Associations Between Physical Activity and ADHD in Adults: Investigating Determinants of Behaviour, Challenges, and Considerations for Implementation

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Rory Luke Tucker, BSc (Hons)

Department of Psychology

Swansea University

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Declarations

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed: Rory Tucker

Date: 02/06/2025

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

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Abstract

Physical Activity (PA) and/or Physical Exercise (PE), is increasingly being considered as an adjunct/alternative treatment for Attention Deficit Hyperactive disorder (ADHD). Emerging evidence suggests that PA/PE may help alleviate ADHD symptoms, but most research has focused on children and males, leaving adults underrepresented. This thesis addressed this gap by investigating the associations between physical activity and ADHD in Adults. A cross-sectional study (Chapter Two) found no significant overall negative relationship between PA and total ADHD symptomatology, but results varied by ADHD subtype and demographics. The correlation was significant in subclinical ADHD and female groups, and for the general sample for specific subsets of PA (PE) and ADHD symptomatology (inattentive ADHD). To address specificity issues around measuring motivation, Chapter Three adopted a Self Determination Theory perspective, also investigating links with Exercise Dependence (ED). ADHD was associated with reduced intrinsic PE motivation (particularly inattentive ADHD) and increased ED (particularly hyperactive ADHD). Chapter Four explored barriers to PE, finding that adults with subclinical ADHD experienced greater levels of specific barriers - Motivation; Beliefs about Capabilities; Skills; Emotion; Action planning; Coping planning; Goal conflict, and Social) - than non-ADHD adults. To investigate how PE interventions might overcome these barriers, Chapter Five investigated the effects of a home-based PE intervention on executive functions linked to ADHD. Limited effectiveness was found, possibly due to a lack of power and experimental control. Overall, these findings suggest that ADHD is associated with reduced PE; reduced intrinsic PE motivation; increased ED risk and increased barriers to PE. These findings can help inform and optimise PE-based interventions by promoting intrinsic motivation; targeting specific PE barriers; controlling and monitoring risk factors for ED; and prioritising certain treatment for symptom presentations/populations. This work adds to the growing body of research on PA on ADHD, offering insights for PE-based treatment design and implementation.

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Abbreviations

ADHD	Attention Deficit Hyperactivity Disorder
ADHD-H	Hyperactive Attention Deficit Hyperactivity Disorder Symptomatology
ADHD-I	Inattentive Attention Deficit Hyperactivity Disorder Symptomatology
ADHD-RS-IV	ADHD Rating Scale – IV with adult prompts
ADHD-T	Total Attention Deficit Hyperactivity Disorder Symptomatology
ASD	Autism Spectrum Disorder
ASRS	Adult ADHD Self Report Scale
BDNF	Brain-Derived Neurotrophic Factor
BREQ-3	Behavioural Regulation in Exercise Questionnaire – version 3
CBT	Cognitive Behavioural Therapy
DA	Dopamine
DE	Determinants of Exercise
DPAQ	Determinants of Physical Activity Questionnaire
DSM	Diagnostic and Statistical Manual of Mental Disorders
EA	Exercise Addition
ED	Exercise Dependence
EDS-R	Exercise Dependence Scale – Revised
EDS-T	Exercise Dependence Score-Total
EF	Executive Function
FA	False Alarm
FTMS	Failure To Maintain Set
ICD	International Classification of Diseases
IGF-1	Insulin-like Growth Factor – 1
IPAQ-L	International Physical Activity Questionnaire – Long Format
MET	Metabolic Equivalents
MRI	Magnetic Resonance Imaging
MRT	Mean Reaction Time
NHS	National Health Service
NICE	National Institute for Health and Care Excellence

PA	Physical Activity
PANAS	Positive and Negative Affect Schedule
PE	Physical Exercise
PVQ-II	Personal Values Questionnaire II
PVQ-S	Motivation Strength
PVQ-T	Motivation Type
RAI	Relative Autonomy Index
ROA	Reductions in Other Activities
SDT	Self Determination Theory
Sub-ADHD	Subclinical-ADHD
Sub-Combined	Subclinical Combined ADHD
Sub-Hyperactive	Subclinical Hyperactive ADHD
Sub-Inattentive	Subclinical Inattentive ADHD
TDF	Theoretical Domains Framework
TFE	Total Forms of Exercise
TNC	Total Number of Comorbidities
$\dot{V}O_{2peak}$	Peak Oxygen Consumption
WCST	Wisconsin Card Sorting Task

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1. Chapter One: Introduction and Literature Review

1.1. Chapter Overview

This chapter will begin by providing an overview of Attention Deficit/Hyperactive disorder (ADHD), its characteristics, prevalence, burden and current available treatments. It will then provide an overview of Physical Activity (PA), its definitions and research concerning its effects and current use as a treatment. The current literature and research regarding the effects of PA on ADHD symptoms will then be explored, while also highlighting the limitations and gaps of that existing research. The nature and implications of these limitations/gaps will then be discussed further. Finally, the overall aims of the thesis will be explained. In summary, the aim of this chapter is to provide an understanding of the key concepts explored in this thesis, an overview of what is already known about the thesis subject, and the key research aims of the following chapters.

1.2. General Introduction

ADHD is a common neurodevelopmental disorder (American Psychiatric Association, 2013) with a global prevalence of around 5.9-7.1% in children and adolescents, and around 5% in adults (Willcutt, 2012). It imposes a significant burden on individuals, affecting their daily functioning and financial stability (Fredriksen et al., 2014; Pitts et al., 2015). On a societal scale, ADHD contributes to increased healthcare costs and loss of productivity (Doshi et al., 2012). Therefore, developing effective treatments and interventions to reduce and effectively manage ADHD symptoms is important. Current approaches primarily involve pharmacological treatments, such as methylphenidates and amphetamines (Wigal, 2009). However, nonpharmacological treatments have also garnered attention, with PA emerging as a promising adjunct therapeutic option for reducing ADHD symptoms in children (Archer & Kostrzewa, 2012; Den Heijer et al., 2017; Neudecker et al., 2019;

Vysniauske et al., 2020). However, significant gaps exist in the literature base, particularly regarding the interaction of different outcome variables, specific forms of Physical Exercise (PE), and potential differences across demographic groups. Notably, little research has explored the use of PE for ADHD symptom management in adults, highlighting the need for further investigation in this area.

1.3. Attention Deficit Hyperactivity Disorder

1.3.1. Characteristics and Diagnosis

ADHD is a neurodevelopmental disorder characterised by a persistent pattern of inattention and/or hyperactivity to the point that it interferes with development or functioning (American Psychiatric Association, 2013). It encompasses a range of cognitive, social and mood-related symptoms that affect multiple areas of an individual's life (Fredriksen et al., 2014; Pitts et al., 2015).

ADHD is typically characterised by patterns of inattention, hyperactivity/impulsivity, or a combination of both (American Psychiatric Association, 2013). Patterns of inattention often express as difficulty focusing, sustaining attention, staying organised, remembering tasks, and being easily distracted (American Psychiatric Association, 2013; McGough, 2014). Importantly, these behaviours are not due to a lack of comprehension or defiance. In contrast, patterns of hyperactivity are often expressed by poor behavioural inhibition, fidgeting, restlessness and poor patience. Similarly, patterns of impulsivity are marked by difficulties in delaying gratification, which may be expressed as social intrusiveness and difficulties with poor long-term planning (American Psychiatric Association, 2013; McGough, 2014).

The DSM-5 (Diagnostic and Statistical Manual of Mental Disorders – Fifth Edition) diagnoses ADHD using five criteria (A – E). Criterion A is split into two subsections - inattentive symptoms, and hyperactive symptoms – with each listing nine specific symptoms (e.g. “Often has difficulty sustaining attention in tasks or play activities”). To qualify for each subsection under Criterion A, an individual must display six out of the nine symptoms over the past six months. The remaining criterion are as follows: criterion B – several symptoms must have been present before the age of 12; criterion C – several symptoms must be present in two or more settings (e.g. home, school, work); criterion D – the symptoms must interfere with social, academic, or occupational functioning; criterion E – the symptoms cannot be better explained by another mental disorder. An individual must meet all five criteria (A, B, C, D, E) to be diagnosed with ADHD. Based on the presentation and composition of criterion A symptoms, three forms/types of ADHD can occur, namely: (1) predominantly inattentive (criterion A1 is met, but not A2); (2) predominantly hyperactive (criterion A2 is met, but not A1), and (3) combined presentation (both criterion A1 and A2 are met). However, as the symptoms of ADHD can change over time, so can its presentation (Biederman et al., 2000; Willcutt, 2012). Likewise, the severity of particular symptoms can be assessed and categorised into three levels: (1) mild, (2) moderate, and (3) severe.

In contrast to the DSM-5, ADHD was not recognised as a distinct condition in the Classification of Diseases (ICD) until the publication of ICD-11 (International Classification of Diseases) (World Health Organization, 2019). In ICD – 10 (World Health Organization, 2016), ADHD was considered a Hyperkinetic Disorder, which differed significantly from DSM-5 criteria (both impaired attention [equivalent to inattentive symptoms] and overactivity [equivalent to hyperactivity symptoms] had to be present). Now, the ICD-11 aligns more closely with DSM-5, now recognising ADHD as a distinct condition with three different presentations similar to those in the DSM-5. However, unlike DSM-5, the ICD-11 does not specify the exact number of symptoms needed to reach clinical threshold, instead referring to the presence of “several” symptoms (World Health Organization, 2019). Comparisons of the diagnostic criteria for ADHD are shown in Table 1.

Table 1

Diagnostic Criteria for ADHD Across DSM-5, ICD-10 and ICD-11

	DSM-5	ICD-10	ICD-11
Name	ADHD	Hyperkinetic Disorder	ADHD
Characterisation	A persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development	A lack of persistence in activities that require cognitive involvement, and a tendency to move from one activity to another without completing any one, together with disorganized, ill-regulated, and excessive activity	A persistent pattern (at least 6 months) of inattention and/or hyperactivity-impulsivity that has a direct negative impact on academic, occupational or social functioning
Onset	Several symptoms before age 12	Some symptoms before age 6	Significant symptoms before age 12
Criteria	Combined: 6-9 symptoms of inattention and hyperactivity in children (5-9 in adults); Predominantly inattentive/ hyperactive: 6-9 symptoms of inattention or hyperactivity respectively (5-9 in adults)	Must have a significant combination of impaired attention and hyperactivity	Combined: both inattentive and hyperactive symptoms significant, with neither dominating the presentation; predominantly inattentive/ hyperactive: inattentive/ hyperactive symptoms are predominant in presentation over the other.
Duration	6 months or more	6 months or more	6 months or more

1.3.2. Historical Approaches and Perspectives

Historical descriptions of symptoms consistent with ADHD date back to the 18th century, with medical classifications evolving over time, from *"minimal brain dysfunction"* in the DSM-I (1952), *"hyperkinetic reaction of childhood"* in the DSM-II (1968), *"attention deficit disorder with or without hyperactivity"* in the DSM-III (1980);, and then *"attention deficit hyperactivity disorder"* in the DSM-III-R (1987) (Centers for Disease Control and Prevention, 2024; Lange et al., 2010). As the conceptualisation of ADHD has changed, so too have research perspectives and approaches.

