies which used a between-subject deign. Two of the studies, however, did not clarify on their concealment process prior to assignment to interventions (Bigelow et al., 2021; Miklós et al., 2020) and therefore had some concerns in the risk of bias assessment. Within-subject designs

measuring both pre- and post-physical activity, with effective randomization to explore the cognitive benefits following acute physical activity interventions, would be the ideal research (Pontifex et al., 2019). However, very few studies have used this design to date; a key limitation of the existing evidence base. The present meta-analysis adds to the current literature by acknowledging study design (between- or within-subject design) as a potential mediating variable on the effect of acute physical activity on cognition in children and adolescents with ADHD, which is an important consideration when interpreting the findings of studies in this area.

The modality of physical activity was also considered as a moderating variable in the present meta-analysis. It was found that physical activity interventions which used running (SMD = 0.21) and 'other' types of physical activity (SMD = 0.39) namely, trampolining, exergaming, and coordinative tasks as their mode of physical activity had beneficial effects on cognition in children and adolescents with ADHD, compared to those who used cycling which was found to have no effect (SMD = 0.06). It is interesting to see those interventions using more open-skills (e.g., exergaming) had a greater beneficial effect on cognition compared to closed-skills. Open-skill sports are activities that are influenced by the environment and often unpredictable (e.g., basketball, tennis, or martial arts); whereas closed-skills are often self-paced and less influenced by environmental factors (e.g., running or cycling). Recent reviews have summarized that open-skill interventions are most beneficial to cognition (Gu, Zou, Loprinzi, Quan, & Huang, 2019; Zhu, Chen, Guo, Zhu, & Wang, 2020). This could account for the greater benefit from interventions which used trampolining, exergaming, and coordinative tasks.

A further consideration is the lack of ecological validity of interventions that used treadmill running and cycling on an ergometer, as these activities are not typical for children and adolescents in everyday situations. Evidence in neurotypical children and adolescents demonstrates a positive effect of acute games-based activities, specifically basketball interventions, on subsequent cognition (Cooper et al., 2018); however, these findings have not yet been shown in children and adolescents with ADHD. Future studies should consider including open-skill or games-based acute physical activity interventions

to help identify the most beneficial type of physical activity to produce beneficial effects on cognitive function in children and adolescents with ADHD; with a particular focus on ecologically valid forms of exercise that can be incorporated into the school day.

Finally, timing of the administration of cognitive tests post physical activity was considered as a potential moderator. The results from the sub-group analysis revealed that studies administering the cognitive function tests between 2 and 10 min post-intervention had a small beneficial effect (SMD = 0.21). Small positive effects were found when tests were completed immediately following the interventions (SMD = 0.17) and >10 min post intervention (SMD = 0.19), however these did not reach statistical significance. It appears that the positive effects of physical activity in children and adolescents with ADHD occur after a short delay. Interestingly, Chang, Labban, et al. (2012) examined the effects of a delay in the administration of the cognitive function tests following physical activity in neurotypical people. Chang, Labban, et al. (2012) found benefits on cognition when cognitive tests were administered 11–20 min, and >20 min post-exercise. Therefore, findings from the broader literature in neurotypical individuals (Chang, Liu, et al., 2012) and the present meta-analysis in children and adolescents with ADHD suggest that the cognitive benefits following physical activity are greatest following a short delay of ~10 min. However, these results should be interpreted with caution, due to the limited number of studies that measure cognition at multiple timepoints following physical activity, thus these effects are potentially confounded by the other moderating variables in the physical activity-cognition relationship when comparing between studies. Alongside future studies to address this gap in the literature, in order to assist with interpretation, the timing of the cognitive tasks following physical activity should be carefully considered and accurately reported in future randomized control trials.

Further research is required as many of the moderating variables such as the cognitive domains measured, duration, study design, modality, and intensity of physical activity, alongside the timings of the measurements will ultimately combine to influence cognitive function in children and adolescents with ADHD. The current understanding of the combined influence of the moderator's relationships is limited and is therefore an

important avenue for future research. However, the present meta-analysis provides important evidence of the effects of moderating variables (cognitive domain, duration of physical activity, study design, physical activity modality, and timing of cognitive tests following physical activity) and their potential to influence cognitive function following physical activity in children and adolescents with ADHD. Specifically, the results from the meta-analysis show that physical activity interventions using running, exergaming, trampolining, and coordinative tasks elicit beneficial effects on cognitive function in children and adolescents with ADHD. Secondly, the results from the sub-analysis for duration showed that interventions lasting 11–30 min in duration significantly improved subsequent cognitive function in children and adolescents with ADHD. Finally, enhancements were greatest when cognitive tasks were completed 2–10 min following physical activity.

Acute bouts of physical activity have been shown to have a small but positive effect on subsequent cognitive function in neurotypical children and adolescents (Chang et al., 2012; Donnelly et al., 2016; Haapala, 2012; Williams et al., 2019); although moderating variables such as the modality, duration, and intensity of activity, the timing of cognitive tests post-intervention, and participant characteristics (e.g. physical fitness) influence these effects (Williams et al., 2019). However, prior to the present meta-analysis, limited research had considered these moderators in children and adolescents with ADHD. Therefore, the present meta-analysis provides novel insight to suggest that 11–30 min of moderate-vigorous physical activity, that consists of running or 'other' (e.g., coordinative) activities will elicit the greatest enhancements in cognition following physical activity in children and adolescents with ADHD.

4.4.1. Strengths, limitations, and future research directions

A strength of the present study is its novelty in being the first meta-analysis to be conducted investigating the effects of acute physical activity on cognitive function in children and adolescents with ADHD. Christiansen et al. (2019) highlighted this by providing evidence that no current meta-analysis has investigated the effects of acute and chronic physical activity interventions separately. Since the review by Christiansen et al.

(2019), Welsch et al. (2021) published a meta-analysis investigating the effects of chronic interventions, yet there has still not been a meta-analysis with sole focus on the effects of acute physical activity interventions, highlighting the importance of the present study.

Although this study is novel in its aims and has added to the current research, there are some limitations which should be highlighted. Firstly, when there was no control intervention for one study (Craft, 1983), pre-intervention results were used as a resting control. Although this method enabled key and valuable research to be included in the present meta-analysis and review, pre-intervention results may not truly reflect a resting control condition. Secondly, due to the variability between studies, medication, sex differences, exercise intensity and comorbidities were not considered in the sub-analysis as potential covariates. The present study was unable to investigate sex differences, this was due to none of the included studies reporting the data individually for girls and boys. It would be interesting for future research to identify if physical activity affects cognition differently between the sexes. Additionally, due to many of the included studies using a range of different cognitive tests, resulting in multiple outcomes, all measures were input into the meta-analysis separately. Currently there is not a standardised method of how to manage multiple outcome measures from a single study. Other studies have suggested combining effect sizes, choosing the most relevant and representative effect size, separating effect sizes into the most coherent subcategories so that effect sizes within subcategories are no longer dependent, and finally, using a multivariate meta-analysis (Fedewa & Ahn, 2011). However, issues surrounding this are the potential for high selection bias (in selecting the most relevant effect size for each study), and speed accuracy trade-offs. Therefore, in the present chapter, it was decided to include all outcome measures to ensure that speed-accuracy trade-offs could not affect the study outcomes, and ultimately more appropriately examine the overall effects of physical activity on subsequent cognitive performance. Finally, caution should be taken when interpreting the findings from this study due to the small effect sizes and heterogeneity of studies, which may suggest that the effects of physical activity on cognition in young

people is small, thus highlighting the requirement of further research to consolidate these findings.

4.4.2. Practical implications

Based upon the findings of the present meta-analysis it is recommended that, to enhance subsequent cognitive function in children and adolescents with ADHD, acute bouts of physical activity should last 11–30 min in duration. Furthermore, the current evidence base suggests that interventions using running, trampolining, exergaming, or coordinative tasks are most beneficial for subsequent cognitive function in children and adolescents with ADHD, whereas cycling was not shown to have a positive effect on cognition. It is also important to consider that the beneficial effects of an acute bout of physical activity on cognition are greatest after a short delay (2–10 min) following physical activity. These findings have the potential to be used as the basis of recommendations for the incorporation of physical activity into the daily lives of children and adolescents with ADHD; thus, may be of interest to teachers, healthcare providers and practitioners working with this population.

4.4.3. Conclusion

In summary, the present chapter is the first meta-analysis to explore the effects of acute physical activity across different domains of cognitive function in children and adolescents with ADHD, and how additional moderating variables including the duration and modality of physical activity, study design, and the timing of cognitive function tasks following physical activity, influence these relationships. The findings suggest that acute physical activity interventions have a positive effect on cognition, with improvements in the domains of cognitive flexibility, inhibitory control, and attention. The present review recommends that future interventions last 11–30 minutes in duration, as this was shown to provide the greatest benefit on cognitive function in children and adolescents with ADHD. As discussed previously, the modality of physical activity also plays a key role in cognitive performance, and therefore we recommend that future studies incorporate more open-skill and games-based physical activity interventions to help in identifying the most beneficial, and ecologically valid, mode of physical activity in children and adolescents with ADHD.

Finally, the delay in cognitive function task administration should be considered in future studies with suggestion that a short delay of 2–10 minutes elicits beneficial effects on cognition in children and adolescents with ADHD. Future research should continue to examine the time course of the acute effects of physical activity on subsequent cognition in this population, as this will be important for the implementation of future interventions, and in particular aid understanding of how physical activity could be incorporated within the school day. The research discussed in this systematic review and meta-analysis can provide some guidance on how to shape future interventions, however more research is required in order to conclude what the optimum dose of physical activity is and how physical activity could be optimally prescribed to children and adolescents with ADHD in the future.

Chapter V

Associations of physical activity and cardiorespiratory fitness with cognitive function, self-control, and resilience in young people with attention-deficit/hyperactivity disorder

5.1. Introduction

Acute physical activity interventions have demonstrated that single bouts of physical activity positively affect cognition in young people with ADHD, as shown in the meta-analysis in Chapter IV. These findings highlight the immediate cognitive benefits that can be harnessed through single bouts of physical activity. Building on this, this following chapter explores how daily physical activity (chronic physical activity engagement) is associated with broader psychological concepts (cognitive function, resilience and self-control) in young people with ADHD. By shifting the focus from acute physical activity to chronic physical activity, this study will begin to address whether the benefits observed acutely can be translated to long-term benefits for young people with ADHD.

Attention deficit hyperactivity disorder (ADHD) is one of the most prevalent neurodevelopmental disorders globally, with approximately 5% of young people aged 6-18 years having a clinical diagnosis (Polanczyk et al., 2007; Sayal et al., 2018; Salari et al., 2023), and an estimated 3:1 ratio of males to females in community samples (Sayal et al., 2018). ADHD has been categorised into three diagnoses, namely; predominantly inattentive presentation (characterised by difficulty maintaining concentration or attention, difficulty following instructions and disorganisation), predominantly hyperactive-impulsive presentation (characterised by fidgeting, excessive talking, or being described as ‘always on the go’), and combined presentation (when an individual meets the criteria for both the inattentive and hyperactive-impulsive presentations) (APA, 2022).

To treat ADHD, pharmacological treatments such as medication (Brahmbhatt et al., 2016; Yildiz et al., 2011) are often utilised. However, pharmacological treatments often come with many side effects such as sleep impairment, headaches, and mood swings (Brahmbhatt et al., 2016; Yildiz et al., 2011). Therefore, finding an alternative or

adjunctive treatment to aid the management of ADHD symptoms and behaviours in young people, whilst managing the side effects of additional treatments such as medication, is important for healthcare practitioners, parents, educationalists, and young people with ADHD. Although certain non-pharmacological treatments such as diet, lifestyle management, parent and teacher interventions, behavioural therapy and neurofeedback have all been proposed to manage ADHD (Brahmbhatt et al., 2016; Chaplin, 2018; Sonuga-Barke et al., 2013), these treatments often lack efficacy and are frequently not adhered to (Brahmbhatt et al., 2016; Sonuga-Barke et al., 2013). In recent years, another option for ADHD management that has gained increased attention is physical activity (Hoza, Martin, Pirog & Shoulberg, 2016), particularly given that evidence in neurotypical individuals suggest that there are many benefits associated with physical activity such as improved health outcomes (reduced adiposity, improved bone health), improved quality of life and wellbeing, improved motor skill-development, and enhanced cognitive function (Donnelly et al., 2016, Poitras et al., 2016; Sun et al., 2023). Furthermore, a recent meta-analysis has highlighted how regular physical activity has beneficial effects on teacher and parent reported ADHD symptoms and behaviours in young people with ADHD (Bustamante et al., 2022), therefore reinforcing the idea of undertaking physical activity aids ADHD management.

Cognitive function can be defined as the brain's functioning and processing capabilities allowing one to store and utilise external (environmental) and internal (memories or thoughts) information (Schmitt, Benton & Kallus, 2005). Cognitive function can be sub-divided into six broad domains, namely attention, memory, executive function (including the sub-domains of inhibitory control, cognitive flexibility, and working memory), perception, psychomotor, and language (Schmitt et al., 2005). Research suggests that cognitive function plays a mediating role in young people's academic achievements (Best, Miller, & Naglieri, 2011) and motor proficiencies with early development of cognition leading to lifelong benefits (Cadoret et al., 2018). In young people with ADHD, cognition is understood to be impaired compared to their neurotypical counterparts (Pievsky & McGrath, 2018; Weyandt et al., 2017). Specific deficits have been highlighted in executive

function; predominantly inhibitory control and working memory (Coghill, Toplak, Rhodes & Adamo, 2018; Daley & Birchwood, 2010) and these are associated with reduced academic attainment (Daley & Birchwood, 2010).

Although the research base investigating the effects of physical activity interventions (both acute and chronic) and cognition in young people with ADHD is extensive (Chang, Liu, Yu & Lee, 2012; Piepmeier et al., 2015; Sarver et al., 2015; Verret et al., 2012; Ziereis & Jansen, 2010), the associations between daily physical activity and cognition to date are poorly understood. Promising initial evidence suggests a positive association between daily physical activity and executive function (Gapin & Etnier, 2010). However, the associations between daily physical activity and other cognitive domains in young people with ADHD remain unknown. Furthermore, emerging findings have begun to suggest positive associations between physical fitness (across multiple components such as flexibility, muscular endurance, muscular power, aerobic fitness, and body composition) and cognition in young people with ADHD (Tsai et al., 2017). Specifically, high-fit children with ADHD (across all components of fitness) demonstrated shorter reaction times in the Flanker task, compared to their low-fit counterparts (Tsai et al., 2017). However, only the cognitive domain of inhibitory control has been examined within this population (Tsai et al., 2017) and it is therefore important to assess whether the benefits of physical fitness extend beyond inhibition. Chapter IV identified the extent to which acute physical activity affects multiple cognitive domains; however this is yet to be examined with daily physical activity.

A further psychological construct that contributes to young people's day-to-day lives is self-control. Self-control can be defined as the ability to alter one's own responses in order to resist temptation, and progress towards long-term goals (Beaumeister, Vohs & Tice, 2007). This chapter discusses trait self-control which refers to the innate ability to control actions and supress impulsive and recurrent responses to situations and environments (Hagger et al., 2021). The ability to utilise self-control varies between individuals (trait self-control perspective), with low self-control suggested to be associated with underachievement in school (Kuhnle, Hofer & Kilian, 2012), violent behaviour, and

inattentiveness (Baumeister, 2002; de Ridder et al., 2012). It is therefore not surprising that previous research has identified low self-control in children and adolescents with ADHD when compared to their neurotypical comparators (Schweitzer & Sulzer-Azaroff, 1995). Moreover, young people with ADHD who are reported (via parents) to have low levels of self-control have been shown to have greater behavioural issues and heightened symptoms of ADHD (Crundwell, 2005). Physical activity has been shown to have an association with self-control in neurotypical individuals; whereby higher self-control was associated with physical activity participation, and ultimately greater physical fitness (Wills, Isasi, Mendoza & Ainette, 2007; Boat et al., 2022). However, currently the relationship between physical activity, physical fitness, and trait self-control in children and adolescents with ADHD is limited. The only study to date suggests that increased physical fitness (assessed through flexibility, muscular endurance, power, and agility) in young people with ADHD is related to improved attentional self-control (measured through EEG theta/alpha ratios) (Huang et al., 2015). However, this is the only study to examine this to date and used measures of brain activation as a surrogate marker of self-control. Thus, further investigation is required to understand the impact of chronic physical activity on trait self-control in young people with ADHD, which is of particular interest given the lower self-control reported in this population compared to their neurotypical counterparts.

Resilience has also been identified as a psychological construct that is important in young people's lives and can be defined as one's ability to maintain functioning under difficult circumstances and positively adapt in the face of adversity (Fletcher & Sarkar, 2013; Southwick et al., 2014). This chapter discusses resilience as a trait; highlighting characteristics that enable individuals to adapt to circumstances they encounter. Although children and adolescents with ADHD often exhibit difficulties controlling their behaviour and emotions in their day-to-day functioning, some research has provided evidence that young people with ADHD often demonstrate levels of resilience that are comparable to neurotypical children (Chan et al., 2022; Wilmshurst, Peele & Wilmshurst, 2011). High(er) resilience is associated with academic achievement outcomes (school grades (Dvosrky et al., 2018)) and has been shown to play an important role in transitions from adolescence

to adulthood in individuals with ADHD (Schei et al., 2018). Although the literature to date is limited in young people, physical activity has been shown to be positively associated with resilience in neurotypical young adults (Arida & Teixeira-Machado, 2021; Gerber et al., 2012). However, currently, the relationship between physical activity, physical fitness and resilience in young people with ADHD is unknown.

In summary, little is known regarding the associations between physical activity and cardiorespiratory fitness with different domains of cognitive function, self-control, and resilience in children and adolescents with ADHD; all of which are important psychological constructs in this population. Therefore, the aim of this chapter was to examine the associations between physical activity and cardiorespiratory fitness with cognitive function, self-control, and resilience in young people with ADHD.

5.2. Methodology

5.2.1. Participant characteristics

Of the original sample (78 participants), twenty-four participants dropped out due to absence on one of the testing sessions, or an incomplete data set (see figure 5.1 for a flowchart outlining dropout). This resulted in a final sample of fifty-four school children (11 female and 43 male) with a clinical diagnosis of ADHD or on the pathway to a clinical diagnosis aged between 9 and 15 years (12.80 ± 1.39 years) that participated in the present study. Due to the reportedly long wait times for an ADHD diagnosis, those on the pathway for a clinical diagnosis were included in the present study (Sainsbury et al., 2023) and ADHD symptoms were assessed by parent ratings of symptom severity on the SNAP-IV ADHD rating scale (Swanson et al., 2001). Height was measured using a Leicester Height Measure (Seca, Hamburg, Germany) accurate to the nearest 0.1 cm (157.96 ± 10.58 cm), body mass was measured using a Seca 770 digital scale (Seca, Hamburg, Germany) accurate to the nearest 0.1 kg (50.17 ± 15.83 kg), body mass index was subsequently calculated (BMI: 19.84 ± 4.93 kg/m^2). Any participants who were prescribed medication for their ADHD symptoms continued to take their medication throughout the study, for reasons of ecological validity and ethical concerns associated with medication withdrawal. For descriptive purposes, 28 participants were medicated (7 female), and 26

were unmedicated (4 female), the most commonly prescribed medications were: Medikinet XL (n = 7), Concerta (n = 4) and Methylphenidate (n = 4).

5.2.2. Study design

The present study was approved by the Nottingham Trent University Human Invasive Ethics Committee. The study employed a cross-sectional design which included a familiarisation trial which took place approximately 7 days prior to a main trail. Following ethical approval, participants were recruited from Special Educational Needs (SEN) schools and local state primary and secondary schools in the East Midlands area of the UK. A total of 6 schools agreed to participate in the study (SEN: 1, mainstream: 5). Headteacher written informed consent was gained in addition to written consent from the parent/guardian of the child participant. A health screen was additionally completed by parent/guardians to determine the participants eligibility to participate in the study, any child with a health condition that could inhibit their ability to participate (e.g., heart condition) was not included in the study. Children also provided their written assent to participate in the study. The following inclusion criteria were applied: (a) participants had a clinical diagnosis of ADHD, or an ongoing assessment for an ADHD diagnosis; (b) no health condition that could inhibit participation in physical activity. A total of 54 children (11 females) with ADHD participated in the present study. Of the original sample (78 participants), 24 participants were excluded from the study (n = 7 withdrew, n = 1 did not meet the inclusion criteria, n = 3 did not return ADHD questionnaires, n = 6 did not take part in the fitness test, n = 1 missing cognitive data and n = 6 did not wear their accelerometer for valid wear time) resulting in a final sample of 54 participants (see figure 5.1.).

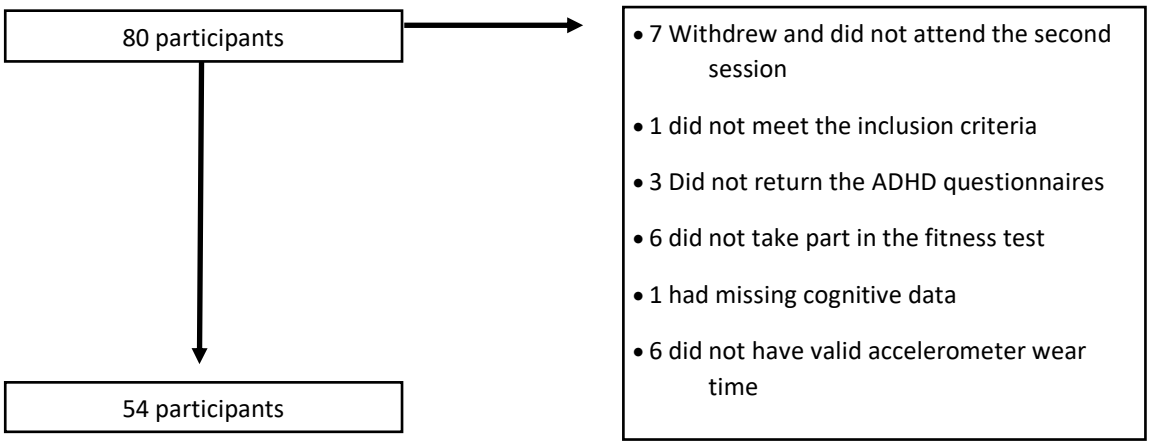


Figure 5.1. Flow chart showing participant dropout

5.2.3 Procedures

Following the completion of the anthropometric measures, participants completed a series of questionnaires to measure their self-control in school using the Brief Self-Control Scale (Tangney, Beaumeister & Boone, 2004), and their resilience in school using the 10-item Connor-Davidson Resilience Scale (CD-RISC (Campbell-Sills & Stein, 2007; Connor & Davidson, 2003)). The children were assisted by a member of the research team on a one-to-one basis when completing the questionnaires to ensure the participants had a clear understanding of the questions. Participants then practiced a battery of cognitive function tests. At the end of the familiarisation trial, all participants were given an accelerometer (ActiGraph GT3X +), which they were instructed to wear for 7 days. On the main trial, upon arrival to school, participants returned their accelerometer. The participants were then seated and completed the battery of cognitive function tests. The participants then took part in a multi-stage fitness test (MSFT (Ramsbottom, 1988). An overview of the study protocol can be seen in figure 5.1.

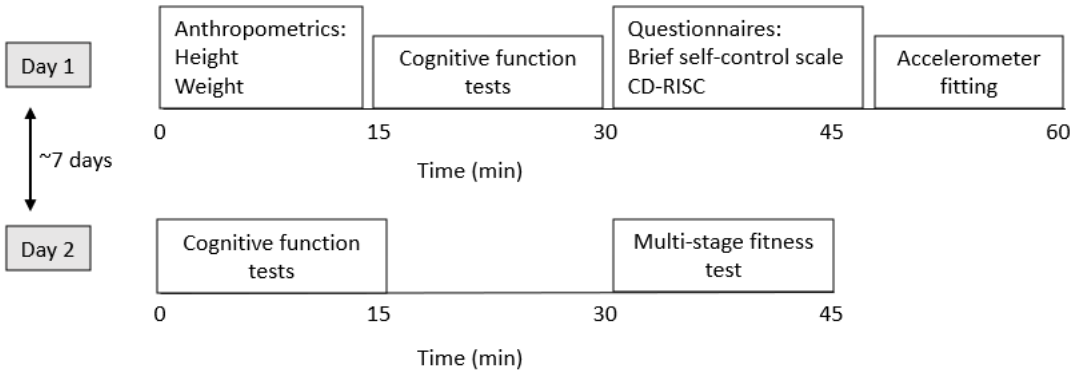


Figure 5.2. Schematic of the experimental protocol. Note. CD-RISC; Connor-Davidson Resilience Scale.

5.2.4. Measures

5.2.4.1 Cognitive tests

The cognitive tests consisted of a Stroop test, Sternberg paradigm, and a Flanker task (further detail regarding cognitive function tests is described in detail in Chapter III section 3.3.3.). The battery of tests lasted approximately 15 min and were administered via a laptop computer (Lenovo ThinkPad; Lenovo). Before starting each test, instructions were presented on the laptop screen as well as verbally by a member of the research team. The research team guided the participants through an example of each test on a projector to ensure the participants fully understood each task. Each test level began with three to six practice stimuli for which the data were disregarded to re-familiarise the participants with the test and negate any potential learning effects. In groups of 4 to 10 participants, participants were asked to complete the tasks in silence wearing noise cancelling headphones. Response time (ms) of correct responses and proportion of correct responses (%) were recorded and subsequently used to calculate an inverse efficiency score (IES (Statsenko et al., 2020)). The IES was calculated (reaction time (ms) / accuracy (proportion correct)) and has been used in previous research to provide a single cognitive outcome that combines both response times and accuracy (Bedard et al., 2021); thus, negating the possibility of speed-accuracy trade-offs affecting study outcomes (Statsenko et al., 2020; Heitz, 2014). For ease of interpretation, a lower IES indicated improved performance on the cognitive task.