A key distinction is whether to conceptualise ADHD as a categorical disorder - a disorder that is qualitatively different from the normal range of expression in the population, and those with the disorder differ in degree and kind) or as a dimensional disorder (that a disorder is only an extreme expression of normal variation in the population, and those with the disorder differ only in degree but not kind). Traditionally ADHD has been conceptualised more as a categorical disorder (Sonuga-Barke et al., 2023) but there is a growing support for dimensional models (Coghill & Sonuga-Barke, 2012; Marcus & Barry, 2011; Sprafkin et al., 2016). While both DSM-5 and ICD-11 classify ADHD as a categorical disorder, more recent research exploring the latent structure of ADHD favours dimensional models (Coghill & Sonuga-Barke, 2012; Marcus & Barry, 2011; Posner et al., 2020). This shift also aligns with broader neurodiversity perspectives, where some conditions like ADHD, Autism Spectrum Disorder [ASD], and OCD are viewed as part of a neurodivergent continuum (as opposed to "neurotypicality"), rather than objective pathologies (Caviola et al., 2024; Grummt, 2024).

Whether ADHD is categorical or dimensional is a consideration for broader approaches/theories to understanding ADHD. Amnie (2022) identified several prominent models/theories, summarised in Table 2, which broadly span a spectrum from Biological/Medical to more Social/Cultural approaches. More biological/medical approaches, such as the Bio-Medical Model, view ADHD as a biologically-based disorder, focussing on underlying biological dysfunctions and typically advocating for pharmaceutical based treatments. Conversely, social/cultural approaches focus on social and environmental factors (e.g., behavioural reinforcement, environmental stressors (favouring non-pharmaceutical interventions).

However, a perspective that challenges the classification of ADHD is a medical disorder is the Social Construct Theory, alongside the growing neurodiversity movement, mentioned above (Banaschewski et al., 2023; Grummt, 2024; Mather, 2012; Wright, 2012). This approach argues that ADHD, among other diagnoses such as ASD and OCD, are not pathological but are an expression of a broad spectrum of neurocognitive variance (labelled as neurodiversity). The classifications and diagnoses of individuals who lay at extreme ends of such spectrums (considered to be "neurodivergent") are then considered to be social constructs. This links with arguments around over-medicalisation (Bergey, 2024; Davies, 2021; Grummt, 2024; Wechuli, 2023; Wright, 2012) where non-pathological behaviours that are not considered to be socially acceptable/productive are medicalised, and existing treatments are focused around enabling neurodivergent individuals to fit the needs of society (Davies, 2021; Wechuli, 2023), rather than wider society making accommodations to support neurodiverse individuals. Framing ADHD as a negative pathology can also lead to stigma and reduced self-esteem among those diagnosed (Mather, 2012). An important aspect of the neurodiversity perspective is that neurodivergent individuals also experience and possesses various strengths, which are often overlooked when they are viewed as having a disorder. In the case of ADHD, strengths have been framed in areas such as determination, resilience, multitasking, creativity, hyper-focus (Hotte-Meunier et al., 2024; Mather, 2012; Maw et al., 2024). Adopting a strength-based approach – reframing ADHD as difference with various strengths and positives instead of a negative disorder – may help reduce stigma, promote greater societal acceptance, and encourage the use of neurodivergent strengths for broader societal benefits (Hotte-Meunier et al., 2024; Mather, 2012; Maw et al., 2024).

Table 2

Selected Models and Theories of ADHD

Model/ Theory	Major Descriptions	Reference
Bio-Medical Model	Disability problem of ADHD framed as being within the individual. Treatment is based around medical professionals utilising medications.	Talbot et al. (2012)
Bio-Psycho-Social Model	Development of ADHD is seen through an interaction of biological, psychological and social factors.	Wade and Halligan (2017)
State Regulation Model	Children with ADHD are considered to have difficulty keeping an optimal activation state for elementary cognitive stages.	Johnson et al. (2009)
Executive Dysfunction Model	ADHD symptoms are viewed as being wholly a result of deficiencies in executive control, due to structural, functional and chemical abnormalities in the brain.	Johnson et al. (2009)
Delay Aversion Theory	Suggests children with ADHD are impulsive only in situations where doing so leads to reduced delays.	Johnson et al. (2009)
Dynamic Developmental Theory	Suggests that ADHD manifests due to altered reinforcement of novel behaviour. Socially desirable behaviour is nor reinforced in time due to a shorter window of opportunity.	Johnson et al. (2009)
Social Construct Theory	Suggests that ADHD is not a disorder, but that an ADHD diagnosis is a socially constructed explanation used to describe behaviours that fall outside of prescribed social norms	Mather (2012); Timimi and Taylor (2004)

Note. Adapted from Amnie (2022).

For the purposes of this thesis, a predominantly medical perspective is adopted, focussing on whether PA could be utilised as a potential treatment/intervention for individuals with ADHD. This is because even though several strengths have been associated with ADHD (Hotte-Meunier et al., 2024; Mather, 2012; Maw et al., 2024), many individuals with the condition perceive it as a burden, with many symptoms often leading to lifelong impairments and difficulties (explored further in section 1.3.5.). Many individuals with ADHD also express a desire for treatments/interventions, with some expressing interest in PA based interventions specifically (Cochrane et al., 2022). Additionally, interventions for the alleviation of symptoms are not mutually exclusive with societal/workplace accommodations (Chandra, 2015; Nelson, 2021). Any suggestions for potential interventions for ADHD symptoms from this thesis should not eclipse potential accommodations for ADHD. Information and findings of this thesis should also be taken with consideration for other approaches, and with awareness that individuals with ADHD have a varied range of views on how they view their condition.

1.3.3. Prevalence and Influence

ADHD is a common condition observed across different ages, countries and gender, with a global prevalence rate of approximately 5.9-7.1% in children and adolescents and around 5% in adults (Willcutt, 2012). Conforming with the DSM-5 assessment of ADHD, the three different presentations of ADHD (inattentive, hyperactive, combined) also differ in prevalence. Typically, the combined presentation is the most frequently diagnosed, accounting for 61% of cases in children and adolescents (Faraone et al., 1998) and 62% in adults (Wilens et al., 2009). The predominantly inattentive presentation has a rate of 30% amongst children and adolescents, and 31% amongst adults. In contrast, the predominantly hyperactive presentation is least common, occurring in 9% of children and adolescents and 7% of adults.

The higher reported rates of the combined presentation could be due to referral patterns, with individuals meeting the combined criteria more likely to be referred for diagnosis (Willcutt, 2012), particularly in school settings. Indeed, inattention alone may be less disruptive and thus more likely to go unnoticed by teachers (Quinn & Madhoo, 2014).

This referral bias is supported by findings from community-based studies, reporting that the inattentive subtype is the most common subtype (Froehlich et al., 2007; Graetz et al., 2005; Wolraich et al., 1996). Conversely, more clinic-based studies (Biederman et al., 2005) tend to report higher rates of the combined presentation (Ramtekkar et al., 2010). Indeed, a meta-analysis of 97 studies (Willcutt, 2012), found that predominantly inattentive presentation was the most common subtype over a lifetime, except in children aged 3-5 years, where other subtypes may be more noticeable.

It is also important to note that while ADHD affects individuals across all cultures, ages, and genders, these same factors may also influence reported prevalence rates – albeit the extent and causes of this reported variance remains a topic of debate. For instance, research studies have identified differences in the prevalence of ADHD across countries (Fayyad et al., 2017; Polanczyk et al., 2007). However, further analysis of this observed effect suggests that geographic location and culture may not be the primary explanation, but rather methodological differences in how studies have measured prevalence (Polanczyk et al., 2007). Additionally, there is also evidence to suggest that prevalence rates differ by income levels, with higher prevalence rates reported in high (3.6%) and upper-middle (3%) income countries, compared to low/lower-middle (1.4%) income countries (Fayyad et al., 2017). This seemingly conflicts with research suggesting a higher prevalence of ADHD in lower socioeconomic status populations compared to higher socioeconomic status populations in the same country (Rowland et al., 2018). One possible explanation is that in lower-income countries, inattention and hyperactivity might be less impairing in their societal and environmental context, resulting in fewer reported cases (Fayyad et al., 2017). Alternatively, while there may be a negative correlation between ADHD prevalence and socioeconomic status, higher income countries may have more resources and better diagnostic services, leading to a higher observed prevalence rate due to increased identification and diagnosis.

The prevalence of ADHD also varies significantly according to age, with higher rates reported in children (6-7%) than adults (5%) (Willcutt, 2012). The persistence rate of ADHD from childhood into adulthood is around 65%, with similar persistence rates observed across genders (Faraone, Biederman, & Mick, 2006). Moreover, symptoms of ADHD evolve over time, with hyperactive/impulsive symptoms declining at a higher rate than inattentive symptoms (Biederman et al., 2000). Indeed, the presentation of ADHD appears to change with age and fluctuate across the lifespan, although research in this area remains somewhat limited (Willcutt, 2012). For example, in pre-school, children may present as predominantly hyperactive-impulsive (ADHD-H) but later shift to ADHD-C early in elementary school. This shift is theorised to result from increased attentional demands in school, making their inattention symptoms more noticeable and impairing. Consequently, the prevalence of ADHD-C rises, while the prevalence of ADHD-H declines. Then, as inattention symptoms remain relatively stable across development, whereas hyperactivity-impulsivity symptoms decline with age, individuals who initially meet criteria for ADHD-C in early childhood may also shift to ADHD-I in adolescence and adulthood, where their hyperactivity-impulsivity symptoms decline below the diagnostic threshold (Willcutt et al., 2012). Thus, such changes illustrate the dynamic nature of ADHD presentations over the lifespan.

A possible reason for the lower rates of ADHD found among adults is the historical perspective of ADHD as a "Childhood disorder", where it was considered to be very rare in adulthood, with a very low persistence rate from childhood into adulthood (Hill & Schoener, 1996). However, later research suggests that the persistence rate is much higher (Faraone, Biederman, & Mick, 2006; Fayyad et al., 2017), possibly due to earlier research taking an overly restrictive criterion for persistence, focussing solely on syndromatic persistence (i.e., meeting full diagnostic criteria) and overlooking cases of symptomatic persistence (i.e., partial diagnostic status with impairment). Despite this, the pervasive bias that adult ADHD is extremely rare may cause some clinicians to approach adult ADHD diagnoses with scepticism, potentially leading to underdiagnosis (Faraone, Biederman, & Mick, 2006).

Additionally, ADHD is found to be more frequent in males than females (Nøvik et al., 2006; Willcutt, 2012). For example, the European ADORE (Attention-Deficit Hyperactivity Disorder Observational Research in Europe) study (Nøvik et al., 2006) analysed 1478 children across ten European countries and found that gender ratios varied from 1:3 to 1:16 (females to males). However, this male predominance in diagnosis rates has been shown to decrease with age, with a meta-analysis finding that the ratio (females:males) decreased from 1:2.3 in children aged 6-12 years to 1:1.6 in individuals aged 19 years and older (Willcutt, 2012).