5.2.4.2. Questionnaires

5.2.4.2.1. Resilience

The 10-item Connor-Davidson Resilience Scale (CD-RISC (Campbell-Sills & Stein, 2007; Connor & Davidson, 2003)) was used to provide a self-report measure of trait resilience (see Chapter III, section 3.3.4.2 for further information on the CD-RISC). The CD-RISC evaluates the psychological trait of resilience. For each item (e.g., “I am able to adapt when changes occur”) participants were provided with a 5-point Likert-type scale ranging from 0 to 4 (0 indicating not true at all, 4 indicated true nearly all the time), with higher scores indicating higher resilience. The CD-RISC 10-item questionnaire has been shown to be successfully administered within a similar aged population (She, Yang, Lau & Lau, 2020). In the present study, the internal consistency of the 10-item CD-RISC was high (α = 0.84) (Taber, 2018).

5.2.4.2.2. Self-control

Participant’s trait level of self-control was measured using the Brief Self-Control Scale (BSCS; Tangney, Beaumeister & Boone, 2004) (See Chapter III, section 3.3.4.1. for further information about the BSCS). This 13-item questionnaire provides a 5-point Likert-type scale ranging from one (indicating not very much) to five (indicating very much). The Brief Self-Control Scale has been proven to be a successful tool for assessing self-control in young people (Boat et al., 2022; Rodríguez-Menchón, Morales, Orgilés & Espada, 2022; Turliuc & Pojoga, 2018). Internal consistency of the 13-item Brief Self-Control Scale was adequate in the present sample (α = 0.66) (Taber, 2018).

5.2.4.2.3. Swanson Nolan and Pelham Rating Scale (SNAP-IV)

The SNAP-IV rating scale (Swanson et al., 2001) was used to measure ADHD symptoms and behaviours. The SNAP-IV includes 18 items to measure inattentive symptoms and hyperactive-impulsive symptoms (see Chapter III, section 3.3.4.4. for further information about the SNAP-IV). Ratings for each item are given on a 4-point scale: ‘not at all’, ‘just a little’, ‘quite a bit’, or ‘very much’. Items scored ‘not at all’ were

given a score of zero, ‘just a little’ was given a score of one, items scored ‘quite a bit’ were given a score of two, and ‘very much’ were given a score of three. A more detailed description of the SNAP-IV is described in Chapter III section 3.3.4.4. Internal consistency of the SNAP-IV was high (according to values represented in the literature (Tavakol & Dennick, 2011)) in the present sample indicating internal consistency and inter-relatedness of items (α = 0.84) (Taber, 2018).

5.2.4.3. Multi-stage fitness test (MSFT)

The MSFT was used as a measure of cardiorespiratory fitness and involves participants undertaking progressive 20 m shuttle runs until exhaustion, or until the participant fails to keep time with the audio signal that dictates the running speed. A more detailed description of the MSFT is described in Chapter III section 3.3.1.

5.2.4.4. Physical activity

Free-living physical activity was measured using hip worn Actigraph GT3X+triaxial accelerometers (Actigraph, Pensacola, FL, USA). For further a detailed description of the physical activity measures, see Chapter III section 3.3.2.

5.2.5. Statistical analysis

Data were analysed using statistical package for social sciences (IBM SPSS version 28). Histograms were completed for each variable to assess normal distribution of the data. Pearson’s *r* bivariate correlation analyses were then completed to assess associations between physical activity, and cardiorespiratory fitness with cognitive function, self-control, and resilience scores. Statistical significance was accepted as $p < 0.05$, with *r* values reported from the Pearson’s correlation analysis.

5.3. Results

5.3.1. Description of variables

For descriptive purposes, mean values for the ADHD questionnaire, self-control, resilience, cardiorespiratory fitness, physical activity, and cognitive function are displayed in Table 5.1. No associations were found between ADHD traits and symptoms, and any of the other variables (all $p > 0.05$), thus the entire sample were analysed collectively. 72% of participants provided valid wear time for the accelerometer measure. Valid wear time (mean ± SD) on weekdays was 4.2 ± 1.1 days and on weekend days was 1.75 ± 0.47 days.

Table 5.1. ADHD score, self-control, resilience, physical fitness, physical activity, and cognitive function

Variable		Mean ± SD	Range
ADHD score	**SWAN hyperactivity score**	1.65 ± 0.5	0 – 3
	SWAN inattentive score	1.86 ± 0.5	0 - 3
Self-control		38.1 ± 7.2	21 - 58
Resilience		21.9 ± 6.4	3 - 37
Physical fitness	**MSFT distance (m)**	780 ± 380	140 - 1660
Physical activity	**Average acceleration (mg)**	24.4 ± 7.5	10.3 – 42.1
	Intensity gradient (AU)	-2.4 ± 0.3	-3.0 - -2.0
Cognitive function (all measures reported as inverse efficiency score [IES])	**Stroop Simple**	959 ± 229	572 – 1824
	Stroop Complex	1433 ± 353	859 – 2377
	Flanker Congruent	710 ± 187	421 – 1586
	Flanker Incongruent	913 ± 430	463 – 2773
	Sternberg Paradigm 1 – item	662 ± 180	427 – 1338
	Sternberg Paradigm 3 – item	1236 ± 2757	283 – 21044
	Sternberg Paradigm 5 – item	1361 ± 1936	340 – 14978

5.3.2. Associations between physical activity, cardiorespiratory fitness, cognitive function, self-control, and resilience

A correlation matrix showing associations between physical activity and cardiorespiratory fitness with cognitive function, self-control, and resilience in young people with ADHD is shown in Table 5.2.

5.3.2.1. Cognitive function

No associations were found between any of the physical activity outcomes and the Stroop task (simple: $p = 0.749$ to 0.887; complex: $p = 0.428$ to 0.773), the Sternberg

paradigm (1-item: p = 0.396 to 0.452; 3-item: p = 0.151 to 0.535; 5-item: p = 0.164 to 0.494) or the Flanker task (congruent: p = 0.099 to 0.999; incongruent: p = 0.145 to 0.675).

Cardiorespiratory fitness was found to have a statistically significant negative moderate correlation with simple Stroop IES ($r(52) = -0.386$, $p = 0.004$) see Figure. 5.2a) whereby, as distance covered on the MSFT increased, IES on the simple Stroop task decreased. Incongruent Flanker task IES ($r(52) = -0.348$, $p = 0.010$) was found to be negatively associated with cardiorespiratory fitness (see Figure. 5.2b), revealing that as cardiorespiratory fitness increased, the IES on the incongruent level of the Flanker task decreased, suggesting improved performance. Finally, the congruent level of the Flanker task was found to be significantly associated with fitness ($r(52) = -0.302$, $p = 0.026$) (see Figure. 5.2c). No further significant correlations were found with other cognitive outcomes (all $p > 0.05$).

Table 5.2. Correlation matrix showing associations between physical activity and physical fitness with resilience, self-control, and cognitive function in young people with ADHD (r values).

	Average acceleration (mg)	**Intensity gradient (AU)**	**Physical fitness (m)**
Resilience	*0.202*	*0.159*	*0.253*
Self-control	*0.241*	*0.370**	*0.054*
Stroop simple (IES)	*-0.053*	*0.023*	*-0.386***
Stroop complex (IES)	*-0.046*	*0.129*	*-0.149*
Sternberg 1-item (IES)	*0.139*	*0.123*	*-0.253*
Sternberg 3-item (IES)	*-0.234*	*0.102*	*-0.141*
Sternberg 5-item (IES)	*-0.231*	*0.113*	*-0.119*
Flanker congruent (IES)	*0.001*	*0.267*	*-0.303**
Flanker incongruent (IES)	*-0.071*	*0.238*	*-0.349***

Note. IES: Inverse efficiency score, PA: physical activity * denotes a significance value of $p < 0.05$, **** denotes a significance value of $p < 0.01$.**

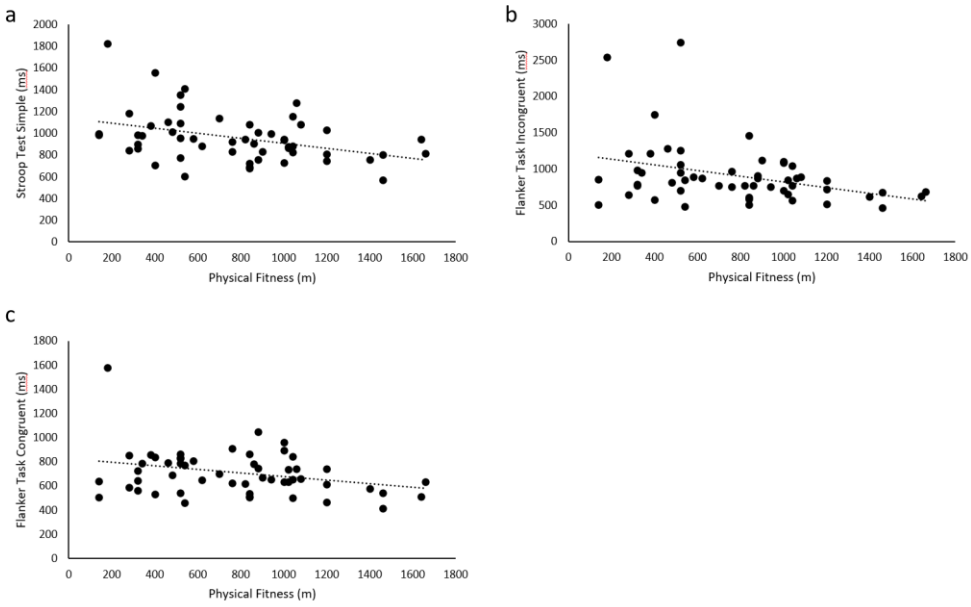


Figure 5.3. Associations between physical fitness (distance covered on the MSFT) and (a) simple Stroop task IES (r = −0.386, p = 0.004), (b) incongruent Flanker task IES (r = −0.349, p = 0.010), (c) congruent Flanker task IES (r = −0.303, p = 0.026).

5.3.2.2. Self-control

Self-control was found to be positively associated with the intensity gradient ($r(37) = 0.370$, $p = 0.021$) whereby participants that had higher self-control were found to spend a greater amount of time in higher intensity physical activity compared to those with lower self-control (see Figure. 5.3).

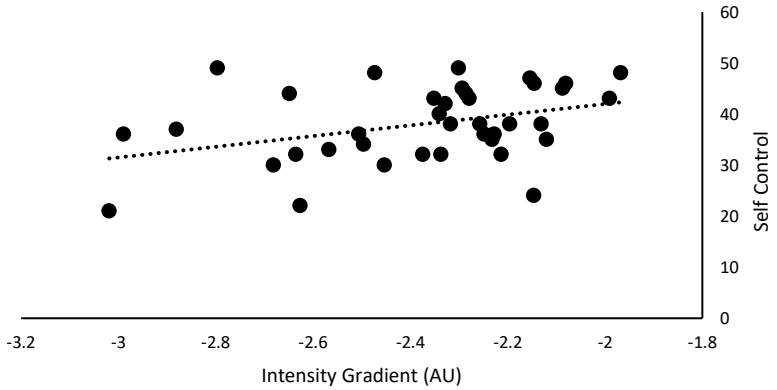


Figure 5.4. Associations between self-control and the intensity gradient ($r = 0.370$, $p = 0.021$).

5.3.2.3. Resilience

The intensity gradient (p = 0.333) and average acceleration (p = 0.216) were not found to be associated with resilience in young people with ADHD. Finally, a non-significant but tendency was found between cardiorespiratory fitness and resilience (r(52) = 0.253, p = 0.065) suggesting that higher levels of cardiorespiratory fitness is associated with greater resilience.

5.4. Discussion

The main findings of the present study are that, in young people with ADHD: (a) higher levels of cardiorespiratory fitness were associated with enhanced cognitive performance (across the domains of inhibitory control and attention); (b) participants who completed more vigorous intensity physical activity reported higher self-control scores; and (c) higher levels of cardiorespiratory fitness tended to be associated with higher resilience, although this did not reach statistical significance. Therefore, the findings of the present study demonstrate that physical activity and cardiorespiratory fitness are associated with three key psychological constructs in young people with ADHD (i.e., cognitive function, self-control, and resilience). Given that these constructs are important for the academic performance and everyday lives of young people with ADHD, the findings of the present study have implications for future intervention design and the management of ADHD symptomatology and behaviours in young people.

A key finding of the present study was that higher levels of cardiorespiratory fitness were associated with enhanced cognitive function in young people with ADHD. These associations were present for the domains of inhibitory control (as assessed by the incongruent level of the Flanker task) and attention (as assessed by the simple level of the Stroop test and congruent level of the Flanker task). In line with the findings of the present study, inhibitory control has been shown to be positively associated with health-related components of fitness (flexibility, muscular endurance, muscular power, aerobic capacity, and body composition) in young people with ADHD; with the findings of the present study extending these findings across multiple domains of cognitive performance. The present study was the first to examine associations between cardiorespiratory fitness and memory

in young people with ADHD with no associations found. This could be due to the type of test used to measure working memory in the present study, as previous research with young people with ADHD has used the Colour Span Backwards Task (Benzing, Chang & Schmidt, 2018), the Digit Span task (Richardson, 2007), and Corsi Block Tapping task (Ziereis & Jansen, 2015) to assess working memory (Welsch et al., 2021) targeting the verbal and visual aspects of cognition. The Sternberg paradigm used in the present study targets the central executive aspect of working memory and therefore, this aspect may be the area most impacted in this population. Assessment of working memory may need to be considered in future research with this population. In summary, better attention and inhibitory control is associated with increased fitness in young people with ADHD, highlighting the importance of promoting cardiorespiratory fitness within this population.

The findings of the present study demonstrated that there were no associations between physical activity and any of the cognitive domains examined. In neurotypical young people, physical activity has also been shown to have no associations with any domains of cognition (Williams et al., 2022). However, some previous work has reported positive associations between daily moderate-to-vigorous physical activity and attention in neurotypical young people (Syväoja et al., 2014). Within young people with ADHD, positive associations have been identified between daily physical activity does have the potential to play an important role in cognitive development (Gapin & Etnier, 2010; Liang et al., 2022). Furthermore, whilst physical activity interventions have shown that physical activity can lead to enhanced executive function in young people with ADHD (Welsch et al., 2021), further research is required to understand how to implement moderate to vigorous physical activity in young people's day-to-day activities to elicit these effects without the need for intervention. Whilst physical activity was not shown to be associated with cognition in the present study, given the highlighted importance between cardiorespiratory fitness and cognition, physical activity should be targeted to improve cardiorespiratory fitness in young people with ADHD.

A further key finding of the present study was that self-control was positively associated with vigorous physical activity and time spent in higher intensity physical activity in young people with ADHD. Tendencies have also been found between time spent in vigorous physical activity and self-control score in neurotypical young people, however, this did not reach statistical significance (Boat et al., 2022). However, physical fitness has been shown to be positively associated with self-control in neurotypical young people (Buck, Hillman & Castelli, 2008). With the assumption that physical activity elicits improvements in self-control (Boat & Cooper, 2019), it is not surprising to have found that high intensity physical activity is positively associated with greater self-control in this population. Furthermore, as young people with ADHD typically participate in greater amounts of physical activity compared to their neurotypical individuals (Villalba-Heredia et al., 2022), it is positive to see that physical activity appears to have positive associations on self-control within this population. Further examination is required to understand why physical fitness however does not appear to be associated with self-control in young people with ADHD. Finally, research in other populations has shown physical activity interventions to have beneficial effects in improving self-control performance, however the literature is still limited, and these findings are yet to be investigated in young people with ADHD (Zou, Liu, Xie & Huang, 2016). To summarise, to the best of our knowledge the present study is the first to examine the associations between device measured physical activity and self-control in young people with ADHD, with initial evidence highlighting that participation in regular physical activity is positively associated with self-control in young people with ADHD.

Finally, there was a tendency for a positive association between cardiorespiratory fitness and trait resilience in young people with ADHD, although this did not reach statistical significance. However, no associations were found between any of the physical activity outcomes and trait resilience. The literature within this area is very limited, however recent findings report that moderate-to-vigorous physical activity is positively associated with resilience in young people with ADHD (Liang, Qiu, & Sit, 2023). Interestingly, the participants in the previous study engaged in an average daily moderate

to vigorous physical activity (MVPA) of 89.59 min (Liang et al., 2023), which was much greater than the present study with an average daily MVPA of 45.29 min. Therefore, further research is required to examine the relationship between physical activity and resilience in young people with ADHD; and specifically, whether there is a threshold of MVPA beyond which young people need to achieve to experience positive associations with resilience. Nonetheless, taken together, the findings from the present study and previous work (Liang et al., 2023) suggest that interventions to increase moderate-to-vigorous physical activity, and subsequently enhance cardiorespiratory fitness, have the potential to enhance resilience in young people with ADHD. Previous research in elderly populations has found physical activity interventions to be beneficial for improving resilience (Kukihara et al., 2020), however more research is required to see whether these findings are reciprocated in young people with ADHD. The findings from the present study have practical importance given the role resilience can play in academic success (Sakiz & Aftab, 2018).

Although the present study is the first to examine the important associations between physical activity and cardiorespiratory fitness with cognitive function, self-control, and resilience in young people with ADHD, it is not without its limitations. Firstly, the present study is cross-sectional, and therefore whilst the study has revealed associations between fitness and cognition, and physical activity and self-control, it cannot demonstrate causality (i.e., the direction of the effect). Previous research has suggested that the relationship between self-control and physical activity is bi-directional in nature (Boat & Cooper, 2019) and therefore, future research should aim to further examine the directionality of this relationship in young people with ADHD, as this will be important to inform intervention design. It is recommended that future research expands on the findings in the present study to compare the associations between physical activity and cardiorespiratory fitness with cognitive function, self-control, and resilience between young people with and without ADHD. Additionally, it would be interesting for future research to examine how physical activity may affect the neurobiological mechanisms associated with ADHD and in turn the subsequent effects on cognitive function, self-control and resilience.

Finally, the findings of the present study only showed small associations and thus the findings should be interpreted with caution.

In conclusion, the present study suggests that there are positive associations between cardiorespiratory fitness in young people with ADHD and higher levels of some aspects of cognitive functioning, and tendencies for higher levels of trait resilience. Furthermore, moderate-to-vigorous physical activity is associated with better trait self-control in young people with ADHD. It is suggested that young people with ADHD should engage in moderate to vigorous physical activity to improve their self-control. Additionally, it is advised that young people with ADHD improve their cardiorespiratory fitness to demonstrate higher levels of resilience, along with demonstrating higher levels of some aspects of their cognitive functioning. With application of these recommendations, benefits are expected to be observed across the three psychological constructs discussed in the present study (cognition, self-control, and resilience), along with improved academic performance and day-to-day functioning in young people with ADHD.

Chapter VI

A qualitative exploration of how physical activity affects young people with ADHD: Perspectives of children with ADHD, their parents, and their teachers.

6.1. Introduction

Although the findings from Chapter IV highlight the cognitive benefits of acute physical activity interventions, and Chapter V identifies positive associations between physical activity and self-control, as well as cardiorespiratory fitness, cognition and resilience, these quantitative results do not capture how these effects are experienced in everyday life. To address this gap, the following chapter qualitatively explored the perceptions of physical activity from those deemed to benefit most from an intervention in this population and to understand how these benefits are experienced in real world contexts.

It is not uncommonly reported that children with ADHD engage in less physical activity than their neurotypical counterparts (Case, Ross, & Yun, 2020; Ludyga et al., 2023; Mercurio, Amanullah, Gill, & Gjelsvik, 2021), however this does not always appear to be the case, as a recent article by Villalba-Heredia et al. (2022) revealed that physical activity levels appear to be greater in children with ADHD compared to neurotypical children. Furthermore, moderate-to-vigorous physical activity levels have been shown to decrease in children with ADHD with age (Villalba-Heredia et al., 2022) which is a concern following evidence of the potential benefits that high intensity physical activity has on cognition, self-control, and resilience in young people with ADHD (Chapter IV). Recent reports and research indicate that current interventions are designed using findings in neurotypical young people (Benzing & Schmidt, 2019; Berwid & Halperin, 2012) however, in order to design a successful intervention with young people with ADHD, it is important to make an informed decision on what modality, intensity, duration, and frequency of physical activity will work best by involving the stakeholders, including those who will benefit from the intervention (O'Cathain et al 2019).

When developing an intervention, it is important to consider the advice and feedback from those who are most likely to benefit from the intervention, in this case, from children with ADHD, their parents, and their teachers. Limited research to date has examined the perceptions of these key stakeholders, and therefore the extent to the qualitative knowledge of a successful and engaging physical activity intervention remains somewhat limited. Currently, it is known that parents perceive physical activity to have positive effects on common ADHD symptoms (Gapin & Etnier, 2014), which is important as it gives us confirmation that physical activity is a potential avenue for management of ADHD symptoms and behaviours as this increases the likelihood to be adhered to and thus more successful. Some interesting findings regarding engagement in school physical education (PE) lessons and free-time physical activity was found by Harvey et al. (2009; 2014), revealing that young people with ADHD engage more in PE for enjoyment, rather than skill development. However, there are still no further insights to what modality of physical activity, duration or frequency would elicit the discussed benefits, Chapter 1 highlighted the variation between different modalities of physical activity in acute interventions, however due to the lack of randomised controlled trials in this population, it is not possible to distinguish the ideal modality. Therefore, research comparing the physical activity modalities in this population is required, however, it is important to consider the perceptions of young people with ADHD, their parents, and their teachers to collate the most popular/ engaging physical activity modalities prior to developing an intervention, a previously identified gap in the literature (Harvey et al., 2014).

Four steps have been highlighted as key to developing a successful intervention: qualitative research, descriptive research, predictive research, and experimental research (Melnyk & Morrison-Beedy, 2012); the present study begins with the first step outlined by Melnyk & Morrison-Beedy (2012), by delving deeper into the qualitative aspect of successful interventions. A key step in the planning is incorporating the stakeholders in the planning process, as these are the individuals that will benefit from the development of a successful intervention within this population (O'Cathain et al. 2019; Koorts et al. 2018). Key stakeholders identified to benefit from an intervention, and therefore should be

involved in planning an intervention, are the children with ADHD, parents of children with ADHD, and teachers of young people with ADHD.

The overarching aim of this chapter is to explore the perceived effects of physical activity on ADHD symptoms and behaviours in young people. This was fulfilled through three stakeholder perspectives: children with ADHD, their parents, and their teachers. A secondary aim of this chapter was to gain a deeper understanding of types of physical activity that are frequently and successfully engaged in by young people with ADHD, in order to curate and collate ideas for future physical activity interventions within this population through conversations with the aforementioned key stakeholders.

6.2. Methodology

6.2.1. Research design and underpinning philosophical assumptions

A qualitative research study design was undertaken for the present study to gain an insight into the effects of physical activity on young people with ADHD from the perspective of the children, their parents, and their teachers. A critical realist perspective was taken in the present study in which the ontological position of realism and the epistemological position of interpretivism is reflected. This approach allows themes to be developed inductively whereby unexpected themes were developed from patterns from the raw data after which deductive reasoning was used to further develop these themes from the questions asked in the focus groups and interviews, as well as an initial analysis of the literature and a preliminary scan of the data. Codebook analysis was selected as it incorporates both the realist and interpretivist elements of this approach by allowing for the constructive development of themes that fall outside of predicted codes yet also allow for a single truth to be presented and agreed upon by multiple researchers (Braun & Clarke, 2020).

6.2.2. Participants

In total, 96 individuals participated in this study representing three stakeholder groups. Children participated in the study via focus groups, while parents and teachers

took part in individual interviews. Participants were provided with information sheets outlining the aims of the study, as well as consent/assent forms. Invitation letters and study information sheets were sent to the headteachers of Special Educational Needs (SEN) schools, and local state and secondary schools in the East Midlands area of the UK. Head teacher consent was obtained, and the school distributed invitations to eligible children (children ages 9-15 years with a diagnosis of ADHD, or in the process to diagnosis of ADHD). A total of 6 schools agreed to participate in the study (SEN: 1, mainstream: 5). The students who participated in the focus groups were from the same pool that participated in Chapter V and were conducted on the final day of testing for the cross-sectional study (Chapter V). Parents of the children who participated in the focus groups were contacted and invited to participate in a 60-minute interview online or in-person. Teachers of the children who participated in the focus groups were invited to participate, and emails were sent to schools in the East Midlands to invite additional teachers to participate in the interviews. Parents and teachers were also invited to participate through a social media poster on local village groups in the East Midlands.

6.2.2.1. Children

Sixty-three young people (16 females) aged 10-15 years (12.89 ± 1.38yrs, range: 10.24 – 15.78yrs) with ADHD were invited to participate in a semi-structured focus group to discuss their experiences of physical activity. Nine focus groups were conducted in groups of three to eight children to encourage a lively discussion without limiting engagement of all participants (Gibson, 2007) lasting approximately 10 mins (10.21 ± 6.47 min). At least two researchers (one male and one were present during all focus groups to facilitate discussions.

6.2.2.2. Parents

To address the second aim of the study, 20 parents (17 female) who have at least one child with ADHD aged 9-15 years were invited to participate in a semi-structured interview. Parents of children who participated in the focus groups were invited to

participate via email and offered the opportunity to participate in either in an online or in-person interview. Following on, parents were then recruited via social media.