Even so, whilst there is some uncertainty regarding how age interacts with gender in the expression and incidence of ADHD, it is also worth recognising how rates of ADHD in females may be under-reported (Berry et al., 1985; Quinn & Madhoo, 2014; Young et al., 2020). A literature review by Quinn and Madhoo (2014) analysed 41 articles and found that females with ADHD may simply be better at developing coping strategies that help mask their symptoms and may also have different comorbidities that may lead to missed or misdiagnoses. For instance, females with ADHD are more likely to internalise their symptoms, experiencing more anxiety, depression and emotional dysregulation than men (Robison et al., 2008). In turn, this internalisation can make their ADHD symptoms less overt, potentially leading them to be overlooked (Quinn & Madhoo, 2014). Support for this comes from studies using population-based samples, which report a more even prevalence ratio between males and females compared to studies using clinical samples, where referral bias may play a stronger role (Ramtekkar et al., 2010). Further, research also indicates that girls are proportionally more likely than boys to present with the inattentive presentation (Biederman et al., 2002; Newcorn et al., 2001; Willcutt, 2012). This has been suggested as a possible reason for the lower observed prevalence rate in girls (Biederman et al., 2002), as those who meet the criteria for only inattentive or hyperactive symptoms may be less likely to be diagnosed than those with the combined presentation (Willcutt, 2012). However, conflicting research has found no significant difference in ADHD presentation between boys and girls (Nøvik et al., 2006). Moreover, evidence suggests that gender-related differences in presentation may diminish with age and post adolescence (Biederman et al., 2004). In a seven-year matched case-control study involving 219 adults with ADHD and 215 without, Biederman et al., (2004) found that gender did not moderate the association between ADHD and phenotypic presentation of the disorder. In fact, the number of ADHD symptoms, and the distribution of symptom clusters of inattention, impulsivity and hyperactivity, was found to be highly similar between genders. Naturally, if differences in ADHD presentations between boys and girls reduce with age, this could explain the decreasing disparity in overall diagnosed prevalence rates between genders as they grow older. That is, the parallel reduction in presentation differences may align with the narrowing gap in ADHD prevalence rates. The underdiagnosis of females with ADHD can lead to long-lasting consequences into adulthood for women with undiagnosed ADHD, such as significant negative impacts on emotional wellbeing, the ability to form/maintain relationships, and feelings of control (Attoe & Climie, 2023).

It is also important to note gender variance – defined as a wish to be a gender different to that assigned at birth - is significantly more common among children with ADHD than controls (6.64 times more likely) (Strang et al., 2014). Additionally, gender variance has also be linked with elevated symptoms of ADHD (Strang et al., 2014). Despite these findings though, there is limited research exploring the prevalence rates and differences in symptomatology between gender conforming individuals and those with gender variance. Most prevalence studies limit the measurement of gender to male and female (binary categories) without including other options and identities (e.g. non-binary) or possible links between ADHD and gender transition.

Although difficult to estimate, research suggests that ADHD is underdiagnosed overall (ADHD UK, 2023; Rowland et al., 2015). Individuals with undiagnosed or subclinical ADHD are still shown to experience significant functional impairments (Able et al., 2007; Balázs & Keresztény, 2014) highlighting the importance for further research on these groups in relation to preventative interventions (Balázs & Keresztény, 2014).

1.3.4. Comorbidities

ADHD in adults is associated with high rates comorbidity (Kooij et al., 2019), with a lifetime comorbidity rate estimated at 60-80% (Fayyad et al., 2017). This is significantly higher than in the general population, with one study reporting a prevalence rate of 77.1% in adults with ADHD compared to 45.7% in a control group (Sobanski et al., 2007). The specific comorbid conditions vary depending on factors such as age, ADHD subtype, and gender. Despite this, the most common psychiatric comorbidities amongst individuals with ADHD include: mood disorders (45%); impulse control/personality disorders (e.g., antisocial and borderline personality disorders, conduct disorder) (70%); anxiety disorders (59%); sleep disorders (23%); learning disorders (56%), and substance use disorders (36%) (Kooij et al., 2012; Reale et al., 2017). A meta-analysis by Nazar et al., (2016) also found an increased risk of all major eating disorders - Bulimia Nervosa, Anorexia Nervosa and binge eating disorder - amongst individuals with ADHD. More recently, increasing research is showing high comorbidity rates with ASD as the DSM-5 has now permitted clinicians to make an ADHD diagnosis in the context of ASD – something not accepted previously. Approximately 13% of youth with ADHD also have ASD (Zablotsky et al., 2020), and ADHD is the most common comorbidity for ASD, with comorbidity rates ranging from 40-70% (Joshi et al., 2014, 2017;

Kaat et al., 2013; Salazar et al., 2015). In addition to psychological comorbidities, ADHD is also associated with increased levels of physical disability (Vogel et al., 2018).

Comorbidity rates also vary across ADHD subtypes, with a large population study of twins in Sweden (n= 17,899) finding lower risks of generalised anxiety disorder and major depression for the hyperactive subtype of ADHD (2.16% and 1.43% respectively), compared to combined (5.6% and 3.03%) and inattentive (5.98% and 3.47%) (Friedrichs et al., 2012). Additionally, studies have also found that those with combined subtype appear to experience more severe comorbid symptoms (Wilens et al., 2009) and higher rates of specific disorders, than those with inattentive subtype, shown below in Table 3.

Table 3

Comorbidity Rates Split by ADHD Subtype

Comorbidity	Combined	Hyperactive	Inattentive
Conduct disorder	36%	0%	12%
Antisocial disorder	23%	12%	6%
Bipolar disorder	23%	15%	6%
Psychosis	15%	25%	0%
Substance dependence	30%	38%	12%

Note. Adapted from Sprafkin et al., (2007).

Comorbidity rates have also been found to vary over the lifespan, with adults with ADHD typically having higher comorbidity rates than children (Choi et al., 2022). The patterns of comorbidities also change, with oppositional defiant disorder and conduct disorder typically being found to be the most prevalent comorbidity in children but in adults substance use disorders become more prevalent during adolescence and adulthood (Franke et al., 2018; Taurines et al., 2010).

Additionally, the effect of gender on comorbidities in ADHD remains uncertain. Some research has found that women have higher rates of affective disorders and eating disorders, while men have higher rates of dyslexia, alcohol dependence, substance abuse and dependence (Anker et al., 2018; Rasmussen & Levander, 2009). However, other research has found no gender differences in the prevalence of comorbid alcohol dependence, bipolar disorder, generalised anxiety disorder, obsessive compulsive disorder (Friedrichs et al., 2012), or eating disorders (Nazar et al., 2016).

1.3.5. Burden

The consequences of ADHD include significant impairments and burdens on personal, community and societal levels. On a personal level, individuals with ADHD suffer from functional impairments that impact several areas of their life (American Psychiatric Association, 2013),affecting social, educational, and work performance on top of additional economic burdens (Fredriksen et al., 2014; Pitts et al., 2015; Ramos Olazagasti et al., 2013). For example, functional impairments typically include poorer academic performance in children, and poorer occupational performance in adults (Fredriksen et al., 2014; Pitts et al., 2015). ADHD is also associated with social difficulties, where children with ADHD often struggle to retain friendships (Caci et al., 2014), while adults find developing and retaining relationships more difficult (Pitts et al., 2015). Risk taking behaviour is also increased across the lifetime. One study (Sørensen et al., 2017) found that children with ADHD showed significantly poorer risk adjustment and more delay-aversion compared to controls, suggesting that ADHD may lead to poorer responses to changing probabilities of success rather than simply being more risk prone.

Regardless though, this functional impairment persists into adulthood and can contribute to poorer life outcomes such as higher rates of criminal behaviour and incarceration in adults with ADHD compared to those without (Pitts et al., 2015; Ramos

Olazagasti et al., 2013). Risk taking, and poor organisational skills can lead to difficulties managing personal finances, where adults with ADHD are more likely to be in debt; have a poor credit rating; have difficulty saving money and managing personal finances; to miss important payments (rent, bills); and to purchase things on impulse (Pitts et al., 2015). Alongside other factors like increased health care costs and lower income, this means individuals with ADHD have significant financial burdens, coming to an average annual cost of €16-23,000 for adults with ADHD in Denmark (Jennum et al., 2020). Functional impairments also lead to poorer health outcomes, with individuals with ADHD having higher injuries and hospitalizations (Fleming et al., 2017); six times the rate of completed suicide to typically developing individuals (Septier et al., 2019); and an overall decrease in estimated life expectancy (Barkley & Fischer, 2019). All this contributes to individuals with ADHD having reduced quality of life compared to typically developing peers (Y. Lee et al., 2016).

ADHD impairments also impact the families of individuals with ADHD, with parents of children with ADHD experiencing a deficit in quality of life (Dey et al., 2019) and increased financial burden (Doshi et al., 2012) compared to parents with typically developing children. The increased financial burden of family members with ADHD also includes partners (Jennum et al., 2020) and children of individuals with ADHD (Doshi et al., 2012). Financial costs of ADHD also extend to national scales, due to healthcare costs, reduced productivity, specialist education and other costs associated, ADHD leads to significant national costs. In the European Union, using the Netherlands as a reference case, the total national annual cost as a result of ADHD ranged from €1,041 – €1,529 million (Le et al., 2014).

1.3.6. Aetiology and Pathophysiology

While the precise mechanisms underlying ADHD symptoms – such as neurological dysfunction, particularly around the processes related to dopamine (DA) - are generally understood, the exact causes of the condition are less clear. Current research and understanding highlights an interplay between genetic and environmental risk factors in its development.

Aetiology

Evidence for a genetic link in ADHD is well-established. Pooled data from 20 twin studies conducted across the United States, European Union, Scandinavia and Australia, estimate the mean heritability of ADHD to be approximately 76% (Faraone et al., 2005). This makes ADHD to be one of the most heritable psychiatric conditions, comparable in heritability to height (McGough, 2014). While exact causal genes have not been identified, several candidate genes have been found to be associated with ADHD. However, the absence of a clear genetic cause and variation in heritability rates suggests that genetics alone cannot fully explain the condition.

Environmental risk factors have also been found to be linked with the development of ADHD and symptom severity. These include prenatal, family, socioeconomic and other environmental factors. A longitudinal study in Quebec (Galéra et al., 2011), which analysed data from 2057 children between the ages of five months and eight years, identified early risk factors for development of ADHD symptoms, including premature birth, low birth weight, and prenatal tobacco exposure. Family-based factors, including family discord, family size, abuse, and maternal mental illness, have also been linked to ADHD symptom development, though are thought to exacerbate symptom severity rather than as direct causes. Conversely, other environmental factors, like lead exposure (Daneshparvar et al., 2016; Donzelli et al., 2019), have shown stronger evidence of a causal role. Further, even though claims that sugar and certain food additives may also be associated with ADHD have frequently been made (McGough, 2014), substantial evidence in support is lacking.

Subsequently, a growing perspective suggests that ADHD may result from gene-environment interactions. While individual genetic nor environmental risk factors have not been identified as definitive causes, genetic predispositions may increase susceptibility to ADHD when combined with environmental risk factors (Faraone & Mick, 2010). For example, the seven-repeat of the DRD4 exon III VNTR or the 10-repeat of the SCL6A3 3' UTR VNTR, have been associated with increased expression of combined presentation ADHD, but only in children exposed to maternal smoking during pregnancy (Neuman et al., 2007). Thus, it is likely that such complex genetic and environmental interactions contribute to the biological/neurological differences observed in those with ADHD.