6.2.2.3. Teachers

Finally, to address the third perspective, 13 teachers (9 female) were invited to participate in a semi-structured interview. To be eligible, teachers had to teach children aged between 9-15 years (UK school years 4 to 10) and have at least one child with ADHD in their classes. Questions were directed to facilitate discussions around how physical activity affects behaviours and symptoms of young people with ADHD in the classroom, alongside on-task behaviour and disruptions, and how a physical activity intervention would fit into a school day. Teachers were recruited via snowball sampling, schools that had taken part in the focus groups sent out information to their teachers and were invited to participate in the study, a maximum of 2 teachers per school were included in the study to ensure heterogeneity in the sample. Furthermore, teachers were also recruited via social media. Teachers were all currently teaching in mainstream schools, with five teachers currently teaching in primary school's year 5 or 6, and 8 teachers currently teaching in secondary school (5 SEN coordinators, 1 maths teacher, 1 science teacher, 1 PE teacher). Special educational needs (SEN) teachers were also recruited.

6.2.3. Procedure and data collection

Ethical approval was obtained from Nottingham Trent University Non-Invasive Ethics Committee. All participants gave written informed consent prior to participating in the interviews. Children were given opportunity to provide written assent prior to participation alongside parental informed consent. Participants were reminded that interviews were recorded, however identities were kept anonymous during the reporting of the study.

6.2.3.1. Focus groups

Focus groups took place in a familiar classroom in the school. Following introductions, children were asked about their views of physical activity (e.g., how do you

feel about physical activity?) how they perceive physical activity to affect their focus (e.g., how does physical activity affect your focus in lessons?), performance on tasks (e.g., how does physical activity affect our performance on tasks in lessons?), and ability to deal with difficult or challenging situations (e.g., how do you deal with difficult or challenging situations after exercise?). Finally, participants were asked about their favourite and least favourite activities along with reasons why (e.g., what is your favourite/least favourite activity you do in P.E. lessons? Can you give me examples of why it is your favourite/ least favourite?), this was to facilitate in the future planning of interventions (see Appendix J for full focus group guide). Focus groups lasted on average (10.21 ± 6.47 min). Focus groups were led by a lead moderator and assisted by a second member of the research team (at least one female was present at all focus groups) who assisted in encouraging all participants to contribute. Children were interviewed within a classroom with at least one of their teachers present. A sheet containing multiple emojis (cartoon faces) were used during the mid-part of the focus group to aid discussions of thoughts and feelings towards physical activity (see appendix K) and were used to frame future discussion points (Gallo, Swaney-Stueve, & Chambers, 2017).

6.2.3.2. Interviews

For the parent interviews, questions were split into 4 sections (see appendix L for full interview guide). The first section consisted of a general discussion about what types of physical activity their child participates in (e.g., in a normal week, what physical activity does your child do?). The next section asked questions surrounding their child's perceptions of physical activity (e.g., what do you think your child's views of physical activity are?). The third section asked about their child's symptoms and behaviours following physical activity (e.g., how does your child think after physical activity? Do they think differently before/after physical activity?) as well as questions regarding potential triggers (e.g., have you noticed any exercises that 'trigger' your child's ADHD symptoms when exercising?). Finally, the fourth section asked questions surrounding physical activity intervention planning (e.g., if we developed a physical activity intervention to help

young people with ADHD to manage their symptoms and behaviours, what would it 'look like' to you?).

Teacher interviews were split into five sections (see appendix M for interview guide). Section one discussed experiences of teaching (e.g., tell me about your experiences of teaching young people with ADHD…) to help open up conversation and set the scene of the interview. The second section addressed P.E. lessons at school (e.g., how does physical activity usually fit into the school day? And how do children with ADHD engage in P.E. lessons?). The next section opened conversation regarding presentation of ADHD symptoms and behaviours and the impact of physical activity (how do you think children with ADHD behave following physical activity) as well as addressing activities that trigger or lessen ADHD symptoms. Section four encompassed the teacher-student relationship and how physical activity may affect the relationship (e.g. how do you think ADHD symptoms and behaviours that are not well managed affects the teacher-student relationship?). The final section asked questions about physical activity intervention planning (e.g., how would a physical activity intervention fit into the school day?).

6.2.4. Data analysis and methodological rigour

All data were transcribed verbatim (resulting in 448 pages of transcribed text). Codebook thematic analysis (Braun & Clarke, 2020; DeCuir-Gunby, Marshall, & McCulloch, 2011; Roberts, Dowell, & Nie, 2019) was selected as the most appropriate method of analysis for this study. The analysis in this chapter follows critical realist perspective. Initial codes were developed from patterns in the raw data inductively. Deductive reasoning was then used to further develop the themes using the questions asked during the focus groups and interviews, and an initial analysis of the current literature. Further codes were then formulated from the transcripts, collated, and then aligned with the codebook. Next, themes were given names, and definitions to complete the codebook. The codebook was shared with the second author who acted as a 'critical friend' to challenge and develop interpretations by gaining different perspectives (Smith & McGannon, 2017). A de-briefing took place with the 'critical friend' to further develop the

themes, sub-themes and definitions, representative quotes were also consolidated for each theme. The final themes and sub-themes were written up in the results with verbatim quotes to represent each theme.

6.3. Results

6.3.1. Children Focus Groups

Following codebook analysis, two higher-order themes were developed, with nine lower-order themes: task requirements and physical activity benefits (busy bodies, busy minds, the highs and lows, and letting off steam), and challenges and difficulties (motivational strategies for success, sensory imbalance, stop/start, managing big emotions, and take a step in my shoes), see table 6.1 for the breakdown of themes.

Table 6.1. Key themes and lower-order themes derived from the transcripts of focus groups with young people with ADHD.

Higher order themes	Lower order themes
Task requirements and physical activity benefits	• Busy bodies, busy minds • The highs and lows • Letting off steam
Challenges and difficulties	• Motivational strategies for success • Sensory imbalance • Stop/start • Managing intense emotions • Take a step in my shoes

6.3.1.1. Task requirements and physical activity benefits

This higher-order theme refers to the importance of different task demands to evoke physical activity benefits in young people with ADHD. Specifically, the lower-order themes were regarding engagement, enjoyable aspects, and post physical activity benefits.

6.3.1.1.1. Busy bodies, busy minds

Busy bodies, busy minds identifies the importance of cognitively challenging activities, as well as the benefits of physical activity outside of the physical benefits.

> The actual games, like handball, which I really enjoy because it's very active but it's also slow at the same time. When you have the ball, you have to really think methodically and decently throw. So, you don't just think fast and do a miracle shot that just won't land, but it's also fast paced because when you don't have the ball you have to get into space before anyone else does, so you can try and score. (P07)

However, this theme also identifies that individual differences play an important factor. One child talked about how they prefer the predictability of some activities, rather than the chaos associated with others.

> Yeah, the reason I like badminton is because when the shuttlecock touches the floor it just stays there, but in tennis you spend half the time running after your ball and it just starts flying across the hall or whatever and then half the time you hit it and it goes wonky so I just don't like tennis. (P62)

Children also identified that physical activity helps their mental health "it's a really positive way to just wake you up a bit and stay fit" (P40). Physical activity also appeared to make young people more confident "you get like mental health, like it makes you feel better. Then you get like looks better, aesthetically, so yeah" (P64).

6.3.1.1.2. The highs and lows

This theme considers the effect of physical activity on classroom concentration in response to the high highs and low lows experienced by young people with ADHD. Some children discussed how if they have not used up their energy then that can subsequently impact their concentration in lessons.

> Yeah, like trampolining especially, you just stand there so then you've just built up all that energy and then when you go back to class, because you have not used it up, so you are still buzzing, but if you actually take something erm, more testing in PE like football, and stuff like that, then you have less energy and you have more sort of tired I guess, you focus better. (P63)

Others talked about how “you get to get rid of your energy, you get to focus on something else, you don’t have to be distracted by other emotions and stuff it’s like you just get on with what you are doing” (P69). The need to achieve balance of using up excess energy whilst not burning too much energy appeared to be a challenge as some children highlighted the negative impact of being too tired on post physical activity concentration “depends on how worn out I am, if I am worn out then it doesn’t work” (P27).

6.3.1.1.3. Letting off steam

The final lower-order theme for the children’s perspective discusses the burden of ADHD symptoms and behaviours and how physical activity relieves the negative experiences of ADHD. Children highlighted that they can release pent up frustrations, “I get to take my anger out and I can’t get told off” (P53), “I feel some sort of relief” (P42). Children also discussed how physical activity is an escape for them. “You get to get rid of your energy, you get to focus on something else, you don’t have to be distracted by other emotions and stuff it’s like you just get on with what you are doing” (P69).

6.3.1.2. Challenges and difficulties

This higher-order theme encapsulates the hardships associated with physical activity and potential factors that limit engagement in young people with ADHD. Within this theme, there are five lower-order themes that discuss motivational strategies for success, sensory imbalance, stop/start activities, management of intense emotions, and taking a step in the students’ shoes.

6.3.1.2.1. Motivational strategies for success

This lower-order theme highlights the importance of finding the balance of task difficulty, highlighting that if a task is too challenging, children with ADHD may ‘cut corners’ or ‘cheat’ to appear as if they have still achieved the goal. One participant talked about how they would approach a task which they would find extremely challenging or uninteresting.

> If I got told to climb Everest, then I would just be honest, I would just make a makeshift elevator and then say to people that I did it and then like two meters down I would get those pokey things and say I climbed up. (P39)

The theme also picks up on motivational factors utilised by young people with ADHD to maintain engagement, for example, one participant discussed different ways of keeping themselves focused on running.

> I don't really get the happiness from it [exercise], I just do it because it is there as an option. But it actually makes me quite bored so when I am running, I try to look for something that actually, well is not noticeable by people. I remember when I was running and I saw quite a few ants, and also a sewing needle and quite a few types of shiny rocks. (P04)

6.3.1.2.2. Sensory imbalance

This lower-order theme identifies sensory factors affecting physical activity engagement in young people with ADHD. Some of the children highlighted the physical pain associated with physical activity such as aching muscles "I like it because I want to get fitter, but I don't like it because of how much it hurts" (P11). Other children discussed how the challenge of physical activity is enjoyable, however also talked about the physical pain.

> I enjoy it because it's a challenge. It helps you ultimately at the end, but I don't enjoy it in the rest of the time. It depends on how much it hurts, which I know that is part of it but it still kind of sucks though, that you have to feel the pain to get better (P14).

6.3.1.2.3. Stop/Start

Stop/start focuses on the negative impact of stagnancy in activity and how this may have a negative effect on engagement giving participants the opportunity to then lose focus. Specifically, activities such as trampolining were identified as activities with large durations of stationary time "Erm, I dunno, maybe trampolining because most of what you

do is standing there watching everyone else on it and then when you go you get like 5 seconds on it" (P68). Furthermore, children talked about how when activities have lots of pauses, they still have lots of energy remaining.

> Yeah like trampolining especially, you just stand there so then you've just built up all that energy and then when you go back to class, because you have not used it up, so you are still buzzing, but if you actually take something erm, more testing in PE like football, and stuff like that, then you have less energy and you are more sort of tired I guess, you focus better. (P68)

6.3.1.2.4. Managing intense emotions

This lower-order theme refers to positive and negative emotions produced following participation in physical activity, with specific focus on the feelings associated with winning or losing in physical activity. Some negative feelings were felt in regard to team sports "for me, especially in team sports, people push past your limits, even if they know you are at your max" (P17) due to the competitive nature of some sports. Other participants felt very positive emotions when and if they win.

> I felt like really happy because I was sparring someone in boxing who was a lot older than me, a lot better than me, but I managed to catch him off guard and hit him in the gut and it winded him and that made me feel very happy. (P62)

6.3.1.2.5. Take a step in my shoes

This lower-order theme highlights the frustration experienced by young people with ADHD when teachers are not understanding of their experiences, for example following a breaktime or lunchtime in the school day "yeah, it's the same after lunch, like everyone gets excited at lunch and then they have energy and then the teachers start screaming at you" (P66). Others discussed the negative task of getting changed following physical activity "It takes time to get changed and they still give you detentions if you are late" (P62).

6.3.2. Parent Interviews

Twenty parent interviews were conducted lasting between 25 to 76 minutes (52.59 ± 12.41 min). From the codebook analysis, four higher order themes were developed, with 14 lower order themes; the middle ground (rethinking discipline, stop/start, little and often, and emotional self-regulation), scaffolding (mixing it up, collaborative approach, keeping it simple, and driving force), the bigger picture (social, emotional and beyond, motivational climate, praise and feedback and skill development), and treatment strategy rewrite (calming influence, and merging technology with physical activity) see table 6.2 for the theme breakdown.

Table 6.2. Higher order themes, and lower order themes derived from the transcripts of interviews with parents

Higher order themes	Lower order themes
The middle ground	• Rethinking discipline • Stop/start • Little and often • Emotional self-regulation
Scaffolding	• Mixing it up • Collaborative approach • Keeping it simple • Driving force
The bigger picture	• Social, emotional, and beyond • Motivational climate • Praise and feedback • Skill development
Treatment strategy rewrite	• Calming influence • Merging technology with physical activity

6.3.2.1. The middle ground

The first higher-order theme from the parent interviews was the middle ground. This theme highlighted the need for balance in regard to ensuring that physical activity is not too overwhelming or underwhelming, whilst also identifying different aspects to avoid and consists of the sub-themes; rethinking discipline, stop/start, little and often, and emotional self-regulation.

6.3.2.1.1. Rethinking discipline

Rethinking discipline discusses the commonly used behaviour management techniques for young people with ADHD; and specifically, how these strategies are typically focussed on sedentary time rather than opportunities for physical activity. It was also noted how such strategies are not well received by parents.

> So, one of the interventions that they tried last year when he was in year eight to try and manage his behaviours… because they were really realising that putting him in detention wasn't working… He is being expected to sit there quietly for X amount, you know, I mean, he was just like, no. (P118)

Additionally, it was highlighted that common behaviour management techniques were not successful in supporting young people with ADHD to remain focused and engaged in a learning environment.

> They just use it as an excuse, or I think they don't have an understanding of this person can't actually concentrate and his mind…he's out the window literally. And actually, you know, he needs to have a little talking to, here and there to keep him concentrating. Instead of just being in trouble all the time (P107).

Other parents talked about how teachers have a lack of understanding regarding different management methods or coping strategies that young people with ADHD may implement to self-regulate resulting in an increase in negative behaviours.

> Erm, but I think other teachers, even though they know something about ADHD, they they don't like him kind of fiddling with the ball in the classroom. And so he tends to get into trouble for that and things tend to escalate. You know, he gets a lot of detentions. I mean it, it's, it's ridiculous, actually, how many he gets. And it's largely for kind of low level disruption involving turning round swinging on his chair. You know, that sort of thing and distract distracting others. Or being distracted by others. But it's kind of, yeah, that's sort of it's very difficult to know how to put a stop to that and teachers have tried all sorts of different things (P109).

6.3.2.1.2. Stop/start

This lower-order theme highlights those activities involving stopping and starting, pauses or stationary aspects can have the opposite effect on behaviour and in turn cause more disturbance. Parents stated that their children are not good at waiting, “waiting… triggers him, he doesn't like waiting. That's a big thing” (P112). Furthermore, this resulted in some children dropping out of some sporting activities.

> But he used to swim. But just when he was younger, he swam. But the problem was is you have to, like, do a bit, wait a bit, do a bit, wait a bit. And he's not very good at the wait a bit (P112).

6.3.2.1.3. Little and often

This lower-order theme refers to how important it is to implement small segments of physical movement, and how those segments should be frequently used throughout the day. Specifically, parents discussed short, daily activities to help reduce excess energy.

> I’d say needs to be a daily thing at least once a day, but twice would be better. It doesn't need to be for long. 10 to 15 minutes. Something…That keeps them on the move. That can be done anywhere, maybe so they can do it in a classroom, in a playground. It could be. I don't know, I'm thinking like. Just it just like a… I don't know. Almost like an aerobic session but a toned down one, but where they can move around and maybe have some free time within that as well. So do what you want for five… let them use their imagination as well. So, 10 minutes of set exercises if you like, or circuit training type things and then 5 minutes of right you do what you want now. And I think almost during the same thing would help those kids because they know what's coming (P112).

Parents also discussed how lack of physical activity can cause negative spirals in behaviours and attitudes:

> If he is at home for a day or two or three without either seeing his friends, cycled to school or walked the dog, he’s pretty hard work. Yeah and he is at times

> unbearable, but I'd say that he has had you know, after he's had exercise he is a much more tolerable child (P103).

6.3.2.1.4. Emotional self-regulation

Children with ADHD were reported by parents to experience overstimulation through physical activity which in turn affected their ability to self-regulate emotions.

> Not that I would have like noticed particularly, but he always tells me that he gets, like, sometimes gets a bad mark in PE because he is so hyped up in there, like he's sort of makes him a bit mischievous because he's got so hyped up while he's doing it (P107).

Other parents talked about how some activities really help young people self-regulate and ground them:

> We had a big trampoline in the garden and when he got home from school, his routine was always go on the trampoline and he used it a lot to like to self-regulate, if you like. Because he's quite sensory as well, he gets a lot of feedback from bouncing (P112).

6.3.2.2. Scaffolding

Scaffolding refers to how important it is to build upon skills during physical activity, to give a purpose for physical activity, the need to mix up activities, and also have a reason for taking part in physical activity. The theme discusses skill development with a focus on skills that SEN students often find more challenging due to comorbidities such as dyspraxia. Sub-themes that form the key theme scaffolding are; mixing it up, collaborative approach, keeping it simple and driving force.

6.3.2.2.1. Mixing it up

Mixing it up refers to how there is a need to change up activities regularly to maintain engagement and concentration of children with ADHD. Specifically, circuits were

highlighted as a potential intervention technique that could be successful, provided there are goals.

> Circuits things to do. To do for a reason, to jump as far as you can, to run as fast as you can, to do whatever, and he's now into, as I said, trying to do sit-ups I don't know if it does do press-ups or and we do have an exercise ball which will occasionally get on, but things like that and then the circuit training I think would be good one because he likes structure. Erm a routine that he knows as in a minute on and a minute off, he probably would, he probably would really get into that (P104).

6.3.2.2.2. Collaborative approach

This lower-order theme discusses how it is important for teachers and parents to communicate effectively and work together when implementing change, whether that is making parents aware of what their children should expect, or if they need to build upon skills at home as well as in the classroom.

> Yeah, not if it was in a routine, so she knew that on a Monday she was doing that on a Monday that's more engaging erm, for her because, if she sees if she was to go into an environment and then they said, 'Ohh, today we're gonna do this', and she thought she was gonna do something else, that'd completely tip her off for the day then. She does need to have that routine and that knowing of what she's gonna be doing, and I think it's good for parents to know what they're gonna be doing so you can introduce it into the week. Like ohh, on Monday you're gonna be doing this and you start speaking about it before they go to it because that seems to be under the like thing that stimulates them where they're going into the unknown. Like, they don't like going into the unknown. So if as a parent you can sit there and be like, ohh on a Friday saying on Monday you're gonna be doing this. And then on Saturday like Ohh you're excited to do this and then Sunday like Ohh are you prepared and you got all your stuff for this… you've introduced it within like

three times so then there are where that that's gonna be happening and that seems to help (P02).

6.3.2.2.3. Keeping it simple

This lower-order theme refers to about how instructions need to be really clear and precise with initial sessions being very simple tasks and instructions “short, sharp attention-grabbing information (P119)” and then progressing on subsequent sessions to avoid overcomplication. Parents also highlighted that their children get impatient waiting for instruction.

Umm. I know the ones that he finds it difficult are anything where he needs to concentrate. If he's if he doesn't know what the sport is and say the teacher trying to tell him what the rules are. He's too impatient to listen to the rules (P105).

6.3.2.2.4. Driving force

The driving force refers to motivational aspects of physical activity, enjoyable aspects, the why, and participant buy-in through structure, predictability, and routine. Some parents discussed buy in through detailed background about the reasons behind doing physical activity.

I mean, I think for kids with ADHD, I think it's I think it is useful for them to know why they're doing it as well and like what, you know what the science is behind it. Like I said, I mean he does understand that stuff that but that on its own hasn't been enough to get him to do all types of exercise. It has to be something that he wants to do. But despite that, I think it's important for them to understand that this is something that's gonna help. And This is why it's gonna help (P109).

Other parents focused on the lack of enthusiasm behind participating in physical activity unless they are passionate about the activity they are taking part in:

Erm, so I don't think all physical activity is equal when it comes to him. I think he he'll do you know, what he wants to do when he wants to do it, but he won't do it

just for the sake of doing it in order to help him focus. He won't do it as a sort of instrumental thing. He'll only do it if it's something that that he wants to do for the sake of it (P109).

6.3.2.3. The bigger picture

This higher-order theme refers to the perceived benefits of physical activity for young people with ADHD, the important mechanisms for engagement and the requirement of personal achievement. The bigger picture consists of four lower-order themes; Social, emotional, and beyond, goal involvement, praise and feedback, and skill development.

6.3.2.3.1. Social, emotional, and beyond

The lower-order theme social, emotional, and beyond discusses the benefits that extend in addition to the physical benefits of physical activity. Parents discussed how physical activity appears to make their children more relaxed and content with a more positive outlook on life.

> Really, I would generally say is their just their whole demeanour it's a lot more their outlook, they are a lot more negative glass half empty before exercise. And it was a lot more glass, half full afterwards so just at more of a positive attitude (P105).

Additionally, parents also talked about how they perceive physical activity to give their children the confidence to express their feelings more positively, even if they were not as successful in their skill completion as they hoped:

> He's really calm when he comes back and he's quite smiley. I think it makes him feel it's not just about the physical side. I think about social, emotional. It feels good. Because he's done something and that he enjoys. So it's more of a self-esteem thing and I'll just say to him, how did it go and he'd go. Yeah. Good. But I couldn't quite get my leg there he'll say or. And that's about it. But yeah, I think he's a lot more energised, but in a positive way (P112).

6.3.2.3.2. Goal involvement

The lower-order theme goal involvement highlights aspects of both ego orientation (competitive mindset with a greater likelihood of dropout), and task orientation (having clear goals to work towards that are intrinsically) present in young people with ADHD. For example, one parent talked about how their child disliked long durations of physical activity however, when having a reason for activity, they were excited for the challenge.

> He actually did a bike ride for charity with his dad, which was his idea. He hates it. He hated going long distances. He likes it for fun, but he don't like doing it for long time. But he set himself for challenge and he raised £200 for a charity to buy a wheelchair for a girl in Ethiopia (P112).

On the other hand, a separate parent discussed how their child did not feel like he was going to get selected for a basketball team resulting in him dropping out of the sport which represents more of an ego-oriented approach.

> I think he kind of… his interest in that kind of waned a bit because he didn't think he was going to be selected for the next team going forward like into the next academic year. So around that time he kind of stopped trying a bit and he didn't really kind of. Yeah. He lost his enthusiasm a bit and then decided he didn't want to carry on with it, unfortunately (P109).

6.3.2.3.3. Praise and feedback

Praise and feedback refer to the importance of reinforcing positive behaviours, successful skills, and offering support for the development of skills. Parents discussed the need to boost confidence through positive reinforcement through genuine praise.

> There's a kind of an aura, I suppose, about him, but he's a he's really good at confidence boosting and saying how good he is and the praise. And it's really genuine. It's lovely. Yeah. So that that needs genuine praise and confidence. Having the confidence that they're doing it right, that they're doing, they're doing

well. They're giving it a go. That's sort of stuff as opposed to not there yet. Yeah. So that so there's a big there is a big lack of confidence, I suppose (P104).

Parents also talked about activities that offer immediate reward of feelings of success such as completing 10 press-ups.

He would enjoy something like that just because it does give that feedback of, oh, I managed to do it. Oh, I didn't manage to do it. Let's try again. And ohh, I did ten in a row. You know that there's like you, you get something back from it immediately (P109).

6.3.2.3.4. Skill development

This lower-order theme refers to the struggles associated with skill development due to difficulty processing information and/or comorbidities that could impact young people's ability to develop new skills.

Possibly because of the dyslexia, possibly just his own mobility stuff where he's got patterns he knows and has got ingrained, like having gone to tennis for so long, there are patterns that he finds more comfortable and easy to do. A different pattern takes him a long time to learn, so a slightly different skill or technique for cricket, for hockey, basketball or whatever. I I think would probably take him a while because he's not precise. There is a precision or accuracy shall I say there's a sort of a looseness in his motion which he wouldn't necessarily identify (P108).

There is also a requirement for the greater focus, commitment and time spent on building up skills, as there is a large mental toll for young people with ADHD when developing skills:

I'll know when she comes out that she's been learning something new because she'll be completely different to how she is normally. So I think it's when you're going into any activity where you've got to learn something new, if it's not been explained to her standard, erm then she'll be she'll act completely different towards it and probably won't have that same feeling (P102).

6.3.2.4. Treatment strategy rewrite

Some parents discussed how important it was for physical intervention rather than verbal talking management techniques, reinforcing the need for more physical movement. This higher-order theme has two sub-themes, calming influence and merging technology with physical activity.

6.3.2.4.1. Calming influence

This lower-order theme highlights the importance of physical activity in managing ADHD behaviours and producing calming behaviours resulting in improved on task concentration “I think it makes him relax. And and it gets... I think it helps him get his thoughts together. Definitely. And he's calmer. And he's able to just carry on with whatever he's doing then” (P112).

This was suggested this could be to do with the release of energy, allowing hormones to balance and subsequently relax children with ADHD:

> Yeah, they think it might be to do with the energy levels erm, because you're burning off that extra energy that you've built up, and I feel it might maybe be to do with the fact that you're releasing certain hormones that are stimulating you in a different mindset. So it's kind of giving you a whatever balance you're missing that's sending you a bit wild or it's kind of realigning your hormones (P102).

6.3.2.4.2. Merging technology with physical activity

The final lower-order theme from the parent interviews highlights the need for a technology intervention to merge young people’s lifestyles to physical activity, such as Pokémon Go. This would bring more excitement to tasks and potentially give the children goals to work towards.

> Yeah, the gamification of it, a target to work for the 10,000 steps or or whatever, it's gonna be or the catching the Pokémon, but something like that, I mean. Blimey.

> Yeah. An ADHD smartphone app or or something like that. That's got that reward in there. Something like that (P110).

Parents believe that these can be implemented to help young people increase physical activity whilst making it enjoyable and gives children the opportunity to track their progress.

> Maybe if it was linked to an app or something? Umm. Possibly because. Umm, you know, I think he like lots of kids is kind of engaged with, you know, computer games and, you know and uh apps on their phone and things. So if there was something, if you had a… if there was a way of kind of keeping track of how many he did this time and whether he can beat his score next time and maybe if that was in app form, then maybe that's something that would help more with engagement (P109).

6.3.3. Teacher Interviews

Thirteen teacher interviews were conducted lasting between 33 to 68 minutes (48.48 ± 9.55 min). From the codebook analysis, four higher order themes were created, with 16 lower-order themes; engagement in school physical activity (more than movement, keep a lid on it, sensory overload, impact of letting off steam, the comedown), building relationships (development of trust and rapport, breaking down barriers, and supporting teachers), the ideal intervention (physically active lessons (class PAL), mixing it up, teacher 'handbook', clearing the hurdles, timing is everything, and autonomy), and setting the standard (I challenge you…, and rethinking discipline methods) see table 6.3 for theme breakdown.

Table 6.3. Key themes and lower-order themes derived from the transcripts of interviews with teachers.

Higher order themes	Lower order themes
Engagement in school physical activity	• More than movement • Keep a lid on it • Sensory overload • Impact of letting off steam • The comedown
Building relationships	• Development of trust and rapport • Breaking down barriers • Supporting teachers
The ideal intervention	• Physically active lessons (Class PAL) • Mixing it up • Teacher 'handbook' • Clearing the hurdles • Timing is everything • Autonomy
Setting the standard	• I challenge you… • Rethinking discipline methods

6.3.3.1. Engagement in school physical activity

This higher-order theme refers to how teachers observe young people with ADHD to participate in physical activity in schools. The theme also discusses the symptoms and behaviours of children with ADHD in the classroom. Finally, this theme identifies potential triggers for young people with ADHD in the form of physical activity. Lower order themes include; more than movement, keep a lid on it, sensory overload, impact of letting off steam, and the comedown.

6.3.3.1.1. More than movement

The first lower- order theme refers to aspects of physical activity that encourage or enhance engagement in young people with ADHD. One teacher identified three key strands in their opinion that collate to form a holistic physical education (PE) lesson.

> PE is not all about the physical ability to you know, get the ball in the hoop. It's about analysing performance and giving feedback, tactics, strategies and how they can work effectively as a team. Understanding the rules and the theory that's surround that so students are kind of assessed in three areas. It's not just their physical ability, it's the cognitive ability of rules and understanding how you know

> when you take that netball shot, what's muscles are gonna be contracting, which ones are relaxing, which energy systems might you be using, but also then looking for the third strand, which is them showing, resilience, communication, teamwork and you know, not giving in and trying to develop the skills so, they're the kind of three strands (T2).

Another teacher articulated how important physical activity is to allow children with ADHD to have “the opportunity to be expressive in a way that they feel confident” (T2) with an important factor being that “the majority of the time they’ve not been confined to one specific area” (T2).

6.3.3.1.2. Keep a lid on it

The second lower-order theme of engagement in school physical activity is ‘keep a lid on it’. This theme talks about how physical activity can be used as a tool to prevent ADHD blow-outs (e.g., how a fizzy bottle overflow’s if the pressure has not been released slowly after being shaken up). One teacher referred to this exact concept in the following quote:

> That releases a bit of tension, and it's a bit like that thing where you shake the bottle up and explode. All those things are in that bottle and then it explodes. But if all day long you're removing it by squeezing, by doing a quick run, by doing some breathing, it's keeps empty in that bottle. It's making them understand why you are doing it. We're not doing it for fun (T6).

However, another teacher expressed how important it is to do PE at the end of the day as a longer duration of physical activity can have adverse effects. “Concentration afterwards is just, there is none, … as soon as they have done PE you've lost them. So it's just, it's just nice to do it last cause and they can just get changed and go home” (T4).

6.3.3.1.3. Sensory overload

The lower-order theme ‘sensory overload’ refers to the different external stimuli that may influence engagement in physical activity in young people with ADHD. One of

the most common responses was with regards to the weather. “It always seems to be much calmer when they've gone and done athletics on a summer's day than when they've done rugby on a rainy day, I think that affects it a lot more” (T1). Other issues were discussed with regards to the uncomfortable feelings on the young people’s skin following physical activity:

> I think then it can be really tricky because they're obviously feeling a bit like they've obviously had a brilliant time at lunchtime or break time that they've been rolling around in the mud but then it's really hard because then they're really uncomfortable for the rest of the time and also like we don't, they don't have showers and things here like I used to do at school, so they're often they can be quite hot and sweaty, certain males, and then sometimes I think that's quite hard for them to get like…I think that in terms of their physical activity, that's brilliant. But then there's sort of aftereffects of being hot and sweaty and muddy or wet is quite hard (T1).

6.3.3.1.4. Impact of letting off steam

This lower-theme refers to the prolonged effects of physical activity on classroom task concentration. Challenges were discussed about how to control the excitement following physical activity. “Their brains are still quite active from having done the activity. So it's about then harnessing that and gearing it towards whatever the learning is rather than I dunno, break time kind of thoughts” (T1). However, positive aspects were also discussed with regards to concentration on tasks, and general wellbeing.

> They find it easier to sit, and aren't necessarily so interested in all the other things that are going on in the classroom and they're quite, they're a bit more like I said before, just see seem a bit more happy in their bodies like they're not thinking about the other things that are going on. (T9)

6.3.3.1.5. The comedown

The comedown describes how it is important to bring the excitement levels back down gradually following physical activity in order to achieve the desired effects on classroom behaviour, including strategies observed that achieve these effects. “I know teachers that … one particular teacher that does do that quite often actually brings them back, does a little bit of five minutes of meditate, you know, meditation” (T7). However, the same teacher also discusses how there are time pressures to ensure that children achieve the tasks required within that lesson. “But if I’m being really honest, they come back here and all I'm thinking of is I need to get this next learning objective written into their book” (T7). Another teacher identified the need for a comedown however, thinks there needs to be “really clear and simple” (T6) steps in order for the class to run efficiently “this, this, this done. But it has to have that end, calm down, finish. And now you're ready to learn. Now you've released that tension in your body. So now you're ready to focus” (T6).

6.3.3.2. Building relationships

This higher-order theme highlights the importance of student-teacher relationships for young people with ADHD, the issues when those relationships are not formed and how physical activity has the potential to aid the development of those relationships. Building relationships is split into three lower order themes; development of trust and rapport, breaking down barriers, and supporting teachers.

6.3.3.2.1. Development of trust and rapport

This lower-order theme encapsulates the importance of building trust and rapport between students and teachers in order to maintain engagement and enjoyment. One teacher discussed how important it is that an intervention is run by someone that the young people are comfortable with.

> So if you are doing an intervention, it needs to be with a key adult that they know and trust, because I think the relationship is so important. But yeah no, I think because I know that for both of my children with ADHD erm when there's external

> coaches, they're just don't show themselves and how good they are. And it's almost because it's like they don't know, then they don't have that trust and also not as much that, you know, I know how to get their attention. (T3)

Another teacher highlighted the challenges experienced if there are breakdown in relationships “if something does happen, that you end up clashing, it's hard to repair it. I suppose you've got to be a trustworthy, reliable source for them” (T7), and discussed how challenging it can be to build and establish relationships with students “but the other unfortunate part of it is, is that teachers don't really have time to do that” (T7). They identified how severity of ADHD plays a significant role in the importance of relationships “that's even more important, the most severe it is, I think” (T7).

6.3.3.2.2. Breaking down barriers

Breaking down barriers is a lower-order theme discussing potential issues faced when relationships are not successfully formed, and what to avoid doing to prevent the breakdown of relationships. Multiple teachers discussed the issues surrounding teachers holding onto emotions from previous lessons which often results in negative experiences from the offset of a lesson “we see a lot of students who are almost sent out as soon as they walk into a lesson” (T1). They also talked about how the negative experiences of teachers being resistant to fresh starts impacts students “So they're kind of not given those chances as soon as they're coming in anyway, so it's. It's making them defensive as they go into the lesson anyway” (T1). Many teachers discussed issues surrounding large class sizes and lack of opportunity to help students who need extra help.

> I think the teachers can get really frustrated and I think it is frustrating and a class of 30 if you've got a student who their symptoms are disrupting the learning for everyone I can see and that I because I used to be a teacher and it's part of the reason I came out of being a teacher is because it was just so frustrating when someone's behaviour changed the whole dynamic of the class but actually I sort of wanted to be helping that student and so that's why I kind of went into this really. It's so so I think I I think it is just a kind of a… the the the student's behaviour then

> makes the teacher frustrated, then that comes back as anger to the student and then it and then it makes their symptoms even greater. (T1)

6.3.3.2.3. Supporting teachers

The final lower-order theme of the 'building relationships' higher-order theme highlights the important matter of lack of support for teachers to help them understand neurodevelopmental disorders and how to manage difficult behaviours within the classroom. Many teachers highlighted the issue that neurodevelopmental disorders and management "should be addressed more as part of the teacher training erm processes" (T2).

> I'd say there are standard of the teacher training, but I think providers should have more of an obligation to either provide the training themselves or to ensure that, you know, potential teachers meet to a certain level of standard of of you know, a bit like in which they have to pass the skills test for maths and English. It should be okay you also need a level of erm, understanding or qualification, let's say that you've met that standard and therefore you then go into your teaching with more knowledge and more strategies in order to help with that (T2).

6.3.3.3. The ideal intervention

This higher-order theme discusses what teachers believe will be successful for engagement of young people with ADHD in a physical activity intervention. The lower-order themes consist of; physically active lessons (Class PAL), mixing it up, teacher 'handbook', clearing the hurdles, timing is everything, and autonomy.

6.3.3.3.1. Physically active lessons (Class PAL)

This lower-order theme talks about how incorporating physical activity into the timetable has the potential to benefit young people with ADHD. Some of the teachers discussed how short "brain breaks" (T10) during lessons could have beneficial effects on task performance and concentration.

> That it'd be really useful is just to have a 5 minute brain break in a lesson erm because I think I think you can do a whole hour of physical activity and it doesn't necessarily help them back in lessons it sort of alleviates symptoms sometimes and then and then obviously that's gonna be one time a week, whereas a little 5 minutes built into each lesson. (T1)

"I think it would have to be short bursts" (T6) was one of the most discussed intervention techniques that teachers believed would be successful "it needs to come in between the lessons, and it's probably 5 minutes" (T6). Furthermore, teachers discussed the need and requirement for "some kind of skill progression within it, but everyone can access something of it at the beginning" (T6) to allow it to be inclusive but also encourage personal achievement.

6.3.3.3.2. Mixing it up

The lower-order theme mixing it up, discusses how shorter durations, circuit training and different activities throughout the week are more likely to encourage engagement rather than the standard PE lesson activities.

> If you changed it up and you were like doing, I don't know there was some kind of circuits that… My upper, so like my year sixes, they loved doing the circuit exercises circuits, one day was daily mile, one day was cardio kids blah blah. In an ideal world, you'd have something different every day. I don't know on a two-week rota so you've done 10 different things over 2 weeks and then you repeat it. (T7)

Structure appeared to be one of the most important contributing factors towards a successful intervention for young people with ADHD, not only in the context of making sure children were prepared and knew what to expect in an intervention, but also to ensure smooth running. "I would say structured, very structured, I would say, fast-paced in that there's not a lot of, I don't mean changing the activity, but almost scaffolding it building upon it and not much stand up, sit down, stand up, sit down" (T3).

6.3.3.3.3. Teacher 'handbook'

This lower-order theme highlights the requirement for a teacher ‘handbook’ or “toolbox” (T8) as an aid for teachers to introduce more physical aspects into lessons without the hassle and stress of planning beyond their normal lessons. This would mean that teachers have the autonomy to select what their class requires and prevents the issue of a one size fits all mindset.

> So I think it's probably about having lots of ideas so that a teacher can find the thing that they're comfortable with, and what will work best for their class? Does their class need something that's high energy? Or does their class need something that's relaxing? And so that there is maybe a sort of a pick, a mix kind of thing that. (T1)

Other ideas that were highlighted for a teacher handbook were clear statements as to why the activities were important which in turn would improve teacher adherence to an intervention. “I would say the fact that we need to be explicit in why we're doing it and what it benefits should be written up as well for staff, because as well, within the school, you've got people who go ‘Oh don't be ridiculous’” (L6).

6.3.3.3.4. Clearing the hurdles

This lower-order theme identifies considerations for the development of an intervention and potential hurdles that may be faced. Some teachers discussed the challenges that may be faced when selecting an activity that would work for the whole class “Yeah, I think I think it does get harder as they get older that they don't necessarily want to do stretching with their bodies in front of everyone” (T1). Issues regarding student engagement were not only discussed, some teachers also discussed how issues might stem directly from the teachers.

> I’ll tell you the other issue is getting teachers involved, because teachers. I mean, for me, I don't mind modelling that kind of not behaviour, modelling the activity, like doing it with them, but some just aren’t bothered, some are just do disengaged

with it. They just they stand there and watch and think, wow, you know, you're not doing it, so that's not going to encourage them to do it. (T7)

6.3.3.3.5. Timing is everything

This lower-order theme discusses how there is need to consider when is best to implement an intervention, the ideal duration, regularity, routine and structure. Outside of the brain break ideas discussed by many of the teachers, it was clearly highlighted that children with ADHD often struggle at certain points of the day with their concentration and focus. “All of our children, regardless of whether they're medicated or unmedicated, struggle more in the afternoons” (T8). Other teachers talked about the importance of a routine when implementing an intervention to reduce anxiety “If the students know to expect it, then they're a not gonna be embarrassed or surprised” (T1).

6.3.3.3.6. Autonomy

Giving the students the opportunity to choose what they want to do, and who with was another lower-order theme from the teacher interviews. One teacher talked about a specific student that autonomy worked well for “Uh, giving him the autonomy to do in those breaks what he would like to do, like pick the activity room, a couple of options. Like I say, not too many because it gets overwhelmed, but just give him that bit of autonomy to pick those breaks” (T5). Some teachers discussed how it is important to allow the students to select who they work with in order for them to engage “I think sometimes small drills and group work if they're placed with a student that they don't particularly get along with erm, I think sometimes they very much want to choose the group and who they work with”.

6.3.3.4. Setting the standard

The final higher-order theme from the teacher interviews discusses how rules should be set, challenges should be included, rewards given, achievement tracked and methods of discipline that do and do not work for young people with ADHD. The lower-

order themes in setting the standard consist of: I challenge you…, and rethinking discipline methods.

6.3.3.4.1. I challenge you…

This lower-order theme refers to how challenges can be introduced in a friendly way without the risk of blow-outs. It was highlighted that competition resulting in winners or losers often demotivates young people with ADHD and can cause issues with engagement. Methods of including competition that encourages personal achievement were discussed.

> Can you get to the top of the league system by doing this task, this task and for them they're kind of focusing on the football, which is, you know, something that helps maintain their focus because it's something that they potentially more interested in the than the lesson content (T2).

Another teacher talked about how to manage expectations and direct goals to each individual rather than a collective class goal that may be unachievable to certain students.

> Therefore they're achieving success by not being expected to, you know, produce too much or be at a certain level by the end of the lesson because I think that is another way that students become dis-focused because okay I have been given a list of 10 instructions and I've gotta do these 3 pages of work and I don't even understand what sir said because I wasn't 100% focused at the time. So just breaking it down into manageable chunks and if they don't understand that, repackaging it into something that's clearer or has a link to a theme, which they are motivated by (T2).

6.3.3.4.2. Rethinking discipline methods

The final lower-order theme discusses how we need to negate new methods of discipline that avoid sedentary behaviour as the current methods come with different

disadvantages. In particular, teachers discussed how challenging it is to discipline students that need the movement to be able to ground.

> Lunchtime detentions, I think is quite harsh on those students who have probably got the detention because they need to be moving around and then they've got extra sitting down, but I don't really know what the other options are for that. (T1)

Another teacher talked about the difficulty of knowing when to discipline a student or when they need time to ground themselves. “It's a hard line to where do you draw the line in terms of discipline and recentring and refocusing for some students” (T2).

6.4. Discussion

The overall aim of the present study was to gain an understanding of how physical activity affects ADHD symptoms and behaviours in young people, and the ideal components to create a successful physical activity intervention for young people with ADHD. To achieve this, we investigated the perceptions of key stakeholders: children with ADHD, parents with at least one child with ADHD, and teachers that teach at least one child with ADHD. Codebook analysis resulted in 2 key themes (challenges and difficulties, and task requirements and physical activity benefit) and 9 sub-themes from the children focus groups, 4 key themes (the middle ground, scaffolding, the bigger picture, and treatment strategy rewrite) and 14 sub-themes from the parent interviews, and 4 key themes (engagement in school physical activity, building relationships, the ideal intervention, and setting the standard) and 16 sub-themes from the teacher interviews. Common themes and suggestions for interventions both in research and/or in educational settings (i.e., schools) include ensuring activities are continuous in nature and do not involve waiting around or stopping and starting, avoiding cognitive overload due to children with ADHD finding it challenging to regulate emotions, within school settings active discipline methods should be considered to avoid sedentary behaviours of which increase pent up excess energy in young people with ADHD, and finally, physical activity should be in short, quick bursts such as circuits to maintain engagement and focus. Such

studies are important to develop a successful physical activity intervention (Koorts, Eakin, Estabrooks, Timperio, Salmon & Bauman, 2018).

6.4.1. Children focus group findings

The first higher-order theme from the children focus groups, ‘challenges and difficulties’, investigated the hardships associated with participation in physical activity. Children discussed different aspects of physical activity participation that make it challenging to remain engaged; motivational strategies for task completion, sensory imbalance, pauses in activity, managing big emotions, and teacher misunderstanding. Of these, similar difficulties have been found in children with autism spectrum disorders (Must, Phillips, Curtin, & Bandini, 2015; Papadopoulos et al., 2020), suggesting perhaps, the challenges discussed by the young people extend beyond ADHD, and are common among multiple neurodevelopmental disorders (Hickingbotham, Wong, & Bowling, 2021). The second higher-order theme derived from the children focus groups ‘task requirements and physical activity benefit’ highlights different task demands to elicit physical activity benefits in young people with ADHD; busy bodies, busy minds, the highs and lows, more than meets the eye, a weight has been taken off my shoulders. In neurotypical young people, cognitively engaging physical activity interventions have proven beneficial on academic achievement (De Bruijn et al., 2020) and executive function (Song et al., 2022), however it is not yet clear the effects of cognitively engaging exercise on young people with ADHD. It is therefore quite interesting to find that young people with ADHD highlighted that physical activity that requires lots of thought as well as movement is important to their engagement.

6.4.2. Parent interview findings

The first higher-order theme from the parent interviews ‘the middle ground’ identified the need for balance in physical activity specifically regarding rethinking discipline, pauses in activity, duration and frequency, and emotional self-regulation. Although alternative school discipline methods aside from detentions does not appear to have been investigated in young people with ADHD, the current school disciplinary

measures appear to be unsuccessful (Wiener & Daniels, 2015). This finding provides a novel practical application in that schools and teachers should consider more active behaviour management techniques for young people with ADHD. Furthermore, the parents highlighted the importance of duration and frequency of physical activity for this population, however, meta-analyses have highlighted that this is yet to be examined in young people with ADHD (Cornelius, Fedewa & Ahn, 2017). The second key higher-order theme from the parent interviews was 'scaffolding'. This theme referred to about the importance of developing skills and building upon different skills and how young people with ADHD may struggle with skill development compared to neurotypical young people. This has been previously researched (Harvey et al. 2009) and supports the concept of focusing on building skills gradually, keeping skills and instructions simple, and giving young people the knowledge for why they are participating in physical activity. Additionally, instructions have been shown to be not well received by young people with ADHD (Orban, Rapport, Friedman, Eckrich & Kofler, 2018) and therefore, the feedback from parents has practical application regarding short, clear instructions.

The third higher-order theme 'the bigger picture', highlighted mechanistic factors that contribute to engagement in physical activity and perceived benefits of physical activity in young people with ADHD. The theme consisted of the social, emotional and mental benefits of physical activity, the contribution of motivational climates, importance for praise and positive feedback, and the requirement for a focus on skill development. Previous research by McIntyre and Janzen (2022) also found important findings regarding the perceptions of physical activity in young people with neurodevelopmental disorders, also highlighting how physical activity 'helps everything' in terms of young people's health and wellbeing, however the present study provides confirmation specific to ADHD and the extent to the perceived benefits. The final higher-order theme 'treatment strategy rewrite' discusses the potential utilisation of physical activity in management of ADHD in young people. Specifically, parents highlighted the importance of physical intervention compared to verbal interventions. Specific interest was highlighted with regards to gamification of physical activity to increase engagement in young people with ADHD. Previous

interventions such as ‘Pokémon Go’ have been successful in increasing engagement in physical activity (Althoff, White & Horvitz, 2016) with research providing evidence of the benefits of exergaming interventions on attention in young people with ADHD (Ji et al. 2022). Further research however needs to be conducted with regards to the frequency of updates on exergames for retention of engagement in this population, the complexity, competitiveness and progression within games, and the application of games (i.e., via mobile app, smart watch, or internal game stations such as Xbox).

6.4.3. Teacher interview findings

The first higher-order theme from the teacher interviews ‘engagement in school physical activity’ discussed how teachers perceive young people with ADHD to participate in physical activity, the importance of utilising physical activity breaks throughout the day and the subsequent impact on concentration if effectively applied. Although physical activity has been identified as a positive method of supporting young people with ADHD in the classroom (Mulrine, Prater & Jenkins, 2008), and many of the teachers in the present study highlighted the importance of releasing energy and pent-up frustrations through physical movement within the classroom, there is still limited evidence within the literature in this population. Furthermore, mental and physical well-being benefits, irrespective of an ADHD diagnosis, are recognised within the literature (Ganjeh et al., 2021; LaCount et al., 2022) with physical activity in the classroom. With the limited evidence in young people with ADHD but the highlighted benefits and need for exercise, there is a greater requirement for more research to be conducted in this area. The second higher-order theme ‘building relationships’ identified the importance of maintaining positive, supportive relationships between teachers and students (Ewe, 2019). It was also highlighted how teachers perceive a lack of support and education in understanding neurodevelopmental disorders and how to manage them within the classroom. Although most teachers have fundamental knowledge of neurodevelopmental disorders, its recognised that evidence-based training, practical advice and more information on management techniques for symptoms and behaviours that teachers may face is necessary (Herwegen, Ashworth, &

Palikara, 2019) and importantly was recognised as a particular concern for teachers in the present study.

The third higher-order theme ‘the ideal intervention’ discusses all the perceived important factors that contribute towards an effective physical activity intervention in young people with ADHD. One of the most common themes that arose was the concept of physically active lessons. In neurotypical young people, physically active lessons have been proven to improve attention and on task behaviour in classroom settings (Ruhland & Lange, 2021; Schmidt, Benzing, & Kamer, 2016) with different protocols as to how to implement physical activity in lessons (Routen et al., 2017, Routen, Chalkley, & Sherar, 2017). However, although the current trends are positive regarding this intervention technique, methodological differences between studies concerning duration and type are still poorly reported, and show no correlations (Ruhland & Lange, 2021). More recently, high-intensity interval training has been explored as a potential physical intervention to aid the management of ADHD (Meβler, Holmberg, & Sperlich, 2016; Soori et al., 2020), however the evidence to date is laboratory based and lacks ecological validity. The present study highlighted that physically active lessons should be applied to young people with ADHD and would be well accepted in the classroom by teachers in the present study. The final higher-order theme, ‘setting the standard’, highlighted the challenges associated with discipline methods, as well as tactics of achievement and development. Previous research has shown that personal best goals are effective for achievement and behavioural engagement (Martin, 2012, McKenna et al., 2023). Furthermore, teachers discussed the issues surrounding current discipline methods, and the lack of effectiveness of school suspensions and detentions (Ramey & Freelin, 2023). Alternative behavioural management techniques that are more active within schools are still relatively underrepresented in the literature for young people with ADHD, and what has already been proven to be effective have not been shared with teachers and educationalists in a way that can be applied (Martinussen, Tannock, & Chaban, 2011). The feasibility of sports-based interventions for students who are excluded from mainstream education has

been successful (Brinkley, Sherar, & Kinnafick, 2022), and so it is suggested that more active interventions for behaviour in young people with ADHD are also considered.