Pathophysiology

The pathophysiology of ADHD has been identified as a combination of structural, functional and neurotransmitter alterations in certain brain regions. Various neuroimaging techniques have revealed structural abnormalities in ADHD brains compared to controls (Qiu et al., 2011; Spencer et al., 2007). Broad findings include a volume reduction in white matter (leading to reduced connectivity) and brain volume in general (Qiu et al., 2011), as well as specific decreases in the frontal cortex, cerebellum, and subcortical structures (Spencer et al., 2007). Longitudinal studies also suggest that some structural differences in ADHD may be characterised as developmental delays (Shaw et al., 2007), as individuals with ADHD show patterns of cortical maturation parallel to controls but delayed by approximately three years, suggesting that structural effects are non-progressive and stable over time. However, it should be noted that despite significant and measurable differences in brain structure and function between ADHD groups and controls, brain imaging is not considered an appropriate tool for the purpose of diagnosis (McGough, 2014).

ADHD has also been linked to the dysfunction and dysregulation of neurotransmitters/neurotransmission symptoms important for various Executive Functions (EF) and reward functions. Perhaps the most important is the differences in dopaminergic system (linked to mediation of cognitive, motor, attentional, emotional, and reward processes) (Del Campo et al., 2011; Speranza et al., 2021) with studies finding reduced DA binding and DA transporter molecules in some areas of the brain (Volkow et al., 2007, 2009). ADHD is also associated with dysregulation in the noradrenergic system (linked with working memory, arousal and alertness processes) (Arnsten & Pliszka, 2011; Del Campo et al., 2011), with reduced noradrenaline transporter availability in various brain regions (Rosa-Neto et al., 2005). Positron Emission Tomography scans have also been used to show that ADHD leads to disturbances in norepinephrine and serotonin (Riikonen et al., 2005; Sigurdardottir et al., 2016) that are linked with cognitive functions such as attention function (Moriguchi et al., 2017) and memory (Yasuno et al., 2003) respectively. To a lesser extent, ADHD has also been associated with the dysregulation of the serotonergic, glutamatergic and GABAergic systems leading to functional impairments in sleep, emotional, behavioural and motor regulation (B. S. da Silva et al., 2023). Dysregulation of these key neurotransmission systems in individuals with ADHD, leads to executive dysfunction and motivational deficits/dysregulation, which in turn lead to the expression of ADHD symptoms (Tripp & Wickens, 2009). Executive Dysfunction in ADHD is displayed through deficits in several key EF domains such as response inhibition, working memory and planning (Willcutt et al., 2005). Likewise, dysregulation of reward and arousal processes can lead to motivational deficits and dysfunction for individuals with ADHD (Modesto-Lowe et al., 2013) through altered sensitivity to reward/punishment and difficulty regulating arousal state (Sergeant, 2000, 2005). Using the Self Determination Theory (SDT) (a motivational framework, conceptualising motivation on a continuum from extrinsic motivations to intrinsic motivations), it has been suggested that dysregulation of neurotransmission systems leads to individuals with ADHD having dysregulated or abnormal intrinsic motivation, particularly for uninteresting tasks (Morsink et al., 2022).

These structural and neurochemical differences also affect various brain networks, leading to further functional differences. This can be expressed in significant overactivation of networks, such as the visual, dorsal attention and default mode networks, and the under activation of others, such as the frontoparietal network (Cortese et al., 2012). The dual pathway model of ADHD suggests that impairments to prefrontal-striatal networks contribute to inattentive symptoms, whereas impairments to fronto-limbic networks contribute to the hyperactive symptoms (Purper-Ouakil et al., 2011).

The causes and psychophysiology of ADHD are therefore highly complex and interconnected. As a result, effective treatment and management of the disorder needs to address these multifaceted aspects rather than be reduced to only tackling one aspect or component, to achieve meaningful outcomes.

1.3.7. Treatments

Treatment of ADHD can involve either pharmacological (e.g., stimulant or non-stimulant medication) or non-pharmacological therapies (e.g., behavioural therapy, digital based training, psychoeducation) or a combination of the two (Faraone et al., 2021; Peterson et al., 2024). Pharmacological treatments typically come in the form of either stimulants (e.g., methylphenidates, amphetamines) and non-stimulants (e.g. atomoxetine, guanfacine), with stimulants being the generally preferred type (Wigal, 2009). The effect of stimulants is to increase the concentrations of DA and norepinephrine, which are typically disrupted in individuals with ADHD and linked to executive dysfunction (see section 1.3.6.) (B. S. da Silva et al., 2023). For instance, methylphenidate and amphetamines inhibit the reuptake of

DA (Faraone, 2018; Zimmer, 2017). They are found to be highly effective in reducing ADHD symptoms, with methylphenidate found to have the best benefit-to-risk ratios for children and adolescents, compared with amphetamines for adults (Cortese et al., 2018). Non-stimulant medications, in contrast, work through various modes of action such as norepinephrine reuptake (atomoxetine) (Sauer et al., 2005), or by decreasing sympathetic nervous system activity (Boellner et al., 2007). Overall stimulants are generally found to be more effective than non-stimulants, but also have an increased risk to be diverted, misused and/or abused (Faraone et al., 2021).

While effective, pharmacological treatments are associated with various side effects that can potentially contribute to negative long-term effects (Wigal, 2009). These can include short-term side effects such as increased adverse cardiovascular events, increased blood pressure (U.S. Food and Drug Administration, 2018), difficulty sleeping (Cortese et al., 2013), and decreased appetite and increased suicidal ideation (Wigal, 2009). Potential long-term effects can include growth retardation (Faraone et al., 2005, 2008; Swanson et al., 2007) and an increased risk of drug misuse and dependence (McGough, 2014). However, some research suggests untreated ADHD is itself associated with higher rates of drug and substance misuse, and the use of pharmacological treatments may reduce or have no significant effect on this risk (Kooij et al., 2019).

The effectiveness of medication can also vary based on individual differences, and clinicians are advised to tailor the prescription of any medication based on the needs of each individual patient (NICE, 2018). Overall, pharmacological treatments are considered to be significantly more efficacious than placebos (Boland et al., 2020; Castells et al., 2020; Faraone, Biederman, Spencer, et al., 2006; Wigal, 2009). Generally, stimulants have also been found to have greater effect sizes than nonstimulants (Faraone, Biederman, Spencer, et al., 2006; Moriyama et al., 2013). However, firm comparisons between different pharmacological treatments are hard to make due to the limited research into nonstimulants (Moriyama et al., 2013) and inconsistencies in study designs and outcome measures (Faraone, Biederman, Spencer, et al., 2006). Furthermore, evidence suggests that the effectiveness of pharmacological treatments decreases over time, with effect sizes decreasing after 14 – 24 months (Goode et al., 2018; J. Parker et al., 2013). Additionally, 10 – 30% of those with ADHD may not respond to stimulants or may be unable to tolerate the side effects (Banaschewski et al., 2004) (e.g., headaches, lack of appetite) (Mohammadi & Akhondzadeh, 2007). Discontinuation rates are also high, particularly among adults (79.7%) compared to children (48.8%) and adolescents (72.1%) (De Crescenzo et al., 2017). This suggests that while pharmacological treatments are relatively effective for many, they have limitations in long-term efficacy and symptom management. While pharmacological medications are typically recommended by National Institute for Health and Care Excellence (NICE) guidelines as a first-line treatments for adults with ADHD, due to the uncertainty over the long-term effects of medication in growing children, they are only recommended for children in severe cases (particularly for children under five years old) (NICE, 2018).

Non-pharmacological treatments, while less commonly used and studied (De Crescenzo et al., 2017), offer alternative options for managing ADHD. These primarily include behavioural therapies and psychoeducation. Behavioural therapies can include parent or class led interventions, Cognitive Behavioural Therapy (CBT), neurofeedback (Kemper et al., 2018) and cognitive training (Scionti et al., 2020). Evidence of efficacy is varied, with small reductions in parent-reported ADHD symptoms but not independently assessed ADHD symptoms found for parent training (Rimestad et al., 2019); associations with small to moderate improvements in ADHD symptoms and functions for CBT (Knouse et al., 2017); and small to moderate improvements to EF for cognitive training (Scionti et al., 2020). In contrast, Psychoeducation focusses on providing information about ADHD, its symptoms and management, to both people with the disorder and those who interact with them closely (e.g., family) (Ferrin et al., 2014). Evidence of efficacy is mixed, with it generally being suggested as a complementary treatment rather than a replacement (Peterson et al., 2024). There is also a growing popularity and interest in mindfulness as a treatment for ADHD, but while initial evidence suggests there could be benefits to mood and socio-emotional ADHD symptoms, further research need to be conducted to provide a more solid evidence base (Kretschmer et al., 2022).

Non-pharmacological treatments generally have significantly fewer side effects and adverse events attached than pharmacological treatments (Kemper et al., 2018), giving them some obvious advantages. Partly for this reason, NICE recommends non-pharmacological treatments as the first line of intervention for children with ADHD and before any pharmacological options are considered (NICE, 2018). However, non-pharmacological treatments are often considered to be more time-intensive and complex to implement and are also typically more expensive than pharmacological treatments (E. Q. Wu et al., 2012) – costing an average of $6,988 compared to $1,180 for medications (Jensen et al., 2005). Consequently, non-pharmacological treatments require a higher level of efficacy to make them comparatively cost-effective alternatives.

Overall, evidence supporting the efficacy of non-pharmacological treatments is more mixed compared to pharmacological options. While some reviews generally report positive effects on ADHD treatments (Kemper et al., 2018), others fail to find substantial evidence of significant benefits (Kooij et al., 2019). However, much of this uncertainty likely stems from a lack of research into the various available treatments, leading to insufficient and inconclusive evidence (Kemper et al., 2018). This issue is also particularly notable in adults with ADHD, where even less is known about the value and efficacy of non-pharmacological treatments (De Crescenzo et al., 2017). Generally initial evidence seems to suggest that non-pharmacological treatments are more effective than inactive control conditions (Nimmo-Smith et al., 2020) but have reduced efficacy compared to pharmacological treatments (Philipsen et al., 2015).

Due to aforementioned limitations of both pharmacological (e.g., diminishing efficacy, relatively high non-response rate) and non-pharmacological treatments (e.g., reduced efficacy and cost-effectiveness), research has increasingly explored alternative and/or complementary treatments. A suggested alternative non-pharmacological treatment includes diet and exercise. However, despite dietary interventions being found to have small benefits on ADHD symptoms in some studies (Nigg et al., 2012) , evidence suggests that they do not have a significant effect on ADHD symptomology to merit routine clinical use (Sonuga-Barke et al., 2013; Wolraich et al., 2019) and are not recommended by NICE (NICE, 2018). Exercise, however, has been found to offer numerous benefits, including improvements in EF, motor abilities, and mood (Den Heijer et al., 2017; Gapin et al., 2011) .

1.4. Physical Exercise, Activity and Fitness

1.4.1. Definition

Before an analysis of the effects of titled concepts can be carried out, it is essential to define and distinguish them for clarity and accuracy. “Physical Activity” (PA), “Physical Exercise” (PE), and “Physical Fitness” are often conflated and used interchangeably in the literature which can lead to confusion and inaccuracies when separate concepts are intended. While strongly correlated with each other (Caspersen et al., 1985), they refer to separate concepts. The definitions used within this thesis are taken from the Centres for Disease Control and Prevention (Caspersen et al., 1985), which remain the most popular and widely cited definitions of physical activity in the field, with most alternative definitions simply being derivations of these definitions (Strath et al., 2013).

PA can broadly be defined as *"any bodily movement produced by skeletal muscles, resulting in energy expenditure above the basal metabolic rate"* (Caspersen et al., 1985). This encompasses a vast range of activities across different domains, including occupation (e.g., standing, lifting, walking), leisure (e.g. household tasks, sports) and even movements during sleep.

PE, on the other hand, is a specific subset of physical activity. It refers to any physical activity that is planned, structured and repetitive with the objective of improving or maintaining physical fitness. Examples of PE include swimming, weightlifting, aerobics, and cycling, etc. While all forms of PE fall under the broad umbrella of PA (as all exercise is defined as a subtype of activity), not all forms of PA qualify as PE (e.g. vacuuming, walking around an office, etc).

Physical Fitness is also distinct from PA and PE. While the latter two are related to movements performed by people, physical fitness is as a set of attributes that people have or achieve. These attributes can be 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) . Components of physical fitness can be broken down into six skill related components - agility, balance, coordination, speed, power and reaction time - and five health-related components - cardiovascular endurance, muscular endurance, muscular strength, body composition and flexibility.

The terminology surrounding PA "type" or "form" can also often be unclear and ambiguous. For instance, they may refer to an activity's physiological effect (e.g., aerobic, flexibility, balance), an activity's commonly known name (e.g., football, swimming, running), or all of its possible components (e.g., all of the above plus intensity, duration, frequency, etc). For the purposes of this thesis "PA form" will refer to the commonly known name of a PA, and "PA dimensions" will refer to all potential components of PA. The PA dimensions used in this thesis will be based on the four dimensions presented by Strath et al. (2013):

1) Mode (physiological and biomechanical demands/types) This is generally considered to be further split into four subtypes: 1) Aerobic (sometimes referred to as cardiovascular or endurance); 2) resistance (sometimes referred to as strength); 3) flexibility; 4) balance (some sources only consider there to be three PE types and do not include balance). Some sources also include a further mode, Coordination exercise (Altermann & Gröpel, 2023; Netz, 2019).
2) Frequency (Number of sessions per day or week).
3) Duration (Time of the activity bout during a specified time frame)
4) Intensity. This can further be broken down into five levels of intensity: 1) Sedentary (activities that have little movement and low energy requirement); 2) Light (aerobic activity that does not cause noticeable change in breathing rate); 3) Moderate (aerobic activity that can be conducted while maintaining conversation); 4) Vigorous (aerobic activity in which a conversation generally cannot be maintained); 5) High (intensity that generally cannot be sustained longer than 10 minutes) (Norton et al., 2010).

1.4.2. Physical Effects

PA in general has been linked with a variety of positive physical traits in the general population. These are expressed over a range of domains and include physiological benefits to the cardiovascular, musculoskeletal, metabolic, endocrine, and immune systems (Vuori, 1998). Improvements to these systems can lead to reductions in the rates of cardiovascular diseases, cancer, non-insulin-dependent diabetes mellitus, osteoarthritis and osteoporosis (Vuori, 1998; Warburton et al., 2006). Improvements to general quality of life are found (World Health Organisation, 2024) as a consequence of various other benefits such as reduced body pains (e.g., lower back, neck and shoulder) and increased functional capacity (Vuori, 1998). These various benefits naturally lead to reduced mortality rates (Vuori, 1998), with individuals who are insufficiently active having a 20-30% increased risk of death compared to individuals who are sufficiently active (World Health Organisation, 2024). The amount of PA recommended as "sufficient" or "optimal" varies depending on sources and demographics of an individual (Warburton et al., 2006; World Health Organisation, 2024). For adults, the World Health Organisation recommends 50-300 minutes of moderate-intensity/75-150 minutes of vigorous-intensity PA/some equivalent combination of moderate-intensity and vigorous-intensity aerobic PA, per week (Bull et al., 2020).

Naturally there is a strong link with physical fitness including benefits to cardiovascular health and the immune system, with at least a 50% reduction in mortality typically found amongst physically high-fit individuals compared to low-fit individuals (Warburton et al., 2006).While both PA and Physical Fitness have been shown to lead to comparable levels of benefits (Warburton et al., 2006), it is generally argued that it is better for people to be encouraged to become more physically active rather than physically fit, as doing the former will likely lead to achieving the latter (Blair et al., 2001).

However, alongside the benefits listed above, increased PA can also lead to adverse effects. These can include risks of sports related injuries (Collard et al., 2008; Maffulli et al., 2011), and damage to the heart and cardiovascular system (O'Keefe et al., 2012; Zilio et al., 2024). These risks are usually more considerable in sports that require more power and speed (Maffulli et al., 2011; Nicholl et al., 1995); at higher PA intensities (Warburton et al., 2006); for individuals with lower levels of habitual PA/are less accustomed to PE (Collard et al., 2008; Nauta et al., 2015); and for individuals with latent or overt cardiovascular disease (Warburton et al., 2006). However, the net benefits of PA are generally considered to outweigh the risks (Warburton et al., 2006; Zilio et al., 2024) and adverse effects can be prevented or kept low by moderating aspects of PA (e.g., avoiding excessive amounts/intensity of PA), gradually working up to the desired level of PA, and monitoring risk factors (Collard et al., 2008; Warburton et al., 2006).

1.4.3. Mental Effects

On top of the physical effects of PA mentioned above, there has also been evidence supporting psychological benefits ranging from reducing anxiety and depression, improvements to cognition and overall enhancements to psychological wellbeing (Caponnetto et al., 2021; Warburton et al., 2006; Weinberg & Gould, 1999). Research has found that PA can lead to improved mood and reduced symptoms of depression and anxiety (Biddle & Asare, 2011; Crone-Grant & Grant, 2000; Mahindru et al., 2023), but these effects may be less pronounced in general population samples than clinical samples (Mahindru et al., 2023). PA has also been shown to lead to improvements in cognitive functioning such as planning, inhibition, working memory, attention and cognitive flexibility (Caponnetto et al., 2021; Ratey & Loehr, 2011). However the nature and degree of the effects of PA on cognitive performance can vary depending on timing of cognitive tasks (with impairments in cognitive performance sometimes found if tasks are performed during PE) (Lambourne & Tomporowski, 2010; Sudo et al., 2022); activity intensity (moderate intensity PE sometimes leading to greater improvements than low and/or high intensities) (Chang et al., 2012; McMorris, 2021); and physical fitness level (with individuals with lower fitness levels possibly more susceptible to cognitive impairments) (Lambourne & Tomporowski, 2010; Sudo et al., 2022).

Both psychological and physiological mechanisms for the mental health effects of PA have been suggested. Psychological explanations (which mainly pertain to the metal health effects) include the distraction hypothesis (where PA acts as diversion from negative stimuli/thoughts, leading to improved mood) (Bahrke & Morgan, 1978); the self-efficacy theory (Bandura, 1977); the mastery hypothesis (where command of a challenging pursuit such as PA leads to a sense of independence and success) (Mellion, 1985); and the social interaction hypothesis (where the social networks and support from PA/PE lead to the positive effects on mental health) (Ransford, 1982; Vilhjalmsson & Thorlindsson, 1992). Physiological explanations include the monoamine hypothesis (PA increases production of monoamines [e.g., DA, noradrenaline, serotonin] in a similar fashion as to how antidepressants are thought to work) (Ransford, 1982); and the endorphin hypothesis (PA increases production of endorphins that reduce pain and increase feelings of euphoria) (Petruzzello et al., 1991; Thorén et al., 1990). Given the wide range of possible explanations, psychobiological models that integrate multiple perspectives are often used in research (Paluska & Schwenk, 2000; Peluso & Guerra de Andrade, 2005).

In comparison, the explanations for the mechanisms behind cognitive effects are primarily physiological, where PA can lead to increased activity in brain regions/systems involved in attention, learning and memory (Ratey & Loehr, 2011). On a molecular level, PA has been found to induce increases in brain concentrations of DA and Norepinephrine (McMorris, 2016), which as mentioned previously (see section 1.3.6.), are linked to various cognitive functions and systems (e.g., working memory, arousal, alertness, and attention). PA can also lead to the upregulation of Brain-Derived Neurotrophic Factor (BDNF) (a molecule important for synaptic plasticity, learning, and memory) and Insulin-like Growth Factor – 1 (IGF-1) (a molecule positively associated with learning, memory and cognitive performance) (Ding et al., 2006; Ratey & Loehr, 2011). These molecules can also increase synaptic plasticity, neurogenesis, and vascular function that promotes a cellular environment to support cognition (Cotman et al., 2007). Psychological factors may also interact with such physiological effects; motivation and perceived effort may modulate the release of neurotransmitters (McMorris, 2021). Despite this, theories that integrate psychological factors in relation to cognitive effects are limited, and further empirical evidence is needed (Sudo et al., 2022).

The mental and physical benefits of PA can also reinforce each other, for instance PA can lead to improved mood and psychological wellbeing, which in turn is important to the prevention and management of cardiovascular disease and other chronic disease (Warburton et al., 2006). Vice versa, improved health and physical functional capability caused by PA can lead to improved psychological wellbeing (Vuori, 1998).

Similarly with physical effects mentioned above, PA can potentially also lead to adverse mental effects. Excessive and/or intense PA can lead to mood disturbances similar to depressive symptoms (Morgan et al., 1987) and can potentially impair cognitive performance (McMorris, 2021; Sudo et al., 2022). Additionally, PE can potentially lead to Exercise Dependence (ED)/Exercise Addiction (EA) (Landolfi, 2013). ED refers to a state in which a person exercises excessively/obsessively to a point of dependence, whereas EA is defined as dysfunctional behaviour marked by exaggerated training, loss of control over exercise behaviour, and negative impacts on daily life (P. M. Miller, 2013). Whilst the rate of EA among general exercisers has been found to be around 8.1% (Trott et al., 2020), it appears to have a very low prevalence in the adult general population, around 0.3 – 0.5% (Mónok et al., 2012). In addition to the low prevalence of EA, many of the adverse mental affects (similar to the adverse physical affects) are outweighed by the positive effects and/or can be mitigated by reducing risk factors (e.g., poor education, poor coping strategies, excessive concern over body image, weight, etc) (Caponnetto et al., 2021; Gori et al., 2021; Landolfi, 2013) and exercising in appropriate ways (Peluso & Guerra de Andrade, 2005).

1.5. Research Landscape and Gaps: The Impact of Physical Activity on ADHD Symptomatology

1.5.1. Range of Effects

As shown above (section 1.4.3.) PA has been found to positively impact on multiple areas closely linked with ADHD symptoms (e.g., concentration, mood, memory) (Weinberg & Gould, 1999) (see section 1.3.1. and 1.3.6.). As such its effects on individuals with ADHD have been investigated. The general consensus is that PA is negatively associated with multiple ADHD symptoms, including cognitive, physical/motor development, socio-emotional domains, and is associated with both short-term (acute) and long-term (chronic) effects (Archer & Kostrzewa, 2012; Den Heijer et al., 2017; Gapin et al., 2011; Neudecker et al., 2019; Vysniauske et al., 2020; Xie et al., 2021). However, the extent and practical significance of those associations is uncertain without further research (Faraone et al., 2021; Peterson et al., 2024).