6.4.4. Commonalities and practical applications

The advice from children, parents and teachers identified different factors that are important for future intervention design. Although there were many different themes and factors that were identified, four themes were identified across all participant groups. These were stop/start, emotional regulation, discipline methods, and duration of physical activity. The practical implications of these themes suggest that a physical activity intervention needs to reduce stagnancy in activity, ensuring that activities are short, quick-paced, and dynamic such as circuit training or high-intensity interval training. Furthermore, certain considerations need to be acknowledged firstly, emotional regulation has been identified as a challenge for young people with ADHD, with this in mind, future interventions should be cautious to avoid environments where sensory overload may occur. Finally, the current discipline methods such as detentions, and suspensions have been consistently picked up as negative and unsuccessful in their goals and more active behavioural management techniques should be applied. Therefore, alternative methods of 'discipline' and 'behavioural management' should be explored for young people with ADHD.

6.4.5. Limitations and future research directions

Although there are many more components that have been highlighted within this study, the four highlighted above appear to be among the most recognised and are a positive starting point for change in physical activity interventions in young people with ADHD. That does not mean however, that other themes identified in this study should be ignored or not applied in future study design. In order to develop an effective intervention, it is recommended that researchers take on board the components identified in this study, with consistent discussions with the stakeholders involved in the interventions namely, young people with ADHD, their teachers, their parents, and other educationalists. Specific intervention designs that should be trialled include games-based physical activity, that

does not involve competition and can be implemented in short bursts of different activities to prevent boredom. Furthermore, physical activity interventions should be simple and avoid lots of instruction to help reduce confusion and subsequently prevent disinterest and frustration. The current study is not without its limitations, specifically, some of the questions administered during the children focus groups were more leading due to ease of interpretation for the population, however, may have resulted in some of the data being researcher guided e.g., “how does physical activity affect your focus in lessons?”. Furthermore, the focus group durations were short (~10 mins), which may limit the quality of data collected. However, keeping the participant group engaged for longer than this duration proved difficult, thus a balance was required between maintaining focus and delving for more detailed responses. This is a key consideration for future qualitative work in this population, where novel approaches of shorter, but numerous, focus groups may be required to glean more detail. It is suggested that future intervention designs are piloted with young people with ADHD, with follow up interviews to be conducted with young people with ADHD, and key stakeholders who are involved in the intervention to check feasibility and validity of intervention design. Furthermore, challenges regarding running focus groups with young people with ADHD were encountered, and therefore future interventions should consider smaller groups with different tactics to get the most out of answers and boost engagement.

6.4.6. Conclusion

In conclusion, children with ADHD, their parents, and their teachers highlighted a multitude of different factors that need to be implemented into physical activity interventions for young people with ADHD. Common themes highlighted across each stakeholder population were stagnancy in activity, duration of activity, emotional regulation, and discipline methods. To develop an effective physical activity intervention, we urge researchers to continue discussions with stakeholders, whilst beginning to apply the different components such as games-based physical activity dosed in short bursts similar to a circuit style activity, highlighted within this study. With successful application of

the aforementioned themes/considerations, we strongly believe that a positive physical activity intervention can be implemented with young people with ADHD.

Chapter VII

Effect of games-based physical activity on cognitive function, self-control, and resilience in young people with attention-deficit/hyperactivity disorder: A pilot study

7.1. Introduction

Although the findings from Chapter IV demonstrated the cognitive benefits of acute physical activity interventions, and Chapter V identified small positive associations between physical activity and self-control, as well as cardiorespiratory fitness, cognition and resilience, the quantitative results did not consider how the effects are experienced in everyday life. Therefore, Chapter VI qualitatively explored how physical activity is perceived from young people with ADHD, their parents and their teachers, offering valuable insights into the real-world impact of physical activity in this population. The final chapter will explore the effects of a single bout of games-based physical activity on the aforementioned psychological constructs. Notably, a single bout of games-based physical activity has not been previously implemented in this population and was identified as a modality of physical activity typically enjoyed in this population in Chapter VI, and thus the chapter will examine whether this ecologically valid physical activity can elicit benefits on cognition, self-control and resilience in young people with ADHD.

In neurotypical young people, meta-analyses have showed that acute physical activity interventions improve working memory, attention, processing speed and inhibition (Gejl et al., 2018), whilst chronic physical activity interventions appear to improve processing speed, attention, cognitive flexibility, working memory and language (Álvarez-Bueno et al., 2017; Chen, et al., 2014; Haverkamp et al, 2020; Liu et al., 2020; Lambrick, Stoner, Grigg, & Faulkner, 2016). A full exploration of the acute physical activity-cognition relationship in neurotypical young people is covered in Chapter II and was summarised as a small positive effect. Chapter IV summarised the current findings regarding acute physical activity and young people with ADHD to show specific improvements in the

cognitive domains of cognitive flexibility, attention and inhibitory control. These improved domains appeared to be enhanced when interventions lasted between 11-30 minutes and used open skills such as trampolining or coordinative tasks (avoiding continuous activities such as running or cycling) (see Chapter IV). Although studies have found promising findings regarding acute physical activity and cognitive function, there are many mediating variables in the acute physical activity-cognition relationship that are yet to be explored, partly due to the lack of rigorous randomised-control trials within the population of young people with ADHD.

In neurotypical adolescents, combined exercise and dietary interventions have been shown to improve aspects of self-control, particularly when using physical performance measures of self-control, such as hand-grip strength (Xiang et al., 2019). This highlights the potential of physical activity to improve aspects of self-control in neurotypical young people, which in turn could be applied to young people with ADHD. Self-control has been defined as “the capacity for altering one’s own responses, especially to bring them in line with standards such as ideals, values, morals, and social expectations” (Baumeister, Vohs, & Tice, 2007). State self-control is an individual’s ability to utilise self-control more at some times than others (Gailliot et al., 2012) and is often described to resemble a muscle with a limited supply of energy (Muraven & Baumeister, 2000). High levels of trait self-control have been shown to be related to healthier eating habits and greater levels of physical activity in adolescents (Junger & Kampen, 2010), further reinforcing the assumption that high self-control is important for healthy lifestyle behaviours (Boat et al., 2022). Chapter V found a positive association between time spent in high intensity physical activities and trait self-control, whereby those individuals with high self-control spent more time participating in high intensity physical activity. Specifically, the focus was on the intensity of physical activity, an aspect of intervention design that had not yet been examined in this population. The relationship between trait self-control and physical activity has been shown to be bi-directional in nature (whereby higher physical activity is associated with higher self-control and vice versa) (Boat & Cooper, 2019), and therefore it is important to encourage young people to participate in

physical activity. However, although these effects have been evidenced to be important in neurotypical young people (Boat et al., 2022), the acute effects of physical activity on self-control in young people with ADHD have not been examined to date.

Another psychological construct that is imperative to day-to-day functioning is resilience. Resilience has been defined as “the personal qualities that enables one to thrive in the face of adversity” (Connor & Davidson, 2003, p. 76). Resilience has been shown to be successfully improved through physical activity interventions in neurotypical young people aged 12-14 (Khalsa et al., 2011; Moore, Woodcock & Dudley, 2018) through different intervention modalities such as martial arts and yoga. Physical activity has been shown to improve resilience by strengthening brain structure and brain function through improved top-down control systems; of which enhance behaviour and emotional self-regulation through using what you already know, to make sense of new information you encounter (Belcher et al., 2021). This may, therefore, explain why higher resilience is associated with improved academic performance, less chance of comorbidities, and improved social relationships in young people with ADHD (Black et al., 2024; Dvorsky & Langberg, 2016). In young people with ADHD, findings from Chapter V highlighted tendencies for a positive association between trait resilience and cardiorespiratory fitness. However, the present chapter aims to assess the effects of physical activity on state resilience to better understand resilience as a (context-specific and time dependent) process.

Although acute physical activity interventions have been shown to improve certain aspects of physical and psychological well-being (including mood, energy, enjoyment and experiences of happiness and loneliness) in young people with ADHD (Fard et al., 2022), the ‘ideal’ intervention is yet to be identified. Currently in ADHD research, interventions have utilised activities such as cycling or running (Hung et al., 2016; Medina et al., 2010; Mahon et al., 2013; Piepmeier et al., 2015), however these activities are not commonly undertaken in the ‘real world’ by young people with ADHD and therefore lack ecological validity. For example, only an estimated 23% of children aged 11-16 years report

participating in regular running (Sport England, Active Lives, 2023). Following focus groups with young people with ADHD, as well as interviews with their parents and their teachers, Chapter 3 identified that 'circuit training' with short stints of exercise with clear, uncomplicated instructions were important aspects of an intervention expected to increase engagement in physical activity in young people with ADHD. Circuit training can be defined as a series of carefully selected exercises that can be specific to sport and fitness level (Lawrence & Hope, 2007). With young people with ADHD preferring the fluidity of physical activity in the form of short, simple, and intense stints, circuit training appears to be an attractive option. Furthermore, data from the Active Lives survey (2023) showed that 60% of young people spent their time in team sports, reinforcing the concept of reducing individual continuous activities such as running, walking and cycling and increasing activities that require teamwork, socialisation and communication. More recently, games-based physical activities have been implemented in neurotypical young people with the aim to improve cognitive function performance (Cooper et al., 2018; Gilbert et al., 2023, Pesce et al., 2009), however, these effects are yet to be examined in young people with ADHD.

Therefore, the aim of the present pilot study was to investigate the effects of acute games-based physical activity on cognitive function, self-control, resilience and mood in young people with ADHD.

7.2. Methodology

7.2.1. Participant characteristics

Thirty-three young people (24 boys, 9 girls) participated in the study. During the familiarisation trial, all participants underwent anthropometric measurements of height (cm) and body mass (kg), allowing the calculation of body mass index (BMI; weight (kg)/height $(m)^2$). Participants also took part in the multi-stage fitness test during the familiarisation. Descriptive characteristics of participant characteristics are presented in table 7.1.

Table 7.1. Participant characteristics, data are mean ± SD.

	Mean	SD	Range
Age (yrs)	12.34	1.30	10.01-14.99
Height (cm)	155.56	12.82	129.00-180.60
Body mass (kg)	47.28	16.12	24.30-87.30
BMI (kg/m^2)	19.18	4.81	13.91-32.63
MSFT distance (m)	640	440	80-1860

Note. MSFT = Multi-Stage Fitness Test.

7.2.2. Experimental design

The present study was approved by the Nottingham Trent University Human Invasive Ethics Committee. Following ethical approval, participants were recruited from local state primary and secondary schools in the Midlands area of the UK. A total of 6 schools agreed to participate in the study. Of the 6 schools that participated in the present study, three also participated in Chapter V. However, only 4 participants took place in both studies. Written parental/guardian consent and participant consent were obtained during the initial phase of recruitment. A health screen was also completed by the parent/guardian to determine eligibility of the child for participation in the study and was subsequently checked by a lead investigator. Any child with a health condition that would inhibit their ability to participate in the study (e.g., heart condition) was not permitted to take part. Of the original sample (50 participants), 17 participants dropped out of the study (due to absence at one or more of the testing sessions), resulting in a final sample of 33 participants.

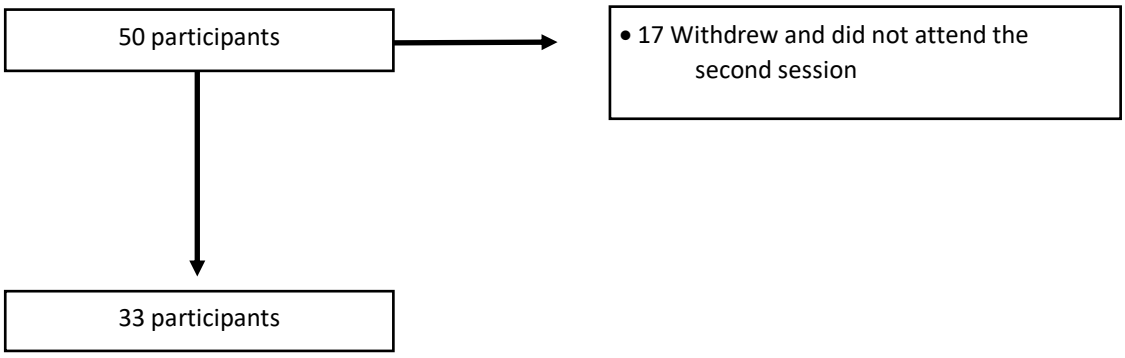


Figure 7.1. Flowchart highlighting dropout

The study employed an order-balanced, crossover, within-subjects design which consisted of a familiarisation and two experimental conditions (exercise and resting); separated by at least 7 d). During the familiarisation trial (~ 7 d prior to the main trial), participants were acquainted with all the measures. Following the completion of the anthropometric measurements, the participants were familiarised with the series of questionnaires (assessing self-control, resilience and mood; see section 7.2.3 for outline of measures) and the battery of cognitive function tests (Stroop test, Sternberg Paradigm, and Flanker task; see section 7.2.3 for outline of measures). The participants were also familiarised with a Basketball session (completed during the exercise experimental condition), which consisted of skill-based drills and circuit style activities to ensure they had all the required skills to participate in the Basketball session as part of the exercise trial. During the familiarisation trial, participants also completed the multi-stage fitness test (MSFT) to assess their cardiorespiratory fitness.

7.2.2.1. Main trials

Participants were instructed to record their breakfast on the morning of experimental trials, ensuring they replicated the breakfast for both trials. Both trials followed a time matched protocol, with the only difference being the 30 min exercise. During the exercise trial, participants completed 30 min basketball; whilst they remained seated in a classroom during the resting trial. During the trials, participants completed the questionnaires and cognitive function tests prior to beginning the experimental condition, participants then participated in either 30 min basketball or 30 min seated rest. Immediately after, and 45 min after, the experimental condition, participants completed the cognitive function tasks and questionnaires (see figure 7.1 for schematic of protocol).

7.2.2.2. Exercise protocol

The exercise protocol consisted of a 30 min basketball session composed of circuit style drills (see table 7.2). Thirty minutes of physical activity was selected as the most appropriate duration in previous literature investigating single-bouts of physical activity in young people with ADHD (Chapter IV), and as a reasonable duration of physical activity

that could realistically be included within the school day. Basketball was chosen because it replicated the activity patterns typically observed in this population (Sun et al., 2022), as well as being a popular and enjoyable form of games-based physical activity in this aged population (Active Lives Children and Young People Survey, 2023). Games-based physical activities and circuit style interventions were also identified by young people with ADHD, their parents and their teachers, as important considerations for the development of a successful physical activity intervention for children with ADHD (Chapter VI).

7.2.3. Measures

7.2.3.1. Cognitive Function Tests

The battery of cognitive function tests consisted of a Stroop test, Sternberg paradigm, and a Flanker task which are described in detail in the General Methods Chapter III (section 3.3.3). The battery of tests lasted approximately 15 minutes and were administered via a laptop computer (Lenovo ThinkPad; Lenovo).

Table 7.2. Outline of exercise protocol.

Activity segment	Duration	Activities
Warm up	5 min	Simon says (e.g. running, skipping, galloping, walking on tiptoes), dynamic stretches (e.g. walking lunges).
Drills	20 min	1. Dribbling ball between cones. 2. 'Red light, green light' 3. Throwing accuracy (throwing ball into target to partner) 4. Circuit (accuracy into hoop, dribbling, balancing and accuracy at hitting target)
Cool down	5 min	Dynamic and static stretches

7.2.3.2. Brief Self-Control Scale

A participant's state level of self-control was measured using an adapted version of the Brief Self-Control Scale (Tangney et al., 2004), which typically is a measure of trait self-control. This 13-item questionnaire provides a 5-point Likert-type scale ranging from

one (indicating *not very much*) to five (indicating *very much*); in response to statements such as “I feel like I can resist a temptation”. The Brief Self-Control Scale has been proven to be a successful tool for assessing trait self-control in young people (Boat et al., 2022; Rodríguez-Menchón, Morales, Orgilés, & Espada, 2022; Turliuc & Pojoga, 2018), however a validated state self-control measure is yet to be developed for this population (see appendix E for adapted questionnaire). Internal consistency of the 13-item Brief Self-Control Scale was adequate in the present sample ($0.643 \leq \alpha \leq 0.842$) (Taber, 2018). Further details of the brief self-control scale are described in the General Methods Chapter 3 (section 3.3.4.1).

7.2.3.3. Connor-Davidson Resilience Scale

An adapted version of the 10-item Connor-Davidson Resilience Scale (CD-RISC; Campbell-Sills & Stein, 2007; Connor & Davidson, 2003) was used to provide a self-report measure of resilience. The CD-RISC is generally used to measure resilience as a trait, however, for the purposes of the present study, the CD-RISC was adapted to measure state resilience (resilience as a process) in the absence of an alternative validated state measure of resilience as a process. For each item (e.g., “I am able to adapt when changes occur”) participants were provided with a 5-point Likert-type scale ranging from 0 to 4 (0 indicating *not true at all*, 4 indicated *true nearly all the time*), with higher scores indicating higher levels of resilience (see appendix G for the adapted questionnaire). The CD-RISC 10-item questionnaire has been shown to be successfully administered within a similar aged population (Durish, Yates, & Brooks, 2018; Fullerton et al., 2021) including with children and young people with ADHD (Black et al., 2024; She, Yang, Lau, & Lau, 2020). In the present study, the internal consistency of the 10-item CD-RISC was high ($0.815 \leq \alpha \leq 0.905$) (Taber, 2018). Further details of the CD-RISC are described in the General Methods Chapter 3 (section 3.3.4.2).

7.2.3.4. Visual Analogue Scale

A visual analogue scale (VAS) was used to assess happiness, energy, tiredness, attention, calmness and concentration (see appendix N). These emotions were selected

to gain a deeper understanding of the effects of the physical activity intervention on mood in young people with ADHD. The VAS scale was presented on a 10 cm line per emotion whereby participants were asked to draw a single line to mark how they perceived that emotion at that precise moment in time. Their answers were then calculated via measuring to the closest 0.1 cm.

7.2.3.5. Multi-Stage Fitness Test

The MSFT was used as a measure of cardiorespiratory fitness and involves participants undertaking progressive 20 m shuttle runs until exhaustion, or until the participant fails to keep intime with the audio that dictates the running speed. With a starting pace of 8.0 $km.hr^{-1}$, the speed increased by 1 $km.hr^{-1}$ from level 1 to level 2 and thereafter increased by 0.5 $km.hr^{-1}$ for every level completed (Ramsbottom, Brewer & Williams, 1988). A member of the research team paced the participants and provided verbal encouragement to ensure maximal effort. The test was terminated when the participant failed to keep up with the pace for three consecutive shuttles, or they reached volitional exhaustion. Cardiorespiratory fitness was measured as distance covered in accordance with previous research in young people (Dring et al., 2019; Dring et al., 2022). Full details of the MSFT are described in the General Methods Chapter III (section 3.3.1).

7.2.4. Statistical Analysis

Data from the Stroop test, Sterenberg Paradigm and Flanker task were analysed using the open-source software R which produced mean response times (ms) and proportion of correct responses (%) for each test level and for timepoint at which the cognitive tests were completed. Response times and accuracy were subsequently used to calculate an inverse efficiency score (IES; Statsenko et al. 2020). The IES was calculated by reaction time (ms) / accuracy (proportion correct) and has been used in previous research to provide a single cognitive outcome that combines both response times and accuracy (Bedard et al. 2021); thus, negating possible speed-accuracy trade-offs affecting study outcomes (Statsenko et al. 2020). For ease of interpretation, a lower IES indicates improved performance on the cognitive task. All data were analysed using IBM SPSS

(Version 29, SPSS Inc, Chicago, IL, USA) via two-way (trial*time) repeated measures analysis of variance (ANOVA). To explore statistically significant two-way interactions (trial*time), paired samples t-tests with a Bonferroni correction for multiple comparisons were conducted to compare between the trials for each time points. Questionnaire data (self-control, resilience, and mood) were also analysed using two-way (trial*time) repeated measures ANOVA, with Bonferroni corrected paired samples t-tests to explore post-hoc differences. Statistical significance was accepted as $p < 0.05$.

7.3. Results

7.3.1. Cognitive function

Data for all three cognitive tests, across all time points, for the exercise condition and control condition are displayed in table 7.3.

7.3.1.1. Stroop test

7.3.1.1.1. Congruent level

Overall, there was no statistically significant difference in IES between the exercise and resting trials (main effect of trial, ($F(1, 29) = 2.736$, $p = 0.109$). Furthermore, the pattern of change in IES across the exercise and resting trials was similar (trial * time interaction, $F(2, 58) = 0.028$, $p = 0.973$).

7.3.1.1.2. Incongruent level

There was no statistically significant difference between exercise and resting trials (main effect of trial; $F(1, 29) = 0.001$, $p = 0.971$). Furthermore, the pattern of change in IES between the trials was similar (trial*time interaction, $F(2, 58) = 1.137$, $p = 0.328$).

7.3.1.2. Sternberg Paradigm

7.3.1.2.1. 1 item level

Overall, there was no statistically significant difference in IES between the exercise and resting trials (main effect of trial, ($F(1, 25) = 1.937$, $p = 0.176$); and the pattern of

change in IES was also similar over time between the trials (trial * time interaction, $F(2, 50) = 0.775$, $p = 0.430$).

7.3.1.2.2. 3 item level

No statistically significant difference was found between resting or exercise trials (main effect of trial, $F(1, 25) = 0.082$, $p = 0.777$), and pattern of change in IES was found to be similar over time between the trials (trial*time interaction, $F(2, 50) = 0.996$, $p = 0.377$).

7.3.1.2.3. 5 item level

Overall, there were no statistically significant difference between the resting and exercise trials (main effect of trial, $F(1, 25) = 0.010$, $p = 0.922$), and the pattern of change in IES between trials were similar (trial*time interaction, $F(2, 50) = 0.690$, $p = 0.506$).

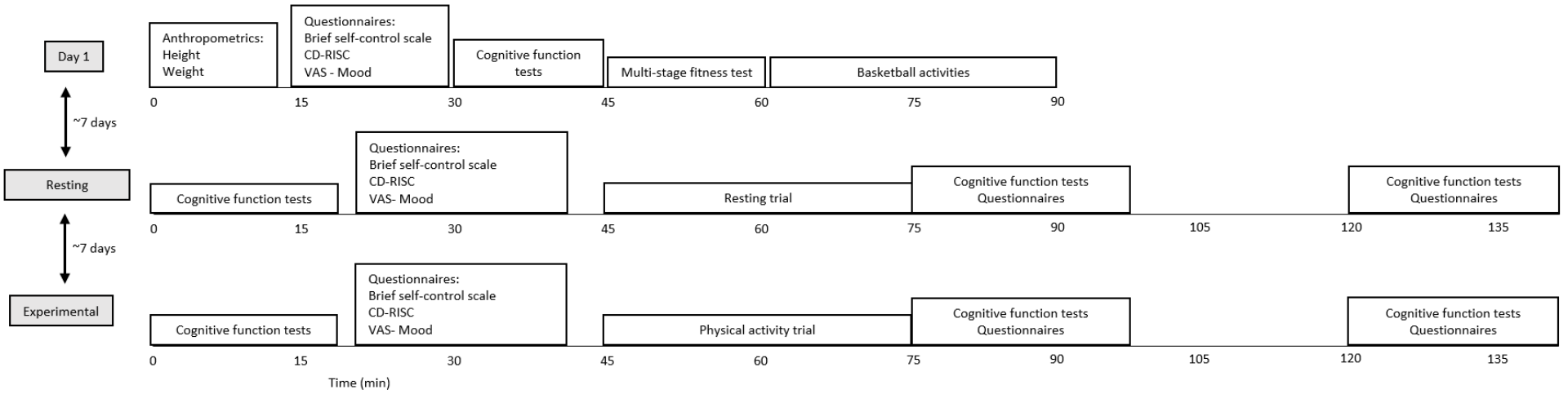
7.3.1.3. Flanker Task

7.3.1.3.1. Congruent level

Overall, there were no statistically significant differences between the exercise and resting trials (main effect of trial, $F(1, 28) = 0.010$, $p = 0.922$), and the pattern of change over time between trial were similar (trial*time interaction, $F(2, 56) = 0.806$, $p = 0.453$).

7.3.1.3.2. Incongruent level

No statistically significant differences were found between exercise and resting conditions (main effect of trial, $F(1, 28) = 0.320$, $p = 0.576$); and the pattern of change of IES was also similar between trials (trial*time interaction $F(2, 56) = 1.274$, $p = 0.278$).



Note. CD-RISC; Connor-Davidson Resilience Scale, VAS- Mood; visual analogue scale

Figure 7.2. Schematic of the experimental protocol.

Table 7.3. Means and standard deviations for all outcome variables for the exercise and resting conditions for three time points (pre-intervention, immediately post intervention, and 45-mins post intervention). Data are mean ± SD

Variable	Exercise			Resting		
	Pre	Immediately post	45-mins post	Pre	Immediately post	45-mins post
Stroop congruent (IES)	1444 ± 394	1524 ± 478	1408 ± 392	1360 ± 382	1440 ± 420	1342 ± 421
Stroop incongruent (IES)	1080 ± 264	1188 ± 393	1187 ± 359	1046 ± 223	1273 ± 381	1141 ± 303
Sternberg 1-item (IES)	698 ± 206	739 ± 271	685 ± 230	738 ± 229	746 ± 277	816 ± 578
Sternberg 3-item (IES)	918 ± 196	925 ± 239	914 ± 234	977 ± 287	916 ± 318	893 ± 283
Sternberg 5-item (IES)	1108 ± 304	1219 ± 441	1184 ± 389	1114 ± 356	1287 ± 640	1128 ± 372
Flanker congruent (IES)	768 ± 203	856 ± 234	748 ± 188	777 ± 219	824 ± 241	762 ± 203
Flanker incongruent (IES)	1186 ± 1640	1130 ± 482	921 ± 339	1040 ± 591	992 ± 405	1056 ± 664
Happiness	7.3 ± 2.0	7.4 ± 2.4	7.4 ± 2.6	6.6 ± 2.6	7.2 ± 2.5	6.9 ± 2.9
Energy	6.7 ± 3.0	6.3 ± 3.2	6.0 ± 3.3	5.8 ± 3.3	6.8 ± 3.3	6.5 ± 3.3
Tiredness	4.2 ± 3.2	4.5 ± 3.3	4.6 ± 3.4	4.7 ± 3.4	4.2 ± 3.3	3.6 ± 3.3
Attention	5.3 ± 2.9	5.0 ± 3.0	5.2 ± 3.3	5.6 ± 2.7	6.1 ± 3.1	5.8 ± 3.4
Calmness	6.3 ± 2.8	6.3 ± 2.8	6.7 ± 2.7	7.5 ± 2.3	6.9 ± 3.1	6.6 ± 3.0
Concentration	5.8 ± 3.3	5.4 ± 3.2	5.5 ± 3.1	5.4 ± 2.9	5.7 ± 2.9	5.9 ± 3.5

Note. IES; inverse efficiency score

7.3.2. Self-control

Self-control levels were similar between the exercise and resting trials (main effect for trial, $F(1, 32) = 1.483$, $p = 0.232$); and the patterns of change was similar over time between trials (trial*time interaction; $F(2, 64) = 0.432$, $p = 0.651$).