Cognitive effects

Multiple review papers and meta-analyses have found positive associations between PA and improvements to cognitive ADHD symptoms (Den Heijer et al., 2017; Hoza et al., 2016; LaCount & Hartung, 2018; Montalva-Valenzuela et al., 2022; Sun et al., 2022; Villa-González et al., 2020; Welsch et al., 2021). For example, Den Heijer et al., (2017) reviewed 25 studies and found that PE led to acute improvements (defined as lasting from immediately after exercising, to 24 hours afterwards) among children with ADHD in response inhibition, cognitive control, attention allocation, cognitive flexibility, processing speed, and vigilance.

Chronic improvements were also noted (defined as lasting for over 24 hours after PE), including improved attention, executive functioning, verbal working memory, and cognitive speed. Research in general populations has also found PE to improve cognitive functions often negatively associated with ADHD, such as attention, working memory and inhibition (Best, 2010; Chang et al., 2012), both in the short and long term (Abdalkareem Jasim et al., 2024; Chang et al., 2012; Ludyga, Gerber, Pühse, et al., 2020).

In contrast, a systematic review by Neudecker et al., (2019) found that whilst PA had significant long-term improvements for motor development and behavioural ADHD symptoms, evidence for long-term cognitive improvements was less substantial. Similarly, Vysniauske et al., (2020) that found smaller positive effect of PE on EF ($g = 0.535$) compared to motor skills ($g = 0.818$). It should be noted though that the interpretation of this effect on EFs is complex as many studies measured different EF skills, with some using composite scores and others focussing on specific components of EF. Thus, it may be that the actual effect size differs across EF skills/domains. (Welsch et al., 2021) In support of this, not all EFs appear equally sensitive to PE (e.g., Miklós et al., 2017). Additionally, findings are not universal, with some studies finding no significant beneficial improvement from PA on certain EFs such as inhibition control (Welsch et al., 2021); set shifting (Piepmeier et al., 2015); and attention (Dinu et al., 2023). Therefore, while most existing evidence supports the beneficial effects of PA on EF, specific findings are mixed regarding the nature and extent of such effects, requiring further research.

Motor Skills/ Physical Effects

PA has also been associated with significant improvements in motor skills among children with ADHD (Den Heijer et al., 2017; Vysniauske et al., 2020a). Den Heijer et al., (2017) reported acute effects such as improved motor persistence, neurocognitive function, and response, as well as chronic benefits, including improved motor performance scores in locomotion, hand–eye coordination, and general motor skills. However, children with ADHD compared to controls were also found to exhibit some abnormal acute effects, including more blunted (nor)epinephrine responses and no DA increase. Further, Vysniauske et al. (2020) also found that the positive effects of PE on motor skills (g = 0.818) were comparable to the effect sizes of stimulant medications, which range from 0.83 for sustained release formulas to 0.9 for immediate-release formulations (Faraone, Biederman, & Mick, 2006).

Socioemotional effects

The effects of PA can also lead to socioemotional improvements in individuals with ADHD, either directly or indirectly. Den Heijer et al., (2017) observed some acute effects (lasting from immediately after PE to 24 hours afterwards), such as diminished interruption and unintentional aggression, but noted no significant effects on intentional aggression, language use, or following directions. Chronic effects (lasting for over 24 hours after exercise) were also much more evident and included improvements to self-esteem, anxiety, depression, social behaviour, academic outcomes, and somatic complaints.

Considering the above therefore, there appears to be differences between the acute and chronic effects of PA on ADHD symptoms. That is, chronic effects seem to have larger effect sizes than acute ones (Den Heijer et al., 2017), potentially due to differences in the causal mechanisms between acute and chronic effects discussed further below (see section 1.5.5.).

1.5.2. Moderating Effect of PA Dimensions

Evidence suggests that the effects of PA on ADHD symptoms can also vary depending on the exact mode, intensity, duration, and frequency of the PA. As mentioned previously, PA is different to PE, and PA can vary according to its mode (aerobic, anaerobic), intensity (light, moderate, vigorous), duration and frequency (see section 1.4.1.). It is important to note that comparisons and consensus between papers can be difficult due to inconsistencies in terminology for PA dimensions. For instance, “Mode” is rarely referred to by the term provided by the Centre for Disease Control and Prevention (Caspersen et al., 1985) (see section 1.4.1.) and is frequently referred to as “type” (Dastamooz et al., 2023; Den Heijer et al., 2017).

Mode

Regarding PE mode, the majority of studies focus on aerobic PA making analysis of the effect of different PA modes limited due to the limited number of studies on non-aerobic PA. However initial evidence suggests that different modes lead to different effect on ADHD symptoms, Den Heijer et al., (2017) compared cardio (e.g., running and cycling, which raise heart rate) and non-cardio exercises (e.g., yoga, which is tranquil). While both modes had positive effects on ADHD symptoms, cardio exercise demonstrated greater acute and chronic cognitive and behavioural benefits. However, the limited number of studies exploring non-cardio based exercise and activities makes it difficult to draw firm conclusions.

While not specific to ADHD, a review by Best (2010) also found that PE induced improvements to executive functions were greatest in PE modes that required higher cognitive engagement, supporting further research showing that coordinative PE produces greater cognitive benefits than other exercise modes (Ludyga, Gerber, Pühse, et al., 2020). Additionally, a systematic review by Neudecker et al., (2019) found that mixed PE programs incorporating various activities (e.g., running, ball games and coordination tasks) were most effective in reducing ADHD symptoms than interventions involving a specific form of PE. This is consistent with existing research exploring PA as a treatment for other psychiatric disorders, where combined PA forms often yield the greatest benefits (e.g., combination of forms practised together) (Silveira et al., 2013).

Despite these findings though, it is difficult to draw firm conclusions about the potential differential effects PA modes. Indeed, a lack of studies either comparing different PA modes or even just using a PA mode other than cardio, hinders robust conclusions.

Intensity

In contrast, the effect of PA intensity has been more thoroughly controlled and investigated. Some meta-analyses have found that intensity does not lead to any difference in effects (Dastamooz et al., 2023; Xie et al., 2021), with Vysniauske et al., (2020) finding no significant effect of PE intensity on intervention outcomes in children with ADHD. However, some studies in the meta-analysis did not use physiological measures (e.g., heart rate) to verify PE intensity, raising concerns about data reliability. The few studies and reviews that have found sufficient evidence to make initial inferences on optimal intensity, have generally found that moderate to vigorous intensities generate the largest effect sizes (Best, 2010; Montalva-Valenzuela et al., 2022; Neudecker et al., 2019; Sun et al., 2022) but with little in support of low-intensity. Regarding general cognitive benefits of PE found in healthy populations, PE intensity can affect the length of effects, with high intensities leading to reduced benefits compared to other moderate intensities during (Zheng et al., 2021) and immediately after PE (Chang et al., 2012); and very light intensity leading to reduced benefits compared to other intensities after a delay (Chang et al., 2012). Additionally moderate intensity PE has been shown to result in greater improvements in cognitive speed (but not accuracy) compared to low or high intensities (McMorris & Hale, 2012). This links with applications of the inverted-U theory (Yerkes & Dodson, 1908), that suggests that PE-induced arousal enhances cognitive performance up to an optimal level, beyond which performance declines (leading to the prediction that moderate intensity would lead to the most beneficial results) (Cooper, 1973; Lambourne & Tomporowski, 2010; McMorris, 2021). However, as individuals with ADHD have been suggested to have difficulty regulating arousal/activation levels (Martella et al., 2020; Sergeant, 2000, 2005; Strauß et al., 2018), the level of intensity to reach optimum arousal (and thus lead to the most beneficial cognitive effects) may be different for individuals with ADHD than healthy controls. Additionally, there are mixed findings regarding the inverted-U model (in regard to cognitive PE effects) (Chang et al., 2012; McMorris & Hale, 2012; Tomporowski, 2003) and how levels of arousal/activation differ in ADHD (Bellato et al., 2020; Isaac et al., 2023) meaning it is difficult to make reliable estimations around how the optimum level of intensity may be different for individuals with ADHD. It is also possible that optimal intensity could be dependent on gender as Neudecker et al., (2019) provided evidence to suggest that high intensity exercise ($\dot{V}O_{2peak}$) in boys with ADHD was required to achieve significant changes in brain dopaminergic activity, compared to girls who performed better with submaximal exercise (~65-75% $\dot{V}O_{2peak}$). Further research is needed to effectively establish optimal intensity ranges across different settings and samples.

Duration

The duration of PA has also been found to have an effect, with longer durations typically associated with greater positive effects (Vysniauske et al., 2020). Acute effects of PA typically require a minimum duration (Neudecker et al., 2019), with many studies demonstrating positive effects after a minimum 20 minutes of exercise (Faber Taylor & Kuo, 2009; Ludyga, Gerber, Mücke, et al., 2020; Pontifex et al., 2013). However, some studies found significant positive effects after just five minutes of PE (Gawrilow et al., 2016; A. P. Silva et al., 2015). However, it remains unclear how duration and intensity may interact, as it is unknown whether the "minimum duration" differs depending on the intensity of the activity (i.e., whether PA is at a moderate intensity or high intensity). Additionally, there may also be a ceiling effect with a meta-analysis by Sun et al (Sun et al., 2022) finding that moderate length sessions (70 minutes) lead to greater improvements on ADHD symptoms in children, compared to short (<50 minutes) or long (90 minutes) sessions.

Longer intervention durations have also been linked to larger effect sizes in functional outcomes for ADHD (Vysniauske et al., 2020). However, it should be noted that 'duration' in that context was defined as the total time spent exercising across all exercise sessions, meaning that the larger effect size could have merely been due to an increase in exercise session frequency, rather than individual session duration. Furthermore, other reviews could not find sufficient evidence for duration to be a significant moderator on the effects on ADHD (Dastamooz et al., 2023; Neudecker et al., 2019; Welsch et al., 2021) with Neudecker et al., (2019) stating that there was clearly a minimum duration required for positive effects to occur, could not find enough evidence to specify an optimum duration of PE.

Frequency

Similar to duration, the frequency of PA may also play a role. Neudecker et al., (2019) found tentative evidence to suggest that longer exercise interventions may lead to a greater reduction in ADHD symptoms (suggesting higher frequency is more optimal than lower frequency). Although, and as with other PA dimensions, insufficient evidence prevents firm conclusions being drawn about the optimal frequency of PA for ADHD symptom management.

Other Factors

Finally, in addition to the primary four PA dimensions - mode, intensity, duration, and frequency - other contextual factors may influence the effectiveness of PA. One such factor is the environment in which PA takes place, with Taylor and Kuo (2009) suggesting that PA in natural environments lead to greater positive effects (e.g., revitalisation, positive engagement, decreases in tension, confusion, anger, and depression than the equivalent in urban environments aligning with research found in the general population (Thompson Coon et al., 2011).

As highlighted above, there is also evidence to suggest that the level of cognitive engagement/demand required by PA can moderate the effects on ADHD symptoms (Best, 2010; Montalva-Valenzuela et al., 2022; Welsch et al., 2021). PA that is more cognitively engaging/demanding (e.g., ballgames) has generally been shown to lead to greater positive effects on EF than less more cognitively engaging/demanding PA (e.g., purely aerobic interventions) as it is assumed to activate multiple cognitive pathways simultaneously (Best, 2010; Montalva-Valenzuela et al., 2022). However, a meta-analysis by Welsch et al., (2021) found that – compared to low cognitive demand PA - high cognitive demand PA only led to greater beneficial effects on inhibition, but inferior effects on working memory, shifting and attention, possibly due to cognitive overload. This demonstrates that the moderating effect of cognitive engagement/demand may vary depending on the role of EF and further research is needed in this area.