7.3.3. Resilience

Resilience scores were found to be similar between the exercise and resting trials (main effect for trial, $F(1, 32) = 0.476$, $p = 0.495$). The pattern of change in resilience was similar over time for the exercise and resting trials (trial*time interaction, $F(2, 64) = 0.435$, $p = 0.624$).

7.3.4. Mood VAS

A tendency for a difference between the resting and exercise trials were found for happiness (main effect of trial, $F(1, 32) = 3.352$, $p = 0.076$); specifically, happiness tended to be higher in the exercise trial (7.27±0.34) compared to the resting trial (6.96±0.39). However, the pattern of change in happiness was similar across time between trials (trial*time interaction, $F(2, 64) = 0.240$, $p = 0.787$).

Energy was found to be similar between trials (main effect for trial, $F(1,32) = 0.004$, $p = 0.950$). However there was found to be a statistically significant trial*time interaction ($F(2, 64) = 4.360$, $p = 0.017$), whereby energy prior to the exercise trial was significantly higher than prior to the resting trial ($p = 0.033$) (see Figure 7.2).

Tiredness was shown to be similar between trials (main effect of trial, $F(1,32) = 0.283$, $p = 0.598$); the patterns of change was also similar across time between trials (trial*time interaction, $F(2, 64) = 1.638$, $p = 0.202$).

A significant difference was found for attention between the exercise and resting conditions (main effect of trial, $F(1, 32) = 5.200$, $p = 0.029$), whereby attention was higher in the resting condition (5.5±0.5), compared to the exercise condition (5.4±0.5). However,

the pattern of change was found to be similar across time between the exercise and resting trials (trial*time interaction, $F(2, 64) = 1.159$, $p = 0.320$).

Calmness was similar between the exercise and resting trials (main effect for trial, $F(1, 32) = 2.445$, $p = 0.128$); and the pattern of change was similar between trials across time (trial*time interaction, $F(2, 64) = 1.743$, $p = 0.183$).

Similar concentration scores were found between exercise and resting trials (main effect for trial, $F(1, 32) = 0.398$, $p = 0.532$). Finally, the pattern of change over time between trials were similar (trial*time interaction, $F(2, 64) = 1.081$, $p = 0.345$).

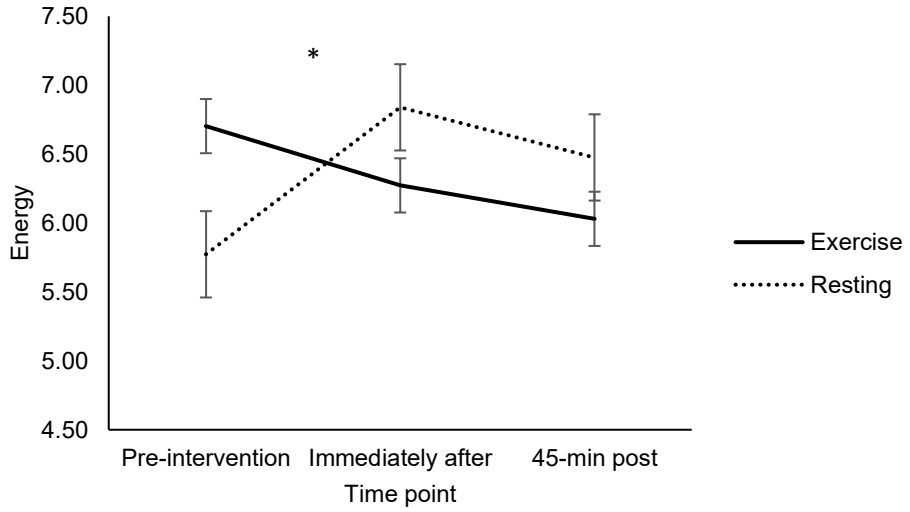


Figure 7.3. Self-reported energy on the exercise and resting trials across the morning (trial*time interaction, $p = 0.017$).

7.4. Discussion

The aims of the present study were to investigate the acute effects of a games-based physical activity intervention on cognitive function, state self-control, state resilience and mood in young people with ADHD. Findings suggest that there were no differences in these key psychological constructs following a 30-minute basketball session compared to following and 30-minutes seated rest in young people with ADHD. The present study is the first of its kind to examine the effects of an acute games-based physical activity intervention on the key psychological mechanisms (cognitive function, self-control and resilience) in children and adolescents with ADHD. The findings suggest that a single 30-

minute bout of games-based activity is not sufficient to elicit changes in these key psychological constructs.

A key finding of the present study was that a 30-min games-based (basketball) session did not influence cognitive function either immediately or 45-min following the activity. Whilst a small number of studies have concluded that acute physical activity has a small positive effect on cognitive function in young people with ADHD (Chapter 1; Meggs, Young & Mckeown, 2023; Suarez-Manzano et al., 2018), a key factor to consider is the ecological validity of the physical activity. Chapter 3 highlighted that games-based activities may be appropriate given the simple instructions, buildability (opportunity to scaffold on skills) and dynamic nature (quick paced and high intensity); hence why examining the acute responses of this type of activity in the present study were important. As previously stated, physical activity interventions implemented in young people with ADHD have predominantly been focused on cycling and running; both activities that lack in ecological validity in this age group due to their individual nature (Ludyga et al., 2023). It has been highlighted that young people with ADHD are less likely to participate in individual sports, compared to team sports and have been found to participate in much lower levels of physical activity compared to their neurotypical counterparts (Ludyga et al., 2023). Furthermore, it is presumed that the reduced participation in individual sports is due to the lack of immediate reward, or total lack of reward (Ludyga et al., 2023). Therefore, basketball seemed to be an attractive avenue for this population with chronic basketball interventions proving successful on working memory in children with ADHD (Eskandarnejad, Mobayen & Dana, 2015), with the added bonus of constant feedback and reward through successful throws and catches. Although benefits have been seen for neurotypical young people when participating in games-based physical activity interventions (basketball) on cognitive function (Cooper et al., 2018), these findings were not replicated in young people with ADHD in the present study.

A potential implication with the type of activity selected in the present study is the increased cognitive demand during participation in games-based sports (Meggs, Young, &

Mckeown, 2023). Unlike running or cycling where an individual needs to focus only on the motions of their body, ball games have external factors that the individual needs to process, for example, throwing and catching a ball, dribbling a ball around cones, footwork, other players, and shooting. These external stimuli, therefore, place additional demands on cognitive processes including cognitive flexibility, inhibitory control and attention. It has also been found that some young people with ADHD have difficulties with impaired motor skills, such as catching and throwing, compared to their neurotypical comparators (Jakobson & Kikas, 2007; Kaiser, Schoemaker, Albaret & Geuze, 2015), which may have added additional challenges for the individuals in the present study. Thus, it is possible that a simplified version of games-based activities may be required to prevent 'overloading' cognition in young people with ADHD, and to maximise the cognitive benefits.

The present study found that a 30-min games-based physical activity intervention did not affect self-control either immediately after or 45-min following the activity. To the best of our knowledge, this is the first study to examine the effect of an acute physical activity intervention on self-control in young people with ADHD. Although an acute games-based physical activity intervention did not elicit improvements in state self-control, the effects of an intervention longitudinally could warrant further investigation to investigate the trait self-control of this population. Previous research has shown positive associations between physical activity interventions and physical measures of self-control (Xiang et al., 2019) and trait self-control (Briki, 2016). Chapter V also highlighted the relationship between moderate to vigorous physical activity levels and process self-control in young people with ADHD, further calling attention to the potential improved self-control in this population with physical activity, and the importance of investigating this relationship longitudinally in future research.

Another key finding in the present study was that a 30-min basketball activity did not influence state resilience immediately or 45-min following the activity. Chapter V highlighted positive associations between cardiorespiratory fitness and trait resilience.

Although the acute effects of physical activity did not improve state resilience in the present study, the longitudinal/chronic effects of a physical activity intervention on state resilience in young people with ADHD has yet to be examined. Previous literature has shown positive associations between chronic physical activity and resilience in college students (Xu et al., 2021), and therefore provides evidence that there is the potential for improvements in young people with ADHD. The present study is the first to examine the acute effects of physical activity on resilience in this population and therefore provides novel findings that a single games-based physical activity intervention is not successful in improving the state resilience of young people with ADHD.

Finally, there were some interesting findings regarding mood. Overall happiness was found to be higher following the exercise trial compared to the resting condition, suggesting that the young people had greater enjoyment in games-based activities compared to the seated rest. This is supported by Chapter VI whereby young people with ADHD discussed their preferences in a physical activity intervention which included dynamic activities that did not involve lots of stopping and starting and cognitively challenging activities, both of which were implemented within the basketball activities. It is clear to see from the findings that young people with ADHD enjoy aspects of games-based interventions and were happy when participating, however in the present study there were only a single session therefore, it could be that other aspects of mood could be improved with physical activity over time. Previous literature by Wymbs, Wymbs, Margherio and Burd (2021) found that over two weeks, mood was negatively impacted following high intensity physical activity in young people with ADHD, however this is the only research to date to examine this. In neurotypical young people, the effects of high intensity interval training appear to be conflicted with some evidence showing positive effects on mood (Martland et al., 2022) whilst some research found negative effects (Selmi et al., 2018). Further research is required to fully understand the effects of high intensity physical activity interventions on mood in young people, including those with ADHD.

7.4.1. Practical applications, limitations, and future research

The challenge faced so far with ADHD management through physical activity is the lack of clarity regarding frequency, intensity, time and type in the current literature base (Xie et al., 2021). Therefore, although physical activity has been shown to elicit benefits across cognitive domains (Suarez-Manzano, Ruiz-Ariza, De La Torre-Cruz & Martínez-López, 2018; Dastamooz et al., 2023) and ADHD symptoms and behaviours (Gapin, Labban, & Etnier, 2011), there does not appear to be an optimum dose for physical activity intervention settings in this population (dose, intensity, type). The present study provides evidence that an acute bout (30-min) of basketball activities does not appear to affect cognitive function, self-control, or resilience in young people with ADHD compared to a resting control condition. The chronic effects of basketball could have greater effects on cognitive function in this population (Eskandarnejad, Mobayen, & Dana, 2015) as well as other neurodevelopmental disorders (Wang et al., 2020), and it is recommended that more research examines the chronic effects of games-based interventions, including basketball, as well as considering the long-term benefits of this type of intervention. Furthermore, if a basketball intervention is used, it is important to consider the different skills (e.g. passing, shooting, games) that are used and are effective in engagement, as well as mechanistic benefits. The present study utilised circuit style drills of which did not improve the desired outcomes; therefore, it could be interesting to examine whether more game style drills could elicit different effects. Furthermore, although it is useful to understand the acute effects of an intervention, for practical applicability, there could be greater benefit from chronic interventions as this naturally builds structure and routine into the lives of young people with ADHD (an aspect highlighted as important during the qualitative chapter (Chapter 3) in this thesis), and therefore has the potential to improve engagement.

Whilst the present study was the first to examine the acute effects of games-based activity on cognition, self-control, and resilience in young people with ADHD, it is not without limitations. A key limitation of this study was the lack of a neurotypical age

matched control group. The inclusion of an age-matched group would be useful to distinguish between whether the basketball intervention would have varied results between those with and without ADHD. Furthermore, another limitation of this intervention was that the intensity of the physical activity was not measured. This was due to the population being reluctant to wear heart rate monitors and accelerometers both in this study and in Chapter V, however, it would have been a useful addition to measure the intensity of the intervention and investigate how this impacts the effects of the intervention.

7.4.2. Conclusion

The current study found that a 30-minute basketball intervention did not influence cognitive function, (state) self-control or (state) resilience immediately or 45-minutes following exercise, when compared to a resting control trial. With focus on the acute effects of physical activity on cognitive function, (state) self-control, and (state) resilience in young people with ADHD, an acute basketball intervention does not appear to be a successful intervention. Therefore, alternative modalities could perhaps be considered, for example, football, which has been proven to be successful in eliciting enhanced cognitive performance in neurotypical young people (Magistro et al., 2023). Furthermore, the longer-term chronic effects of physical activity interventions should be implemented, and including an age-matched neurotypical comparison group, would further enhance our understanding of optimising physical activity interventions in this population.

Chapter VIII

General Discussion

8.1. Summary of key findings

The studies presented within this thesis have examined the effects of physical activity on cognitive function, self-control, and resilience in children and adolescents with ADHD. The main findings are summarised below:

8.1.1. Chapter IV

- Via a meta-analytical lens, it was revealed that acute physical activity interventions have a statistically significant small positive effect on cognitive function, specifically in the domains of cognitive flexibility (SMD = 0.18), attention (SMD = 0.20), and inhibitory control (SMD = 0.18). However, memory was not enhanced by acute physical activity (SMD = 0.02).
- Cognitive function is improved following acute physical activity interventions lasting 11-20 minutes (SMD = 0.23) and > 20 minutes (SMD = 0.13) in duration. Physical activity of less than 10 minutes in duration does not improve cognitive function in young people with ADHD (SMD = 0.11).
- Interventions employing running (SMD = 0.21), and 'other' modes of physical activity (including trampolining, exergaming, and coordinative tasks) (SMD = 0.39) had beneficial effects on cognitive function in young people with ADHD, however cycling was not shown to improve cognition (SMD = 0.06).

8.1.2. Chapter V

- Higher levels of cardiorespiratory fitness were associated with enhanced cognitive function, specifically the domains of inhibitory control and attention, in young people with ADHD.
- Young people with ADHD who spent more time spent in vigorous intensity physical activity reported higher self-report trait self-control scores.

- Higher cardiorespiratory fitness tended to be associated with higher self-reported trait resilience in young people with ADHD.

8.1.3. Chapter VI

- Following children focus groups, 2 key themes (task requirements and physical activity benefits; challenges and difficulties) and 9 sub-themes were developed. Parent interviews resulted in 4 key themes (the middle ground, scaffolding, the bigger picture, and treatment strategy rewrite), and 14 sub-themes. The teacher interviews resulted in 4 key themes (engagement in school physical activity, building relationships, the ideal intervention, and setting the standard), and 16 sub-themes.
- Commonalities between key stakeholders (children with ADHD, parents of children with ADHD, and teachers with ADHD) include ensuring that physical activity is continuous (avoiding long stagnant breaks between activities such as trampolining) and developing interventions that include fast-paced, short, and dynamic physical activity (e.g., circuit training or high-intensity interval training). Common findings also highlighted sensory overload as a key consideration and discussed the use of physical active discipline methods in place of current (more sedentary) behavioural management techniques.

8.1.4. Chapter VII

- A 30-minute games-based physical activity intervention did not affect cognitive function, specifically the domains of inhibitory control, attention or working memory in young people with ADHD compared to 30-minute seated rest, immediately or 45-minutes post physical activity/rest.
- 30 minutes of basketball did not affect state self-control immediately after, or 45-minutes post physical activity when compared to 30-minutes of seated rest in young people with ADHD.

- There was no difference in state resilience immediately after- or 45-minutes after a 30-minute physical activity intervention or 30-minute seated rest in young people with ADHD.

8.2. Effects of physical activity and physical fitness on cognitive function in young people with ADHD

The effects of physical activity on different domains of cognitive function were examined meta-analytically (Chapter IV), cross-sectionally (Chapter V), and in response to a 30-minute games-based (basketball) physical activity intervention (Chapter VII). In addition, the effects of physical fitness on cognitive function were measured cross-sectionally (Chapter V). In the experimental studies presented in this thesis, cognitive function (specifically, attention, inhibitory control and working memory) was examined by the Stroop task, Sternberg paradigm, and the Flanker task.

8.2.1. Attention

Acute physical activity has been shown to have a small positive effect on the cognitive function domain of attention in young people with ADHD (Chapter IV). Although the findings in Chapter IV provide critical insights to the current literature via a meta-analytical lens to provide evidence that acute physical activity interventions improve attention in young people with ADHD, findings throughout the remainder of the thesis provide contradictory results. Using the findings provided in Chapter VI, as well as previous literature that has shown improvements in cognition using games-based interventions in neurotypical young people (Cooper et al., 2018; Gilbert et al., 2023), a games-based intervention was examined in Chapter VII. The findings revealed that a 30-minute basketball intervention did not improve attention in young people with ADHD (Chapter VII). A recent intervention examining the effects of an acute endurance, strength or coordination exercises on cognitive function in adolescents found that coordinative tasks (involving ball throwing and catching activities) improved attention in neurotypical adolescents (Altermann & Gröpel, 2023). Although the findings by Altermann and Gröpel (2023) found beneficial effects of coordinative activities on attention compared to a control

condition, coordinative exercises did not improve attention any more than endurance or strength interventions. Furthermore, coordinative exercises in children appear to improve attention, however these effects were only present after 90-minutes after exercise (Schmidt, Egger, & Conzelmann, 2015). It is clear that coordinative tasks involving ball throwing and catching activities have the potential to improve attention in neurotypical young people. However, the reason why these effects did not extend to young people with ADHD in Chapter VII remain unclear. Currently, interventions investigating the effects of coordination exercises in young people with ADHD on attention have focused on longitudinal exercises (Vogt, 2024), therefore further research investigating the effects of games-based coordinative tasks acutely in this population are required.

Daily physical activity was also not found to be associated with attention in young people with ADHD (Chapter V). However, cardiorespiratory fitness was found to be positively and significantly associated with attention (Chapter V), whereby higher cardiorespiratory fitness was positively associated with improved performance on the Stroop and Flanker task (as demonstrated by a lower IES score). In neurotypical young people, higher physical fitness has been shown to be positively associated with attention (Reigal et al., 2020). In neurotypical people, daily physical activity is associated with higher physical fitness implying physical activity and physical fitness are fundamental to each other (Wang, 2019). It may be that although daily physical activity does not improve attention in young people with ADHD, improved physical fitness as a result of daily physical activity may explain why physical fitness was associated with improved attention in this population (Chapter V). Furthermore, previous literature has suggested acute physical activity has the potential to improve attention in young people with ADHD (Chapter IV), however, the present thesis was the first to examine the associations between cardiorespiratory fitness on attention in young people with ADHD. Further research is required to confirm the findings in young people with ADHD.

In summary, the effects of physical activity and physical fitness on the cognitive function domain of attention remain inconclusive. Previous literature has found small

beneficial effects of physical activity on attention in young people with ADHD (Chapter IV), however an acute basketball intervention did not improve attention in this population. Furthermore, cross-sectionally, physical activity was not found to be associated with attention, however cardiorespiratory fitness was found to be positively associated with attention in young people with ADHD. Therefore, further research is required to understand what the optimum dose and modality of physical activity are, and how this subsequently affects fitness, in order to improve attention in this population.

8.2.2. Inhibitory control

Acute physical activity interventions were shown to have a small positive effect on the cognitive function domain of inhibitory control in young people with ADHD (Chapter IV). Although meta-analytically, the effects of physical activity improve inhibitory control. When applying the qualitative recommendations from Chapter VI to develop a basketball intervention it appears that an acute basketball intervention did not improve inhibitory control in young people with ADHD (Chapter VII). Furthermore, chronically, daily physical activity was not associated with inhibitory control in this population (Chapter V). A recent review by Wang et al. (2023), revealed that specific physical activity moderators, that were also identified in the present thesis (e.g., frequent, open-skill physical activity) appear to improve inhibitory control function in young people with ADHD. Wang et al. (2023) suggest that interventions should be at least 60-minutes and implemented twice a week using open-skill exercises that are dynamic to subsequently improve inhibitory control in this population (Zhu et al., 2023). Therefore, with this in mind, the longitudinal effects of a basketball intervention should be examined in young people with ADHD in the future.

Moreover, research investigating the effects of a basketball intervention has been conducted in young people with autism spectrum disorders (Wang et al., 2020; Yang et al., 2021). Wang et al. (2020) conducted a chronic basketball intervention, with 40-minutes of basketball performed 5 times per week, over 12-weeks. It was found that a chronic basketball intervention improved inhibitory control in young people with autism spectrum disorders (Wang et al., 2020). Furthermore, a recent review by Wang et al.

(2023) identified that long-term interventions have significant positive effects on inhibitory control in children with ADHD, whereas the effects of acute physical activity were non-significant. These findings support the lack of improvement in inhibitory control following acute physical activity in Chapter VII. Therefore, this suggests that there may be improvements in inhibitory control following a chronic basketball intervention, as opposed to a single bout of physical activity (Chapter VII). It is recommended that future research investigates the longitudinal effects of a basketball intervention (that incorporates dynamic, open-skill activities) in young people with ADHD to understand the chronic effects of basketball on cognition in this population.

Cross-sectionally, there was no association between daily physical activity and inhibitory control in young people with ADHD, however, cardiorespiratory fitness was shown to be positively associated with inhibitory control in this population (Chapter V). Tsai et al. (2017) also found an association between inhibitory control and physical fitness in young people with ADHD. This is important given that the current thesis investigated cardiorespiratory fitness, whereas the research by Tsai et al. (2017) examined different components of physical fitness; muscular endurance, muscular power and body composition. Furthermore, research by Brassell et al. (2017) found a positive association between physical fitness and inhibitory control in young people 'at risk' of ADHD, whereby those with higher aerobic fitness (measured by the progressive aerobic cardiovascular endurance run) were associated with improved working memory. Thus, the present thesis supports pervious literature in providing further evidence that physical fitness is positively associated with inhibitory control in young people with ADHD.

In summary, acute physical activity interventions have been shown to have a small positive effect on inhibitory control in young people with ADHD (Chapter IV). However, an acute 30-minute basketball intervention did not improve inhibitory control in young people with ADHD. Chronically, physical activity was not positively associated with inhibitory control (Chapter V), however cardiorespiratory fitness was found to be positively associated with inhibitory control in young people with ADHD (Chapter VII). The

longitudinal effects of a basketball intervention should be investigated in young people with ADHD.

8.2.3. Working memory

Working memory has not been shown to be positively affected by acute physical activity interventions (Chapter IV and Chapter VII) in young people with ADHD. Previous literature in neurotypical young people (Álvarez-Bueno et al., 2017; Hsieh et al., 2018), has found beneficial effects of physical activity on working memory, however, the findings in the present thesis indicate that these effects do not extend to young people with ADHD (Chapter VII). In young people with autism, a chronic basketball intervention found improvements in working memory (Wang et al., 2020). Therefore, although an acute bout of basketball does not improve working memory in young people with ADHD (Chapter VII), a basketball intervention implemented over a longer period of time improved working memory in young people with autism, thus suggesting that implementing a basketball intervention longitudinally has the potential to improve working memory in young people with ADHD. It is recommended that future interventions investigate the effects of chronic games-based activities in young people with ADHD.

Daily physical activity was also not associated with working memory in young people with ADHD, nor was cardiorespiratory fitness (Chapter V). Currently, the effects of chronic physical activity interventions on working memory are underrepresented in young people with ADHD, however, a previous review investigating the effects of chronic physical activity interventions on cognition in young people with ADHD found improvements in working memory (Welsch et al., 2021). Specifically, a chronic 12-week physical activity intervention elicited improvements in verbal working memory (measured through the digit span and letter number sequencing task) in young people with ADHD (Ziereis & Jansen, 2015). Ziereis and Jansen (2015) conducted an intervention involving cognitively engaging activities that were both sport specific (e.g., gymnastics) and unspecific (e.g., catching, throwing, balancing). The findings showed positive effects of chronic physical activity on working memory in young people with ADHD (Ziereis &

Jansen, 215). These findings imply that physical activity has the potential to improve working memory in this population, however further research is required to confirm whether a chronic games-based intervention in young people with ADHD could elicit the same effects.

Working memory was not found to be associated with cardiorespiratory fitness (Chapter V) in young people with ADHD. Although the present thesis is the first to examine these associations in young people with ADHD, previous literature has examined the relationship between physical fitness and working memory in adults with ADHD (Ogrodnik et al., 2023). Ogrodnik et al. (2023) found similar results; whereby physical fitness was not found to be associated with working memory in individuals with ADHD. It appears that working memory may be a domain of cognition not affected by physical fitness in young people with ADHD.

In summary, acute physical activity interventions were not shown to improve working memory in young people with ADHD both in a review of the previous literature (Chapter IV) and following an acute physical activity intervention (Chapter VII). Chronically, daily physical activity and cardiorespiratory fitness were not associated with working memory in young people with ADHD, however previous literature has suggested that chronic physical activity interventions improve working memory in this population (Welsch et al., 2021). Regardless of this, the findings in this population are still in its infancy, and it is therefore recommended that future research investigates the chronic effects of physical activity interventions on working memory in young people with ADHD, specifically, interventions should utilise a randomised controlled trial design.