While PA has been shown to lead to improved mood (Biddle & Asare, 2011; Mahindru et al., 2023) (see section 1.4.3.) its effectiveness can be moderated by the motivations behind PA engagement. Intrinsic motivations are linked with increased positive affect and decreased negative affect after PE interventions (Gaitan-Sierra & Hyland, 2014) and one study showed that PA alone did not work as a stress buffer on life satisfaction – this only happened when intrinsic motivation was also high (Meyer et al., 2021). Therefore, intrinsic motivation appears to be a potential important pre-requisite to maximise the beneficial effects of PA on the ADHD symptoms of mood dysfunction.

1.5.3. Influence of Demographic Factors

In addition to investigating the changes linked to attributes of PA, the influence of certain demographic factors such as age, gender, and prescribed medication use, also warrants specific discussion.

While significant positive effects of PA on ADHD symptoms have been found in both children (Neudecker et al., 2019; Vysniauske et al., 2020) and adults (Fritz & O'Connor, 2016; Mehren et al., 2019) with ADHD, evidence around how age may mediate effects is mixed. Some evidence suggests that the effects of PA may be different in adults compared to children. For example, PA having the greatest chronic effects during the developmental period when the brain is more malleable, such as in childhood and adolescence (LaCount & Hartung, 2018). However, meta-analytic evidence by Vysniauske et al., (2020) found no significant main effect between age and effect size for the effect of PA on ADHD symptoms. However, this meta-analysis only included participants up to age18 years (M= 9.3, SD = 1.9), meaning that a comprehensive analysis of age as a moderating factor across the lifespan could not be performed. Further meta-analyses have not been able to able to identify whether age group was a significant moderating factor due to insufficient numbers of studies (Dastamooz et al., 2023) particularly adult studies (Xie et al., 2021).

Additionally, most research is also heavily focussed on children and adolescents with ADHD, with relatively little research on adults with ADHD. For example, Den Heijer et al (2017) reviewed 25 studies, but only four of these included adult participants. This limited evidence base therefore makes it difficult to determine whether the general reduction of ADHD symptoms due to exercise extends to adults, and whether effects may change based on different PA dimensions.

There is also mixed evidence regarding the role of gender in moderating PA's effects on ADHD symptoms. While gender may lead to potential physiological differences in response to PA (Tantillo et al., 2002), this may not translate to significant behavioural differences (Vysniauske et al., 2020). Tantillo et al., (2002) found that there were different levels of DA (determined by acoustic startle eye blink response) between girls and boys with ADHD based on the intensity of exercise. While this might suggest that this would lead to differences in functions influenced by DA (e.g., EF and motivation, see section 1.3.6.) the meta-analysis by Vysniauske et al., (2020) found that gender was not related to the effect size of measurable behavioural outcomes.

Similarly to adults, the existing research suffers from an unequal gender distribution, with males being overrepresented in studies (Den Heijer et al., 2017). For instance, of the four studies involving adults reviewed by Den Heijer et al (2017), none included female participants. Such underrepresentation is commonly attributed to recruitment challenges, such as there not being sufficient power to investigate gender differences, leading researchers to focus solely on males due to the perceived higher prevalence rate (Abramovitch et al., 2013; Fritz & O'Connor, 2016).

Research into whether the effects of PA on ADHD are moderated by medication status is very limited, with reliable meta-analysis of the effects being limited due to insufficient number of studies and variability in strategies used to account for possible medication effects (Vysniauske et al., 2020; Xie et al., 2021). However initial research seems to suggest that there is no significant difference in the level of cognitive performance improvement between medicated versus unmedicated children with ADHD after 30 minutes of PE (Medina et al., 2010).

1.5.4. Difference Between ADHD Subjects and Controls on PA Effects

While general effects of PA have been linked to a reduction of ADHD symptoms, it is also important to determine if this effect is any different between individuals with and without ADHD. Overall, research suggests that while improvements in ADHD related traits (see section 1.5.1.) occurs in both ADHD and non-ADHD populations, the rate of improvement appears to be slightly greater in individuals with ADHD (Fuermaier et al., 2014; Pontifex et al., 2013; Tantillo et al., 2002).

Pontifex et al., (2013) investigated the effects of 20 minutes of aerobic PE with 20 children with ADHD compared to matched healthy controls (match controlled by sex, age, puberty status and socioeconomic status). Both groups exhibited improvements in multiple areas, but only the ADHD group exhibited PE-induced facilitations in action monitoring processes and regulatory adjustments in behaviour. In contrast, Wigal et al. (2003) found that while PE induced DA, norepinephrine and epinephrine levels in children without ADHD, norepinephrine and epinephrine responses (while still present) were severely blunted in children with ADHD, and DA levels did not increase. However, as the study did not include cognitive or behavioural measures, it is unclear how such physiological changes may translate into changes in observable behaviour.

It is also important to consider whether improvements bring ADHD participants to levels of performance comparable to non-ADHD controls. Limited research has explored this, making analysis of this question difficult, but most evidence suggest that even after PE, ADHD individuals generally perform worse than controls (Fuermaier et al., 2014; Pan et al., 2017; Tantillo et al., 2002). For instance, Tantillo et al., (2002) found that whilst PE decreased motor impersistence in boys with ADHD, the group with ADHD still had higher motor impersistence than healthy controls, before and after PE. However, Pontifex et al. (2013) found that post-exercise regulatory adjustments in behaviour were greater in the

ADHD group than healthy controls. This suggests that while PA may not reduce the ADHD symptoms in ADHD individuals to an equivalent level of healthy controls, the *level of improvement* from PA might be greater for ADHD individuals than healthy controls (possibly due to a ceiling effect). Overall, though, the limited evidence and lack of comprehensive post intervention analysis between ADHD and non-ADHD participants across various outcome variables make it difficult to draw firm conclusions.

1.5.5. Causal Mechanisms

Multiple theories have been proposed to explain the underlying mechanisms through which PA positively effects ADHD symptoms. These include immediate neurochemical responses, long-term neurostructural changes, and indirect consequences of other effects, such as improved physical health and a reduction of common comorbidities (Archer & Kostrzewa, 2012; Den Heijer et al., 2017; Neudecker et al., 2019) . However, objective and direct evidence on ADHD populations is scarce, where much of our current understanding is drawn from research involving either animals or non-ADHD participants.

PA has been linked with neurochemical responses (see section 1.4.3.) that positively affect multiple factors that are compromised in ADHD, leading to cognitive improvements (Ding et al., 2006; LaCount & Hartung, 2018; Ratey & Loehr, 2011). In particular, the link between PA and cognitive improvements has been suggested as being due to PA increasing levels of noradrenaline (Lehmann et al., 1985), DA (Sacheli et al., 2018), and serotonin (Gomez-Merino et al., 2001) in the prefrontal cortex, striatum, and hippocampus (LaCount & Hartung, 2018). As the dysregulation of these neurotransmitters in individuals with ADHD is believed to explain executive dysfunction symptoms (see section 1.3.6.), PA is believed to mirror the mode of action of existing ADHD stimulant medication, which target these same neurotransmitters (see section 1.3.7.). As mentioned previously (see section 1.4.3.) PA has also been linked with the upregulation of BDNF and IGF-1 (Ding et al., 2006). The immediate production of both of these growth factors is associated with structural affects such as neuroplasticity, neurogenesis and cell proliferation, which can lead to longer term structural effects and changes (Cotman et al., 2007).

The long-term effects of PA have also been linked to neurostructural changes in brain regions found to have abnormalities in ADHD (see section 1.3.6.). Structural Magnetic Resonance Imaging (MRI) has been used to show that older adults who engage in more physical activity show increased structural integrity in the Prefrontal Cortex (Colcombe et al., 2006) leading to improvement in cognitive functions that are associated with ADHD (e.g., inhibitory functioning). Additionally, these cognitive enhancements appear to be cumulative and last long term (Pesce, 2009). Gons et al., (2013) used MRI scans to show that PA is associated with the structural integrity of white matter, as participants with higher PA had greater integrity than those with lower PA. The difference in the short term (neurochemical) and long term (neurostructural) physiological effects could also explain differences found in the acute and chronic behavioural effects of PA (see section 1.5.1) as greater neurostructural changes could lead to the greater effect sizes found for chronic effects of PA.

PA can also indirectly lead to positive socio-emotional effects (e.g., improvements to self-esteem, anxiety, depression, social behaviour, academic outcomes, and somatic complaints, see section 1.5.1.) by effecting common comorbidities, overall physical health and inducing social interaction. PA has been found to lead to positive benefits for multiple common comorbid conditions for ADHD such as ASD (Sowa & Meulenbroek, 2012), mood disorders (Hearing et al., 2016); and anxiety disorders (Jayakody et al., 2014). This in turn can lead to improvements in related comorbid symptoms such as self-esteem, anxiety and depression. Improvements to social behaviour can be explained by the social interaction hypothesis (Vilhjalmsson & Thorlindsson, 1992) with PA/PE facilitating the development of social networks and support.

As discussed previously, the effects of PA can vary based on factors such as PA dimensions (section 1.5.2), demographic differences (section 1.5.3), and ADHD versus non-ADHD status (section 1.5.4.). Therefore, it is important to consider what mechanisms may lead to variance in outcomes. As covered in section 1.5.3 and 1.5.4, physiological differences have been found between boys and girls with ADHD (Tantillo et al., 2002), and between ADHD children and healthy controls (Wigal et al., 2003). However, while research suggests that physiological effects will have the greatest impact in children when the brain is still developing (LaCount & Hartung, 2018), little research has investigated, via objective measures of physiological change, the effects of PA in adults with ADHD.

Indeed, numerous review papers have highlighted this need for more research into the underlying physiological mechanisms behind the effect of PA on ADHD symptoms (Neudecker et al., 2019; Vysniauske et al., 2020; Wigal et al., 2013). As very few studies have measured physiological changes, a lot of the current understanding comes from the interpretation of animal-based studies which has obvious limitations as to how far they can be generalised to humans (LaCount & Hartung, 2018). Understanding these mechanisms can not only help better explain any differences based on previously mentioned individual differences but also help optimise the implementation of any PA based interventions (Wigal et al., 2013).

1.5.6. Use of PA as a Treatment

Due to the apparent effectiveness of PA on reducing ADHD symptoms, PA has naturally been considered as a potential treatment for ADHD. PA offers several advantages, including being low cost, non-invasive, and having fewer risks and side effects compared to pharmacological options (Den Heijer et al., 2017; Hoza et al., 2016; LaCount & Hartung, 2018; Sun et al., 2022). However, its effectiveness in a real-world setting may differ significantly from well-controlled, study-based environments. To date though, limited research has explored PA as a real-world treatment for ADHD, consequently, insights from its use in treating other conditions may help inform its potential effectiveness and utility for ADHD.