8.2.4. Summary of the effects of physical activity on cognitive function within this thesis

Overall, the findings of this thesis suggest that physical activity and physical fitness have some beneficial effects on or were positively associated with cognitive function in young people with ADHD (Chapter IV and Chapter V). Furthermore, the findings suggest that some of these effects may be domain specific, whereby attention and inhibitory

control are more likely to be affected than working memory. However, the acute effects of physical activity on cognitive function were not evident in Chapter VII, this is potentially due to the duration of physical activity not being long enough. Previous literature has suggested longer durations of physical activity (Wang et al., 2023) are more successful in improving cognition in young people with ADHD. It is therefore recommended that different durations of games-based physical activity should be examined both acutely and chronically in young people with ADHD. Finally, the observed relationships between physical activity and cognitive function could be due to changes in cerebral blood flow (Endres et al., 2003; Swain et al., 2003), brain-derived neurotrophic factor (BDNF) (Piepmeier & Etnier, 2015; Vaynman, Ying, & Gomez-Pinilla, 2004) and cerebral structure (Chaddock, Pontifex, Hillman & Kramer, 2011). However, direct measurement of such mechanisms was beyond the aims and scope of this thesis; thus, further research is required to fully explore these mechanisms.

8.3. Effects of physical activity and physical fitness on self-control in young people with ADHD

In the studies presented in this thesis, self-control was examined both in terms of trait self-control (Chapter V), and state self-control (Chapter VII).

8.3.1. Trait self-control

The current literature has identified reduced trait self-control in young people with ADHD (Bunford et al, 2015), therefore, understanding different factors that may influence trait self-control in this population is important. Physical activity has been identified as a potential intervention strategy to influence self-control in young people with ADHD. The findings within this thesis (Chapter V) demonstrate that a greater amount of time spent in higher intensity physical activity was positively associated with trait self-control in young people with ADHD. This supports the only other study that has examined the associations between physical activity and self-control in young people with ADHD (Barnard-Brak et al., 2011), who also found a positive association between physical activity and self-control in this population. The present thesis built on the research by Barnard-Brak et al. (2011) and

was the first to examine device measured physical activity on self-control in this population, of which previous literature had only examined using self-reported physical activity. Finally, cardiorespiratory fitness was not found to be associated with self-control in young people with ADHD (Chapter V). In neurotypical young people, physical fitness has been shown to be positively associated with self-control (Buck et al. 2008), however, it may be that this was not found in young people with ADHD due to differences in fitness levels between the included participants. Future interventions should investigate differences between physical fitness and self-control levels in young people with and without ADHD.

8.3.2. State self-control

In many situations, young people with ADHD have to use self-control to manage their symptoms and behaviours, which in line with the strength model of self-control (Baumeister et al., 2007), may deplete subsequent state self-control (e.g., using self-control to stop themselves shouting out answers in class). It is therefore of high priority to identify a potential management technique to improve the quality of life for young people with ADHD and negate the negative consequence of ADHD management. The findings of this thesis demonstrate that a 30-minute basketball physical activity intervention did not affect state self-control, immediately or 45-minutes post-activity, compared to a resting control. The reasons as to why physical activity did not improve state self-control in this population remains unclear. However, future physical activity interventions that incorporate more cognitively engaging activities to investigate the impact on self-control in this population (Bedard et al., 2021) would be of value. The incorporation of cognitively engaging tasks would help decipher whether self-control is positively or negatively impacted, and whether cognitively engaging activities should be integrated in future interventions. Furthermore, the research by Bedard et al. (2021) highlighted the importance of cognitively engaging exercise in the development of neural pathways that are associated with cognitive functioning. The present thesis was the first to examine the

acute effects of a games-based physical activity intervention on state self-control in young people with ADHD.

8.3.3. Summary of the effects of physical activity on self-control in young people with ADHD

The findings from the present thesis highlight that increased participation in physical activity (Chapter V) is associated with higher trait self-control in young people with ADHD. Moreover, after applying the findings throughout the chapters presented in this thesis, it was found that an acute basketball intervention did not affect state self-control compared to a resting trial. The chronic effects of a physical activity intervention in this population are yet to be examined, and therefore, it is recommended that the chronic effects of a games-based physical activity intervention on self-control are investigated in young people with ADHD. Finally, cardiorespiratory fitness was not found to be associated with self-control in young people with ADHD, however the research investigating these effects are limited and therefore, future interventions should look longitudinally at the effects of interventions to improve physical fitness and self-control in this population.

8.4. Effects of physical activity and physical fitness on resilience in young people with ADHD

In the studies presented in this thesis, resilience was examined both in terms of trait resilience (Chapter V), and process resilience (Chapter VII).

8.4.1. Trait resilience

Young people with ADHD typically have a similar resilience level to neurotypical young people (Chan et al. 2022). However, young people with ADHD face many different adversities (such as academic difficulties and difficulties maintaining peer relationships; Gardner & Gerdes, 2015), which may affect trait resilience in young people with ADHD, thus requiring a greater level of resilience in this population compared to their neurotypical counterparts. Therefore, finding a method to improve resilience in this population is of interest to enhance the quality of life in young people with ADHD, and to improve the

management of ADHD symptoms and behaviours. The findings within this thesis highlight that there were no associations between daily physical activity and trait resilience in young people with ADHD (Chapter V). To date, only one other study has examined the associations between physical activity and resilience in young people with ADHD (Liang, Qiu, & Sit, 2022). It was found that moderate to vigorous physical activity was positively associated with higher resilience in young people with ADHD. There were no differences between the methods employed in Chapter V, and the research by Liang et al. (2022) aside from the length of the CD-RISC used, therefore further research is required to investigate the effects of chronic physical activity engagement and resilience in a larger sample of young people with ADHD.

The present study also examined the associations between physical fitness and trait resilience, finding a tendency for a positive association between cardiorespiratory fitness and resilience in young people with ADHD (Chapter V). With physical activity being fundamental to higher physical fitness (Blair, Cheng & Holder, 2001), it could be that increasing physical activity and subsequently improving fitness, could have a knock-on effect on resilience in this population. The present thesis was the first to examine the associations between physical fitness and resilience in this population and highlights the potential for a positive association. However, purposeful increased physical activity via a longitudinal physical activity intervention would be of key value in future research designs to employ the valuable findings in this thesis and understand the implications of physical activity on resilience in young people with ADHD. Especially with chronic physical activity interventions having shown to have promising effects on resilience in neurotypical college students (Xu et al., 2021), thus evidencing the importance for further research, even if direct comparisons cannot be made between research with neurotypical young people and research with young people with ADHD.

8.4.2. Resilience as a process

Resilience as a process (state resilience) was measured following an acute basketball intervention. Chapter VII examined the effects of a 30-minute physical activity

intervention on state resilience in young people with ADHD, compared to a resting control condition. The findings from the thesis demonstrate that there was no beneficial effect of 30-minutes of basketball on state resilience immediately after, or 45-minutes after activity, compared to a resting trial. These findings highlight that the acute effects of physical activity do not appear to improve state resilience in young people with ADHD. With the findings from this thesis indicating associations between higher physical fitness and improved trait resilience in this population (Chapter V), it is vital that the optimum dose of acute physical activity on resilience are examined in this population, as well as investigating these effects longitudinally.

8.4.3. Summary of the effects of physical activity and physical fitness on resilience in young people with ADHD

The findings from the present thesis highlight that participation in daily physical activity (Chapter V) was not associated with trait resilience in young people with ADHD, however there was a tendency for physical fitness to be associated with higher trait resilience in this population. Moreover, after applying the findings throughout the chapters presented in this thesis, it was found that an acute basketball intervention did not improve state resilience compared to a resting trial. The chronic effects of a physical activity intervention in this population are yet to be examined, and therefore, it is recommended that the chronic effects of a games-based physical activity intervention on resilience are investigated in young people with ADHD.

8.5. Strengths and limitations of the present thesis

The work presented in this thesis has many strengths. First, the chapters employ methods that provide an ecologically valid approach to research in young people with ADHD; such as using accelerometers to obtain information regarding free-living physical activity, conducting focus groups and interviews with the key stakeholders most likely to experience benefits from a successful physical activity intervention in young people with ADHD (young people with ADHD, parents of young people with ADHD, and teachers of young people with ADHD), and a games-based physical activity intervention conducted

on-site within schools. Although conducting field-based research made it difficult to use laboratory-based measurements (e.g., direct measurement of VO_2 max), field-based alternatives were used (e.g., the multi-stage fitness test). Furthermore, with the lack of research identifying ethically correct methodology surrounding medication use in research with young people with ADHD, the current research requested that participants maintained their normal medication routine to give a representation of the effects of acute physical activity as a conjunctive ADHD treatment; thus, the findings have real-World application.

However, the work presented in this thesis is not without limitations. One of the main limitations was the small sample sizes for Chapter VII. These were due to the challenges encountered with the recruitment and maintenance of young people with ADHD within research, resulting in high drop-out rates and incomplete data. Due to limited data (such as participants who dropped out not providing SWAN ADHD questionnaires), a comparison of characteristics from dropouts between studies, and subsequent effects on the sample could not be analysed. Furthermore, due to the diverse and complex nature of ADHD, in addition to many comorbidities (such as ASD/autism and anxiety; Ercan et al., 2022; Reale et al., 2017), many of the participants in the thesis struggled with sensory issues, which limited the ability to collect more invasive measures of physical activity intensity (e.g., participants refused to wear heart rate monitors). Thus, it would be valuable for future research to identify a method of gathering physical activity intensity that negates the sensory issues often encountered within this population. With such a high number of young people with ADHD having a comorbidity (66%; Reale et al., 2017), any findings within this population and specifically within this thesis, should be considered and interpreted with this in mind. It is important to acknowledge that any comorbidities may have had an impact on the effects of physical activity on cognition, self-control and resilience. However, due to the high percentage of comorbidities associated with ADHD it is important to include young people with ADHD and comorbidities to give the findings greater ecological validity and enable greater applicability for this population.

8.6. Conclusions and practical applications

Throughout this thesis, several patterns have emerged relating to the importance of physical activity and physical fitness for cognitive function, self-control and resilience in young people with ADHD. Specifically, these are:

- *Physical activity type/mode is a significant moderator for improvements in cognitive function in young people with ADHD* (Chapter IV). Specifically, interventions with running, trampolining and exergaming (Chapter IV) significantly improve cognitive function in young people with ADHD. Furthermore, following conversations with key stakeholders (children with ADHD, their parents and their teachers), cognitively engaging activities such as circuit training, that is quick, avoids pauses in activity and has little instructions, should be used in physical activity interventions (Chapter VI).
- *Self-control is positively associated with higher levels of moderate to vigorous physical activity in young people with ADHD.* However, cardiorespiratory fitness was not associated with self-control in this population.
- *A 30-minute basketball physical activity intervention did not improve cognitive function, self-control or resilience in young people with ADHD*, compared to a resting control condition.
- *Young people with ADHD enjoy participating in physical activity that is cognitively engaging, yet simple and avoids stopping and starting.* Successful application of physical activity helps young people with ADHD feel like they have burnt off excess energy and improves post activity concentration (Chapter VI).
- *Parents and teachers should encourage daily physical activity in young people with ADHD to improve management of ADHD behaviours.* Furthermore, increasing physical activity, to subsequently increase physical fitness, could improve cognitive function, self-control, and resilience in young people with ADHD.

- *Teachers should promote active learning in lessons to maintain attention and engagement of young people with ADHD*, with potential interventions such Class PAL (Chapter VI).

8.7. Reflections on conducting research in young people with ADHD in the school setting: lessons learned and recommendations

The following section highlights reflections from working with young people with ADHD from this thesis and provides insights into conducting research with this population. Furthermore, these reflections may provide practical implications for researchers working with young people with ADHD in the future.

- Due to the many challenges faced with high drop-out throughout the different studies presented in this thesis, future research within this population should approach with caution and expect that there will be a high drop-out due to the challenges faced with on task attention in ADHD.
- Furthermore, recruiting young people with ADHD was much more challenging than expected, with barriers to recruitment coming from the schools themselves. It was found that the schools were extremely protective of this population, and due to the extensive planning involved in arranging data collection in schools by school staff, many schools were not able to supply staff and facilities to aid in the planning and execution of testing sessions, and therefore were reluctant to participate.
- A main reflection from the studies presented within this thesis is that when working with young people with ADHD, it is difficult to predict what will happen during data collection sessions. ADHD presentations vary drastically between young people with ADHD, and with multiple comorbidities, and behaviour during sessions could vary day-to-day. This resulted in data collection being, at times, extremely challenging. Specifically, collecting certain types of data proved particularly challenging including collecting detailed, rich quality data from focus groups without using some leading questions, collecting diverse physical activity and physiological measures such as heart-rate data due to sensory issues experienced

by young people with ADHD. Regardless of these challenges, data collection with young people with ADHD was exceptionally rewarding and definitely outweighs any challenges.

- Building positive relationships with young people with ADHD is key to participant engagement, with one such method of building this trust being to hold video calls with participants (in class) prior to testing sessions. Giving facts about the researchers, talking to students about what to expect during the testing sessions, and allowing the young people to ask questions, reduced anxiety and boosted researcher-participant relationships and trust.
- Too collect rich, high quality qualitative data, focus groups should ideally be conducted in small groups (2 or 3 participants) of whom are already acquainted, if possible. This familiarity in participants can encourage more open and fruitful discussions. Furthermore, additional time should be allocated to these focus groups, starting with introductory or "icebreaker" questions to help participants feel comfortable and initiate conversation. It is also important to anticipate that discussions may stray from the original question and thus, in such situations the research should be prepared to gently steer conversation back on track whilst maintaining a natural flow.

8.8. Directions for future research

To develop the knowledge regarding the importance of physical activity and physical fitness for enhancing cognitive function, self-control, and resilience in young people with ADHD, the following suggestions are recommended for future research:

- Investigations that use games-based physical activity, manipulating duration and modality (i.e., circuit style activities or competitive games), and examining how they affect cognitive function, self-control and resilience in young people with ADHD; so that the optimum dose that could be used in the school day can be identified.

- Long-term physical activity interventions that can be implemented into the school day to give familiarity, predictability and routine for young people with ADHD, with a focus on cognitively engaging activities that can be implemented in short doses.
- Key stakeholders should be regularly involved in the development of physical activity interventions, to check for feasibility, validity, enjoyment and engagement. Furthermore, explicit and easy to implement interventions should be developed to assist with implementation.
- The qualitative research (Chapter VI) suggests that future interventions should implement physically active lessons, with key focus on improvements of cognition, self-control, resilience and management of symptoms and behaviours of young people with ADHD. This would allow for easier integration of physical activity interventions into the school day.

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Appendix A.1

Effects of Physical Fitness and Physical Activity levels on Cognitive Function, Self-Control and Resilience in Young People with Attention-Deficit/Hyperactivity Disorder (ADHD) Symptoms and Behaviours.

What is the purpose of this research?

- Previous research has shown that exercise can produce many positive effects on cognitive function in children. However, currently, little is known about the effects of physical activity and physical fitness on cognitive function (the ability to think), self-control (resisting temptation to achieve a goal) and resilience (to positively deal with a setback) in young people with attention-deficit/hyperactivity disorder (ADHD).
- Due to this lack of research, **the purpose of the present research is to examine the effects of physical fitness and physical activity on cognitive function, self-control and resilience in young people with ADHD.**
- We aim to measure this through cognitive function tests, questionnaires and a 'Bleep' test. More information on these measures are discussed below.



What does the study involve?

- The study will involve your child completing a series of computerised cognitive function tests, complete some questionnaires and participate in a multi-stage fitness test. We will also take some simple measures including height, body mass and waist circumference. Your child will be given an accelerometer to measure their physical activity levels over 7 days.
- Your child will also take part in a focus group where we will ask some questions about what types of exercise they like to participate in.
- Parents will also be invited to participate in a single online interview (via Microsoft Teams).








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Information on measurements to be taken:

Cognitive Function Tests:

The cognitive function tests will be conducted on a laptop and will take approximately 12 minutes to complete. The cognitive function tests to be completed include:

- Stroop Test (attention): A word will appear (this word is always a colour) in the centre of a laptop screen. Your child must select the colour the word has been written in rather than the word itself.
- Sternberg Paradigm (working memory): Letters will appear on screen and participants must select whether it is one of their "target" letters (assigned before) by pressing the right arrow key, or whether it is a distractor by pressing the left arrow key.
- Flanker (executive function): Arrows will appear on screen (in groups of 5) and participants must select the direction of the middle arrow.
- Visual Search Test (perception): Triangles will appear on screen with participants pressing the space bar when they see them. On the difficult level, dots will form the triangles amongst a flickering background as a "distractor"







Questionnaires:

During the session your child will be asked to complete questionnaires assessing physical activity, self-control and resilience. All of the questions are designed to be completed by young people and your child will have access to help if they struggle to understand anything and will be able to ask questions at any stage.



Exercise:

Your child will take place in the multi-stage fitness test, also known as the 'bleep' test. The 'Bleep' test is a 20-metre shuttle run performed to the sounds of bleeps on a CD player. The exercise is designed to be physically challenging but when you cannot keep the pace with the bleeps you stop running and walk to cool down. This exercise test is designed to measure your child's physical fitness.



Important Notes:

- While your school has agreed to take part in this study, it is **NOT** compulsory for you to take part.
- Your school has agreed to participate in this project, thus taking time off normal lessons to participate has been cleared with the school.
- You can withdraw at any time without providing a reason and your data will be destroyed.
- Although it is extremely unlikely, high intensity exercise has been known to reveal unsuspected heart or circulation problems and very rarely these have had serious or fatal consequences.
- All staff involved in the study undertake training in the measures involved and undergo a DBS check to clear them to work with children.
- You will be supervised at all times when completing the study and will only leave the testing session once you feel comfortable to do so.
- All information will be stored anonymously, and your individual data will not be reported in the findings of the study.
- The study has been approved by Nottingham Trent University's Ethical Advisory Committee.
- There will be COVID-19 precautions in place to ensure the maximum safety of participants and researchers. These will include research staff wearing face masks and visors. We kindly request that you respect these precautions and abide by social distancing rules.



What is requested of you and your child next?



What to do next?

If you are willing for your child to participate in this study, please complete the enclosed consent form and health screen questionnaire and return them to your child's school as soon as possible.

Contact Details: If you have any questions you wish to ask – please do not hesitate in contacting Elise Sibbick (PhD student), Dr Simon Cooper, Dr Ruth Boat and Dr Mustafa Sarkar on the details below:

Elise Sibbick: elise.sibbick2020@my.ntu.ac.uk

Dr Simon Cooper: simon.cooper@ntu.ac.uk or 01158 488059

Dr Ruth Boat: ruth.boat@ntu.ac.uk or 01158 483596





Appendix A.2

Participant information sheet (Parent/guardian/caregiver and child with ADHD)

Nottingham Trent University

Purpose

Physical activity has been shown to elicit beneficial effects on management of ADHD symptoms and behaviours in young people with ADHD. However, an ideal physical activity intervention is yet to be developed. Our research aims to use practical applications from young people with ADHD, their parents, and teachers, to develop a physical activity intervention that young people with ADHD will enjoy and will ultimately help them manage their symptoms.

What the study involves



The study will involve your child taking part in a short focus group (with 5-10 other children) where they will have the opportunity to discuss their perceptions of physical activity, to tell us about exercises that they enjoy and do not enjoy, and how they think that physical activity helps them concentrate in school.



Additionally, we are inviting parents who have at least one child with ADHD to take part in a face-to-face or an online interview via Microsoft Teams to discuss their perceptions of what types of physical activity help their children and in what ways we can create and develop an effective intervention. This interview should take approximately 1 hour.

Important info

- Both the focus group and interview will be recorded for transcription and analysis purposes and the recording and transcripts will be stored securely and kept confidential.
- While your school has agreed to take part in this study, it is NOT compulsory for you to take part.
- Your school has agreed to participate in this project, thus taking time off in normal lessons to participate has been cleared with the school.
- You can withdraw your and/or your child's data up to two weeks after completing the focus group/interview without providing a reason and your data will be destroyed.
- All staff involved in the study undergo a DBS check to clear them to work with children.
- All information will be stored anonymously, and your individual data will not be identifiable in the findings of the study.
- This study has been approved by Nottingham Trent Non-Invasive Ethical Advisory Committee.

Contact details



If you would like to take part in the face-to-face or online interview, and/or if your child would like to take part in the focus group, please contact the lead researcher Elise Sibbick (elise.sibbick2020@my.ntu.ac.uk), who will send you a consent form to complete and return.
If you have any questions you wish to ask, please do not hesitate to contact Elise Sibbick, Dr Simon Cooper, Dr Ruth Boat, or Dr Mustafa Sarkar on the details below:

Elise Sibbick: elise.sibbick2020@my.ntu.ac.uk
Dr Simon Cooper: simon.cooper@ntu.ac.uk
Dr Ruth Boat: ruth.boat@ntu.ac.uk
Dr Mustafa Sarkar: Mustafa.sarkar@ntu.ac.uk





Appendix A.3

Participant information sheet
(Parent/guardian/caregiver with a child aged 9-15 who has ADHD)

Nottingham Trent University

Purpose

Physical activity has been shown to elicit beneficial effects on management of ADHD symptoms and behaviours in young people with ADHD. However, an ideal physical activity intervention is yet to be developed. Our research aims to use practical applications from young people with ADHD, their parents, and teachers, to develop a physical activity intervention that young people with ADHD will enjoy and will ultimately help them manage their symptoms.

What the study involves



We are inviting parents who have at least one child with ADHD to take part in a face-to-face or an online interview via Microsoft Teams to discuss their perceptions of what types of physical activity help their children and in what ways we can create and develop an effective intervention. This interview should take approximately 1 hour.

Important info

- The interview will be recorded for transcription and analysis purposes and the recording and transcripts will be stored securely and kept confidential.
- You can withdraw your data up to two weeks after completing the interview without providing a reason and your data will be destroyed.
- All information will be stored anonymously, and your individual data will not be identifiable in the findings of the study.
- This study has been approved by Nottingham Trent Non-Invasive Ethical Advisory Committee.

Contact details



If you would like to take part in the face-to-face or online interview, please contact the lead researcher Elise Sibbick (elise.sibbick2020@my.ntu.ac.uk), who will send you a consent form to complete and return.

If you have any questions you wish to ask, please do not hesitate to contact Elise Sibbick, Dr Simon Cooper, Dr Ruth Boat, or Dr Mustafa Sarkar on the details below:

Elise Sibbick: elise.sibbick2020@my.ntu.ac.uk
Dr Simon Cooper: simon.cooper@ntu.ac.uk
Dr Ruth Boat: ruth.boat@ntu.ac.uk
Dr Mustafa Sarkar: Mustafa.sarkar@ntu.ac.uk





Appendix A.4

Participant information sheet (Teachers)

Nottingham Trent University

Purpose

Physical activity has been shown to elicit beneficial effects on management of ADHD symptoms and behaviours in young people with ADHD. However, an ideal physical activity intervention is yet to be developed. Our research aims to use practical applications from young people with ADHD, their parents, and teachers, to develop a physical activity intervention that young people with ADHD will enjoy and will ultimately help them manage their symptoms.

What the study involves



The study will involve teachers taking part in a face-to-face or an online interview via Microsoft teams to investigate their perceptions of how physical activity effects young people with ADHD in the classroom, what types of activities children with ADHD engage in the most, and how a physical activity intervention might fit into the school day.

Important info

- The interview will be recorded for transcription and analysis purposes and the recording and transcripts will be stored securely and kept confidential.
- You can withdraw your data up to two weeks after completing the interview without providing a reason and your data will be destroyed.
- All information will be stored anonymously, and your individual data will not be identifiable in the findings of the study.
- This study has been approved by Nottingham Trent Non-Invasive Ethical Advisory Committee.

Contact details

If you would like to take part in the face-to-face or online interview please contact the lead researcher Elise Sibbick (elise.sibbick2020@my.ntu.ac.uk), who will send you a consent form to complete and return.

If you have any questions you wish to ask, please do not hesitate to contact Elise Sibbick, Dr Simon Cooper, Dr Ruth Boat, or Dr Mustafa Sarkar on the details below:

Elise Sibbick: elise.sibbick2020@my.ntu.ac.uk
Dr Simon Cooper: simon.cooper@ntu.ac.uk
Dr Ruth Boat: ruth.boat@ntu.ac.ukDr
Mustafa Sarkar: Mustafa.sarkar@ntu.ac.uk



Appendix A.5

The effect of an acute games-based physical activity intervention on cognitive function, self-control, and resilience in children and adolescents with ADHD

What does the study involve?

- This study will involve three experimental sessions: a familiarisation (practice) session and two main experimental trials.
- During the familiarisation, we will fully explain all aspects of the study to you, and you will be given a chance to practice all of the measurements involved and ask any questions that you may have. We will also take some simple measures of your height, sitting height, body mass, and skinfolds (a fold of skin measured at 4 different sites: the triceps, supraspinle (above the hip bone), subscapular (below the shoulder blade), and the front thigh.
- On one of the main experimental sessions, you will take part in a 30-minute basketball session, whereas during the other session you will remain in the classroom. Across both of these days you will be required to have the same breakfast before the session, complete some computer-based cognitive function tasks and complete some questionnaires. Don't worry if you do not fully understand these – there is a more detailed explanation of each of the measures below and you will also have a chance to practice all of these in the familiarisation session and you will be able to ask any questions that you may have.



Information on measurements to be taken:



Cognitive Function Tests:

The cognitive function tasks will be conducted on a laptop and take approximately 12 minutes to complete. The set of tasks will include the following;

- ***Stroop Task (attention):*** A word will appear (this word is always a colour) in the centre of a laptop screen. The colour of the font the word is written in will differ to the word itself. You must select the colour the word has been written in rather than the word itself.
- ***Sternberg Paradigm (working memory):*** Letters will appear on screen and participants must select whether it is one of their "target" letters (assigned before) by pressing the right arrow key, or whether it is a distractor by pressing the left arrow key.
- ***Flanker (executive function):*** Arrows will appear on screen (in groups of 5) and participants must select the direction of the middle arrow.
- ***Visual Search Test (perception):*** Triangles will appear on screen with participants pressing the space bar when they see them. On the difficult level, dots will form the triangles amongst a flickering background serving as a "distractor".

Questionnaires:

During the study you will be asked to complete four questionnaires assessing mood, self-control, resilience, and physical activity. Each of these questionnaires require you answering some questions regarding how you feel at that point in time or your activities over the last week/month. All of the questionnaires are designed to be completed by young people and you will get an opportunity to practice them during the familiarisation.

Exercise:

1. The 'Bleep' test is a 20-metre shuttle run performed to the sound of bleeps from a CD player. The exercise is designed to be physically challenging but when you cannot keep pace with the bleeps you stop running and walk to cool down.

2. The basketball session will be 30 minutes and will involve a warm-up, some skill-based drills, and small sided games (e.g., 2 vs. 2, 3 vs. 3 etc.).



Important Notes:

- While your school has agreed to take part in this study, it is **NOT** compulsory for you to take part.
- Your school has agreed to participate in this project, thus taking time off normal lessons to participate has been cleared with the school.
- If at any point you decide to withdraw from the study, your data will be destroyed.
- Although it is extremely unlikely, high intensity exercise has been known to reveal unsuspected heart or circulation problems and very rarely these have had serious or fatal consequences.
- All staff involved in the study undertake training in the measures involved and undergo a DBS check to clear them to work with children.
- You will be supervised at all times when completing the study and will only leave the testing session once you feel comfortable to do so.
- All information will be stored anonymously, and your individual data will not be reported in the findings of the study.
- The study has been approved by Nottingham Trent University's Ethical Advisory Committee.
- We will follow the government, university, and your schools COVID-19 precautions.





Why should I take part?

- You will get the opportunity to contribute towards the understanding of how physical activity can help young people with ADHD.
- You will get to work with sport scientists from Nottingham Trent University and will have the opportunity to ask questions about sport science, university, and how to conduct research.

Finally, you will get to take part in a fun research study!



What is requested of you and your child next?



What to do next?

If you are willing for your child to participate in this study, **please complete the enclosed consent form and health screen questionnaire and return them to your child's school as soon as possible.**

Contact Details: If you have any questions you wish to ask - please do not hesitate in contacting Elise Sibbick, Dr Simon Cooper, Dr Ruth Boat, or Dr Mustafa Sarkar on the details below:

Elise Sibbick: elise.sibbick2020@my.ntu.ac.uk or 07896318614
Dr Simon Cooper: simon.cooper@ntu.ac.uk or 01158 488059
Dr Ruth Boat: ruth.boat@ntu.ac.uk or 01158 483596
Dr Mustafa Sarkar: Mustafa.sarkar@ntu.ac.uk or 01158 486359

Appendix B

Parent/Guardian/Caregiver Statement of Consent for Child/Dependent to Participate in the Investigation Entitled:

Effects of Physical Fitness and Physical Activity levels on Cognitive Function, Self-Control and Resilience in young people with ADHD symptoms and behaviours.

1) I, (*name of parent/guardian)* agree for my child/dependent, *(name of child) to* partake as a participant in the above study.

2) I understand from the participant information sheet, which I have read in full, and from my discussion(s) with *Dr Simon Cooper* that this will involve my child/dependent *participating in a familiarisation trial whereby body mass and height will be taken, they will be given an accelerometer to wear, and have an opportunity to practice the battery of cognitive function tests. They will then attend an experimental trial whereby they will complete a battery of cognitive tests, complete a series of questionnaires, participate in a multi-stage fitness test and participate in a focus group. The sessions will last no longer than a total of 4 hours (including the familiarisation trial).*

3) It has also been explained to me by *Dr Simon Cooper* that the risks and side effects that may result from my child/dependent's participation are as follows: *maximal exercise may cause delayed onset muscle soreness however, in active individuals the risks are minimal and all individuals who wish to take part in this study will complete a health history questionnaire beforehand which will be thoroughly checked by the lead investigator.*

4) I confirm that the study has been explained to my child/dependent and that I and my child/dependent have had the opportunity to ask questions about the study. Where we have asked questions, these have been answered to our satisfaction.

5) I undertake to abide by University regulations and the advice of researchers regarding safety.

6) I am aware that I can withdraw my consent for my child/dependent to participate in the procedure at any time and for any reason, without having to explain my withdrawal and their personal data will be destroyed.

7) I understand that any personal information regarding my child/dependent, gained through their participation in this study, will be treated as confidential and only handled by individuals relevant to the performance of the study and the storing of information thereafter. Where information concerning my child/dependent appears within published material, their identity will be kept anonymous.

8) I confirm that I have had the University's policy relating to the storage and subsequent destruction of sensitive information explained to me. I understand that sensitive information provided through my child/dependent's participation in this study, in the form of *consent forms, health screens, questionnaires, anthropometric measures (height, sitting height, body mass and waist circumference), exercise performance and cognitive function test data* will be handled in accordance with this policy.

11) I confirm that I have completed the health questionnaire and know of no reason, medical or otherwise that would prevent my child/dependent from partaking in this research.

12) It has been explained to me that there may be additional risks arising from the current COVID pandemic. I h*ave read the NTU recommendations for* undertaking 'Research with human

participants' and undertake to encourage my child/dependent to abide by the special measures w*hich have been explained to me for this study* together with such Government Guidelines that are at the time prevailing. I and my child/dependant have had the opportunity to ask questions about these precautions and where we have asked questions, they have been answered to our satisfaction.

Parent/Guardian signature: ……..**Date**: …….

Contact number: ……

Email address: ……

Appendix C

Health screen

Childs name .....

Please complete this brief questionnaire to confirm your child's fitness to participate:

1. **At present,** does your child have any health problem for which they are:

(a) on medication, prescribed or otherwise Yes ☐ No ☐

(b) attending your general practitioner Yes ☐ No ☐

(c) on a hospital waiting list Yes ☐ No ☐

2. **In the past two years,** has your child had any illness which required them to:

(a) consult your GP Yes ☐ No ☐

(b) attend a hospital outpatient department Yes ☐ No ☐

(c) be admitted to hospital Yes ☐ No ☐

3. **Has your child ever** had any of the following?

(a) Convulsions/epilepsy Yes ☐ No ☐

(b) Asthma Yes ☐ No ☐

(c) Eczema Yes ☐ No ☐

(d) Diabetes Yes ☐ No ☐

(e) A blood disorder Yes ☐ No ☐

(f) Head injury Yes ☐ No ☐

(g) Digestive problems Yes ☐ No ☐

(h) Heart problems Yes ☐ No ☐

(i) Problems with bones or joints Yes ☐ No ☐

(j) Disturbance of balance / coordination Yes ☐ No ☐

(k) Numbness in hands or feet Yes ☐ No ☐

(l) Disturbance of vision Yes ☐ No ☐

(m) Ear / hearing problems Yes ☐ No ☐

(n) Thyroid problems Yes ☐ No ☐

(o) Kidney or liver problems Yes ☐ No ☐

(p) Allergy to nuts, alcohol etc. Yes ☐ No ☐

(q) Any problems affecting your nose e.g. recurrent nose bleeds Yes ☐ No ☐

(r) Any nasal fracture or deviated nasal septum Yes ☐ No ☐

4. **Has any,** otherwise healthy, member of your family under the age of 50 died suddenly during or soon after exercise? Yes ☐ No ☐

5. Are there any reasons why blood sampling may be difficult? Yes ☐ No ☐

6. Has your child had a blood sample taken previously? Yes ☐ No ☐

7. Has your child had a cold, flu or any flu like symptoms in the last month? Yes ☐ No ☐

8. Has your child ever been diagnosed with Coronavirus (COVID-19)? Yes ☐ No ☐

If you answered **YES** to question 8, please answer the following questions.

(a) How was this diagnosis confirmed? . . . . . .

(b) Was your child hospitalised? Yes ☐ No ☐

(c) What was the date of your child's diagnosis? . . . . . .

(d) What was the duration of your child's illness? . . . . . .

(e) Is you child currently free from COVID-19 symptoms (unexplained fever, dry continuous cough, sudden loss of taste or smell)? Yes ☐

No ☐

Please provide details of any medications that you child is currently taking, including the dosage, frequency and type:

……

……

……

……

Appendix D

Brief Self-Control Scale

Using the scale provided, please indicate how much each of the following statements reflects how you ***typically are in school lessons***. Please circle your answer.

	Not at all				Very much
I am good at resisting temptation	1	2	3	4	5
I have a hard time breaking bad habits	1	2	3	4	5
I am lazy	1	2	3	4	5
I say inappropriate things	1	2	3	4	5
I do certain things that are bad for me, if they are fun	1	2	3	4	5
I wish I had more self-discipline	1	2	3	4	5
Pleasure and fun sometimes keep me from getting my school work done	1	2	3	4	5
I have trouble concentrating	1	2	3	4	5
I am able to work effectively toward long-term goals	1	2	3	4	5
Sometimes I can't stop myself from doing something, even if I know it's wrong	1	2	3	4	5
I often act without thinking through all the alternatives	1	2	3	4	5
I refuse things that are bad for me	1	2	3	4	5
People would say that I have strong self-discipline	1	2	3	4	5

Appendix E

Adapted Brief Self-Control Scale

Using the scale provided, please indicate how much each of the following statements reflects how you ***are right now***. Please circle your answer.

	Not at all				Very much
I feel like I can resist a temptation	1	2	3	4	5
I feel like doing something I know I shouldn't	1	2	3	4	5
I am feeling lazy	1	2	3	4	5
I feel like saying inappropriate things	1	2	3	4	5
I feel like doing certain things that are bad for me because they are fun	1	2	3	4	5
I wish I had more self-discipline	1	2	3	4	5
I would rather do fun things than my work	1	2	3	4	5
I do not feel like I can concentrate	1	2	3	4	5
I feel like I can work on tasks that I know I need to get done	1	2	3	4	5
I can't stop myself from doing something, even if I know it's wrong	1	2	3	4	5
I would act without thinking through all the alternatives	1	2	3	4	5
I feel like I could refuse things that are bad for me	1	2	3	4	5
People would say that I have strong self-discipline at the moment	1	2	3	4	5

Appendix F

Connor-Davidson Resilience Scale 10

(CD-RISC 10)

Name: ID code: Date:

Please indicate by ticking the relevant box about how much you agree with the following statements as they apply to you over the last month. If a particular situation has not occurred recently, answer according to how you think you would have felt.

	0 - Not true at all	1 - Rarely true	2 - Sometimes true	3 - Often true	4 - True nearly all the time
1. I am able to change the way I behave when new things happen.					
2. I can deal with whatever comes my way.					
3. I try to see the funny side of things when I am faced with problems.					
4. Having to cope with stress can make me stronger.					
5. I tend to bounce back after illness, injury, or other difficult situations.					
6. I believe I can achieve my goals, even if there are things that get in my way.					
7. Under pressure, I stay focused and think clearly.					
8. I am not easily put off by failure.					
9. I think of myself as a strong person when dealing with life's challenges and difficulties.					
10. I am able to deal with painful feelings like sadness, fear, and anger.					

Appendix G

Adapted Connor-Davidson Resilience Scale 10

(CD-RISC 10)

Name: ID code: Date:

*Please indicate by ticking the relevant box about how much you agree with the following statements as they apply to **how you are feeling right now**.*

	0 - Not true at all	1 - Rarely true	2 - Sometimes true	3 - Often true	4 - True nearly all the time
11. I feel like I could change the way I behave if new things were going to happen.					
12. I could deal with whatever comes my way.					
13. I could see the funny side of things if I was faced with problems.					
14. If I had to deal with stress right now, it would make me stronger.					
15. I feel like I would cope well with difficult situations at the moment (for example, if I had to do an exam).					
16. I believe I could achieve my goals right now, even if there were things that got in my way.					
17. If I was under pressure, I could stay focused and think clearly.					
18. I would not easily be put off by failure right now.					
19. Right now, I think of myself as a strong person if I had to deal with life's challenges and difficulties.					
20. I could deal with painful feelings like sadness, fear, and anger at the moment.					

Appendix H

Physical Activity Questionnaire – Children version

Name: ID code: Date:

We are trying to find out about your level of physical activity from the last 7 days (in the last week). This includes activities that make you sweat, make you breathe heavily or make your legs feel tired (e.g., running, swimming, football, rugby, basketball, dancing or tennis).

Remember:

1. There are no right or wrong answers – this is not a test.
2. Please answer all of the questions honestly and accurately as you can – this is very important.
3. Please only tick one box per question unless specified otherwise.

1. In the last 7 days, during your physical education (PE) classes, how often were you very active (playing hard, running, jumping, throwing)?	
I don't do P.E.	
Hardly ever	
Sometimes	
Quite often	
Always	
2. In the last 7 days, what did you do most of the time on your break?	
Sat down (talking, reading, doing schoolwork)	
Stood around or walked around	
Ran or played a little bit	
Ran around and played quite a bit	
Ran and played hard most of the time	
3. In the last 7 days, what did you normally do at lunch (besides eating lunch)?	
Sat down (talking, reading, doing schoolwork)	
Stood around or walked around	
Ran or played a little bit	
Ran around and played quite a bit	
Ran and played hard most of the time	
4. In the last 7 days, on how many days *right after school*, did you do sport, dance or play games in which you were very active?	
None	
1 time last week	
2 or 3 times last week	
4 times last week	
5 times last week	
5. In the last 7 days, on how many *evenings* did you do sports, dance or play games in which you were very active?	
None	
1 time last week	

2 or 3 times last week	
4 or 5 times last week	
6 or 7 times last week	
6. On the *last weekend*, how many times did you do sports, dance, or play games in which you were very active?	
None	
1 time	
2-3 times	
4-5 times	
6 or more times	
7. Which one of the following describes you best for the last 7 days? (Read all five statements before deciding on the one answer that describes you)	
All or most of my time was spent doing things that involve little physical effort.	
I sometimes (1-2 times last week) did physical things in my free time (e.g., played sports, went running, swimming, bike riding, did aerobics).	
I often (3-4 times last week) did physical things in my free time.	
I quite often (5-6 times last week) did physical things in my free time.	
I very often (7 or more times last week) did physical things in my free time.	

8. Mark how often you did physical activity (like playing sports, games, doing dance, or any other physical activity) for each day last week.

	none	Little bit	medium	often	Very often
Monday					
Tuesday					
Wednesday					
Thursday					
Friday					
Saturday					
Sunday					

9. What are the three most common sports you take part in every week? (list below)

Appendix I

SNAP questionnaire

Child's name: _____ Gender: _____ Age: _____
Completed by: _____ (circle one) Parent Teacher Physician
Date Completed: _____

For each item, check the column that best describes this child over the past six months.

	Not at all	Just a little	Quite a bit	Very much
1. Gives close attention to detail and avoids careless mistakes	____	____	____	____
2. Sustains attention on tasks or play activities	____	____	____	____
3. Listens when spoken to directly	____	____	____	____
4. Follows through on instructions and finishes school work and chores	____	____	____	____
5. Organizes tasks and activities	____	____	____	____
6. Engages in tasks that require sustained mental effort	____	____	____	____
7. Keeps track of things necessary for activities (doesn't lose them)	____	____	____	____
8. Ignores extraneous stimuli	____	____	____	____
9. Remembers daily activities	____	____	____	____
10. Sits still (controls movement of hands or feet or controls squirming)	____	____	____	____
11. Stays seated (when required by class rules or social conventions)	____	____	____	____
12. Modulates motor activity (inhibits inappropriate running or climbing)	____	____	____	____
13. Plays quietly (keeps noise level reasonable)	____	____	____	____
14. Settles down and rests (controls constant activity)	____	____	____	____
15. Modulates verbal activity (controls excessive talking)	____	____	____	____
16. Reflects on questions (controls blurting out answers)	____	____	____	____
17. Awaits turn (stands in line and takes turns)	____	____	____	____
18. Enters into conversation and games without interrupting or intruding	____	____	____	____

Scoring Section: For each question, place a 1 next to the question number below if the response was "not at all" or "just a little" and a 0 if the response was "quite a bit" or "very much".

Appendix J

Understanding the perceptions of physical activity in young people with ADHD and how it affects their cognition, self-control, and resilience.

Focus groups with children

Key questions are highlighted in bold font

Questions	Probes
1. Tell me about your experiences of doing P.E. and physical activity…	Positive experiences Negative experiences *Probe for specific examples*
2. **How do you feel about physical activity?**	What is it about physical activity that makes you feel that way? How does physical activity make you feel good? How does physical activity make you feel bad? 'Yes'-What do you enjoy most about physical activity? E.g. Why? 'No'- what do you not enjoy about exercise? E.g. Why?
3. If you could pick two or three emojis to represent how physical activity makes you feel, what would they be?	Why those emojis? What do those emojis represent to you?
4. Based on those emojis, tell me in more detail how physical activity makes you feel?	Can you give some examples of how it makes you feel? When does exercise make you feel good/bad? How does exercise make you feel good/bad?
5. How do you feel in your lessons after doing P.E?	Can you give an example of when physical activity helped you feel more focused? Do you think you get less distracted after doing physical activity? Why do you think that is?
6. **How does physical activity effect your focus in lessons?**	How does physical activity effect your concentration?

(SELF-CONTROL)	How do you act in situations following physical activity (how do you think through alternative actions and responses)? (Question tapping into self-control)
7. **How does physical activity effect your performance on tasks in lessons?** **(COGNITIVE FUNCTION)**	What are the similarities and differences before and following physical activity? (Question tapping into cognition)
8. **How do you deal with difficult or challenging situations after exercise?** **(RESILIENCE)**	What are the similarities or differences to how you deal with situations before physical activity? (Question tapping into resilience)
9. What is your favourite activity that you do in P.E. lessons?	Can you give examples of why it is your favourite? What is it about that activity that you enjoy most? How does that activity make you feel? How does that activity make you feel compared to other activities that you do in P.E. lessons?
10. What is your least favourite activity that you do in P.E. lessons?	e.g. Why? What is it about the activity that you do not enjoy? What could be changed about the exercise to make it more enjoyable? Is there anything about the activity that you do enjoy (if so, what is it and why do you enjoy that aspect?)?
11. If you could do any sport in P.E. what would it be and why?	Type (individual/ teams; competitive/fun) Time of day? Inside/outside How often do you like to do P.E.

Appendix K

Appendix 1c: Emoji sheet for children focus groups



Appendix L

Appendix 1a: Parent Interviews

Key questions are highlighted in red bold font

Section 1: General discussion about what types of physical activity your child currently participates in.

Questions	Probes
1. In a normal week, what physical activity does your child do?	• Duration • Intensity • Inside/outside school • Time • Type
2. A. How much physical activity does your child participate in? **B. When does your child participate in physical activity?**	• School time • Afterschool • Afternoon • Evening • What time of day do you think they are most engaged in physical activity?
3. What are the similarities and differences in your child's physical activity pre-post covid?	• More/less? • Why do you think that's the case? • Individual vs team • Sport vs recreational

Section 2: Your child's perceptions of physical activity.

4. What do you think your child's views of physical activity are?	• Why do you think that your child enjoys/does not enjoy PA? • What aspects of physical activity does your child enjoy/ not enjoy?
5. What type of physical activity does your child engage in outside of school?	• E.g. • Why do you think they engage in this more? • Team/individual? Or competitive/fun

	• If none, why do you think that is? • What do you think would make them engage more?
6. What types of physical activity does your child enjoy most outside of school?	• Why that type compared to other types (give examples)? • If they had more access, what other types of activities do you think they would like to do?

Section 3: Your child's symptoms and behaviours following physical activity.

7. How does your child think after physical activity? Do they think differently before/after physical activity?	• E.g. • Does physical activity affect how your child controls their actions? • **Do you think your child is better at thinking through alternative options in situations? (self-control)** • **How does your child deal with challenges, difficulties, or setbacks after physical activity? (resilience)** • **Are there any similarities/differences before or after physical activity?** • Does physical activity affect your child's concentration on tasks?
8. How does your child feel after physical activity?	• What positive feelings do you think they have? • What negative feelings do you think they have?
9. How does your child behave after physical activity?	• Impulsivity • Quieter/inattentive • Aggression • Subdued • Energy levels
10. How do your child's ADHD symptoms present after physical activity?	• Better or worse?

	• Less symptoms?
11. What differences, if any, do you notice **after school** when your child has taken part in physical activity or P.E. at school?	• Better management of behaviours • Can concentrate more?
12. Have you noticed any exercises that 'trigger' your child's ADHD symptoms when exercising?	• More impulsive behaviours? • Team vs individual • Competitive vs non-competitive
13. Do you participate in any physical activity with your child?	• If so, what? • If no, would you like to?

Section 4: Physical activity intervention planning

14. If we developed a physical activity intervention to help young people with ADHD to manage their symptoms and behaviours, what would it 'look like' to you?	• Inside or outside • Competitive or non-competitive • Physical activity or sport • Individual or team • Aerobic, muscular strength or flexibility • Timing/scheduling • Location
15. What activities would your child be most likely to engage in?	• Type • Modality • Team vs individual • Short activities over longer time or long activities in short time • Sport/competitive games vs recreational/sport orientated activities
16. What do you think would help make the intervention effective?	• Advice • What have you found works best for engagement in activities? • Routine? • Regularity

Appendix M

Appendix 1d: Teacher interviews (Key questions in red bold font)

Section 1: Experiences of teaching

Questions	Probes
1. Tell me about your experiences of teaching young people with ADHD…	• What age group • Only ADHD students or ADHD integrated into mainstream classroom • Good experiences • Bad experiences

Section 2: P.E. lessons at school

2. How does physical activity usually fit into the school day?	• How many P.E lessons a week • How long do they typically last? • What types of activities do you do? • Sport or physical activity based? • Regular or ad-hoc?
3. How do the children with ADHD engage in the P.E. lessons?	• Are there sports they do not engage in? • Sports they do engage in? • Do they engage for the entire lesson? • How long before they lose concentration?

Section 3: Presentation of ADHD symptoms and behaviours and physical activity impact

4. How do ADHD symptoms present in young people with ADHD during P.E lessons?	• Impulsive behaviours? • Inattentive – lack concentration • What type of symptoms? • How do ADHD symptoms present in young people with ADHD after extracurricular afterschool physical activity?

5. Are there any activities that 'trigger' ADHD symptoms and behaviours?	• Can you give examples? • What types? • Why do you think that is the case?
6. What activities do you think 'lessen' ADHD symptoms and behaviours?	• Aerobic, muscular strength, flexibility • Examples • Why do you think that these help the symptoms?
7. How do the children with ADHD think following physical activity?	• Listening • Concentration • Performance on tasks • Working with others • How do you think children deal with challenges, difficulties and setbacks after physical activity? (resilience) • How do you think children focus on tasks and concentrate on tasks following physical activity? (cognitive function) • How do you think children control their actions (e.g., thinking through all options) following physical activity? (self-control)
8. How do you think children with ADHD feel following physical activity?	• What positive feelings do you think they have? • What negative feelings do you think they have? • Do you think they are more in control of their actions?
9. How do you think children with ADHD behave following physical activity?	• Impulsivity • Quieter/inattentive • Aggression • Subdued • Energy levels

Section 4: Teacher-student relationship and relationship with physical activity

10. How do you think ADHD symptoms and behaviours that are not well managed affects the teacher-student relationship?	• Is there any difference between those on medication and unmedicated after physical activity? • Good/positive experiences

	• Bad/negative experiences
11. Following from this, do you think that physical activity affects the teacher-student relationship?	• How does it affect the relationship? • Aid or hinder?

Section 5: Physical activity intervention planning

12. If we develop a physical activity intervention to help young people with ADHD manage their symptoms and behaviours, what would it 'look like' to you?	• What types of activities • Inside or outside • Competitive or non-competitive • Physical activity or sport • Individual or team • Aerobic, muscular strength or flexibility • What would work well for all types of ADHD?
13. What would children enjoy most to encourage engagement?	• Type • Modality • Team vs individual • Short activities over longer time or long activities in short time • Sport/competitive games vs recreational/sport orientated activities
14. What do you think would help make the intervention effective?	• Advice • What have you found works best for engagement in activities? • Routine? • Regularity
15. How would a physical activity intervention fit into the school day?	• Could it be integrated into day-to-day running of a school day? • What time would be best…morning or afternoon/lunchtime • Would it need to be tied in with medication effectiveness? • If so, what about children not on medication.

Appendix N

Visual Analogue Scale (VAS scale) for happiness, energy, tiredness, attention, calmness, and concentration

Name:

Date:

Trial:

Place a mark on the line below to indicate your current level of happiness:

Happiness

Not happy _____ Very happy

Place a mark on the line below to indicate your current energy level:

Energy

Low energy _____ Lots of energy

Place a mark on the line below to indicate your current level of tiredness:

Tiredness

Not tired at all _____ Very tired

Place a mark on the line below to indicate your current level of attention:

Attention

Low attention _____ Good attention

Place a mark on the line below to indicate your current level of calmness:

Calmness

Not calm _____ Very calm

Place a mark on the line below to indicate your current level of concentration:

Concentration

Low concentration _____ Good concentration