PA has been applied as a treatment for multiple other conditions, including depression, anxiety, stress and neurodegenerative diseases (Deslandes et al., 2010; Salmon, 2001). The mechanisms underpinning its positive effects are often similar to those proposed for ADHD, including the increase of neurotransmitters and BDNF, leading to neurogenesis, angiogenesis, and neuroplasticity (Portugal et al., 2013). Consequently, PA has generally been found to be an effective alternative or supplementary treatment for psychiatric disorders/conditions (Barbour et al., 2007; Deslandes et al., 2010; Stanton & Reaburn, 2014; Stonerock et al., 2015). Of particular note, these include conditions with high comorbidity rates with ADHD (see section 1.3.4.) such as mood disorders (Hearing et al., 2016; Kvam et al., 2016); Anxiety (Deboer et al., 2012); ASD (Sowa & Meulenbroek, 2012); Substance use disorders (Dowla et al., 2022); Sleep Disorders (H. H. Huang et al., 2023); and learning disorders (Fathi Azar et al., 2023).

In depression for instance, multiple Randomised Control Trials have found that exercise interventions lead to significant reductions in depressive symptoms (Stanton & Reaburn, 2014). In terms of determining the most optimal method of intervention, a meta-analysis by Silveira et al., (2013) found no significant differences between strength and aerobic interventions in reducing depressive symptoms. However, they reported that a combination of high-intensity strength training and moderate-intensity aerobic training led to more positive benefits than alternative interventions.

Similarly, multiple Randomised Control Trials have found that PE interventions lead to significant reductions in anxiety symptoms, with PE conferring anti-panic and anxiolytic effects, along with long-term programs providing relief from anxiety symptoms (Deboer et al., 2012; Stonerock et al., 2015). However, it is important to note that most of while some research has highlighted the potential for PA interventions to be implemented as alternative/stand-alone treatments (Deboer et al., 2012; Kvam et al., 2016) current evidence is limited. Therefore, most recommendations position PA as an adjunct or supplementary treatment (Alnawwar et al., 2023; Hearing et al., 2016; Kvam et al., 2016; Y. Wu et al., 2024) rather than as a replacement treatment to existing treatments.

However, more research is needed into the use of PA as a treatment specifically for ADHD, as symptom reduction does not guarantee its effectiveness or feasibility as an intervention. Likewise, its success in treating other psychiatric conditions cannot be assumed to translate directly to ADHD, which may present unique challenges, including specific barriers to engaging in PA (Harvey et al., 2014; Ogrodnik et al., 2023). For instance, the well documented challenges individuals with ADHD experience in maintaining routines (Wender, 1998; Wolf & Wasserstein, 2001) suggest that adherence to PE interventions could potentially be a significant challenge. This is a particular issue as one of the biggest limitations and obstacles for PA based treatments is low adherence rates (Garber et al., 2011), where adherence is a critical factor influencing the success of any intervention protocol (Portugal et al., 2013). Motivation appears to play a key role (Barbour et al., 2007), with tailored counselling aligned to an individual's level of motivation significantly increasing the likelihood of adherence and an individual reaching their intervention goals (Bock et al., 2001).

The question as to whether PA can be utilised as a treatment for ADHD is particularly pertinent for adults, as most research has focussed on children, leaving significant gaps in the evidence base for adults where there are potentially additional barriers and challenges in this group. Compared to children with ADHD, differences in primary symptoms, as well as life circumstances and conditions, may influence both the effectiveness and feasibility of PA based interventions, as well as how adults engage with such programmes. For instance, for school-age children, interventions can commonly be incorporated into school schedules or closely encouraged and monitored by parents. In contrast, adults must engage with it voluntarily and allocate it time amongst other commitments such as work (LaCount & Hartung, 2018). Additionally, the challenges of adherence for PA based treatments highlighted above (Garber et al., 2011) could be particularly salient for individuals with ADHD due to low adherence rates for other treatments (Gajria et al., 2014) and the well documented challenges individuals with ADHD experience in maintaining routines (Wender, 1998; Wolf & Wasserstein, 2001). Thus, it is important to consider PA interventions for adults, including barriers to adherence and how to offset disengagement, in order to optimise such treatment.

1.6. Themes, Reasons, and Implications of Gaps in Current Research

1.6.1. General

Despite some progress in the field, multiple review papers (Den Heijer et al., 2017; Gapin et al., 2011; Neudecker et al., 2019) have consistently highlighted the need for further research on the effects of PA on ADHD. This need stems from several key issues, including the limited number of studies, methodological issues and shortcomings (Den Heijer et al., 2017), limited research exploring physiological effects (Vysniauske et al., 2020), and gaps in research for certain demographic groups, such as females and adults.

As outlined in section 1.5., there is also a paucity of research exploring multiple other factors, particularly concerning the potential interplay between different PA dimensions, demographic factors, and the measurement of outcome variables.

1.6.2. Lack of Standardisation

One of the recurring themes in the literature is a lack of standardisation across studies, notably in regard to defining and categorising PA dimensions and types (e.g., mode, frequency, duration, intensity), methodologies, and the measurement of outcome variables. As mentioned previously (see section 1.5.2.) such inconsistencies pose significant barriers to drawing reliable conclusions and comparisons across studies. Such inconsistencies also complicate meta-analyses for instance, often making findings difficult to interpret, unreliable, or even necessitating the exclusion of studies (Den Heijer et al., 2017; Neudecker et al., 2019; Vysniauske et al., 2020). As mentioned previously (see section 1.4.1.) there are also inconsistencies around the use of the phrases "physical activity" and "(physical) exercise", with the terms often being used interchangeably. For instance, reviews by both Archer and Kostrzewa (2012) and Den Heijer et al., (2017) are both titled to be focussed on PE specifically, but both then review studies that are focused on PA (Abramovitch et al., 2013; Flöel et al., 2010; Gapin & Etnier, 2010; Hartanto et al., 2016). To a lesser extent, similar issues extend to the measurement of outcome variables, where the use of different assessment tools and scale further hinders comparability efforts (Den Heijer et al., 2017).

One possible reason for this lack of standardisation is the absence of firm definitions and clear distinctions (i.e., a framework for PA). Indeed, without a standardised framework in which to explore PA, individual studies may adopt different methodologies and distinctions, and researchers may also adopt their own distinctions and definitions of PA attributes, leading to substantial variability in study design and methodology.

1.6.3. Existing Biases

As highlighted previously (1.5.3.) there has been extremely limited research in certain demographics, notably adults and females with ADHD. This is most significant in adults, where not only is there limited research into the general effect of PA, but almost no existing research exploring how these effects might be influenced by moderators such as PA dimensions and gender differences. As outlined in section 1.3.2, ADHD was historically commonly considered a childhood disorder with few, if any, adult cases. Although this perception is changing, research into ADHD still disproportionally focuses on children over adults (Ramos-Quiroga et al., 2014). This could be due to existing biases within academia (still conceiving of it as primarily a "childhood disorder"), leading to a lack of interest in ADHD research in adults. Additionally, the potentially high prevalence rate of undiagnosed ADHD in adults may lead to recruitment challenges, further increasing the sparsity of adult focussed studies (Ginsberg et al., 2014; Goodman, 2009).

Much like research involving adults, the underrepresentation of females in the topic of PA and ADHD, reflect a broader trend in ADHD research, and for similar reasons. Also mentioned previously (section 1.3.2), ADHD has historically been considered a predominantly male disorder (Nussbaum, 2012) and multiple other factors have potentially led to under diagnosis in females (e.g., greater masking, less hyperactive symptoms, comorbidities leading to misdiagnoses) (Quinn & Madhoo, 2014). This means that female ADHD participants are often not considered when particular studies have sample size restrictions resulting in only one gender being recruited. This is done under the assumption that the effect of PA on ADHD symptoms may be different depending on gender.

This lack of inclusive research has meant it is difficult to determine if/to what extent there are any gender or age-related differences regarding the associations between PA and ADHD. As such further research needs to be inclusive of these different demographics to further our understanding of this subject.

1.6.4. Importance of Addressing Gaps in ADHD and PA Research: Implications and Potential Benefits

Addressing current gaps in research on PA and ADHD holds significant potential for numerous positive implications.

Firstly, further exploring the physiological mechanisms of PA on ADHD symptoms could enhance our understanding on how existing treatments work, providing insights into the development of future treatments. Additionally, analysing differences between demographic groups could contribute to existing research and knowledge regarding the physiological differences of ADHD across populations of interest. Likewise, investigating the optimal conditions for PA to have positive effects on ADHD symptoms could also be used to inform the implementation of PA as a treatment for other psychiatric conditions. Indeed, adherence rate is a common limiting factor of many PA based interventions (Portugal et al., 2013), largely attributable to issues with motivation (Barbour et al., 2007). Arguably, finding the optimal conditions for PA to be implemented as an effective treatment for ADHD - a condition characterised in part by difficulties with motivation – could lead to useful insights into improving adherence rate for other conditions as well.

More specifically, addressing these gaps could help progress our understanding of how PA could potentially be implemented as an effective treatment for ADHD. As previously highlighted (1.3.6.), there is clear need to supplement, or provide alternatives to, pharmacological treatments due to their diminishing long-term efficacy (Goode et al., 2018; J. Parker et al., 2013) and unsuitability for different populations (Mohammadi & Akhondzadeh, 2007). However, a key challenge for non-pharmacological treatments for ADHD, including PA, is uncertainty regarding its efficacy (Kooij et al., 2019). Therefore, determining the conditions under which PA has the greatest effect size is critical for establishing its use as a viable and efficacious treatment option.

Furthermore, PA has the potential to be a significantly cost-effective treatment. It is low cost compared to medication and therapy, and the high comorbidity rate of ADHD (1.3.3.) (Kooij et al., 2019), specifically with disorders that also benefit from PA (Barbour et al., 2007; Deslandes et al., 2010; Stanton & Reaburn, 2014; Stonerock et al., 2015), then further amplifies such potential. Therefore, an effective treatment (potentially PA based) capable of treating multiple comorbidities – whether diagnosed or undiagnosed – would naturally increase its cost effectiveness further (Jensen et al., 2005).

The development of PA as a treatment for ADHD could be particularly beneficial for adults with ADHD. The diminishing effect of medication over time is especially pronounced in adults (De Crescenzo et al., 2017), highlighting an even greater need to find supplementary or alternative treatments. This need is further accentuated by the paucity of research exploring non-pharmacological treatments in general for adults with ADHD, highlighting a critical gap that warrants further research and examination (De Crescenzo et al., 2017).

1.7. Purpose of current research

1.7.1. Overall aims

Considering the findings and gaps identified in the existing literature, the primary aim of this thesis is to investigate the association between PA and ADHD in adults. A secondary aim is to investigate how these associations, if present, are influenced by additional variables, such as PA dimensions and individual participant characteristics. While previous research has investigated a number of these variables individually and in isolation, this thesis aims to provide a more comprehensive review and analysis by considering multiple factors in a population that has previously been omitted.

1) Investigate whether PA is associated with ADHD in adults and if so, investigate the nature and extent of the association.
2) Examine how different demographics (e.g., gender; [sub]clinical diagnosis of ADHD; ADHD subtype) may influence associations between PA and ADHD.
3) Investigate underlying factors that may influence PA behaviour and associations in relation to ADHD in adults (e.g., motivations; environmental factors).
4) Explore the feasibility of implementing PA as a treatment for ADHD in adults (e.g., practical considerations, potential risks).

1.7.2. Implications of findings

The most important potential implication of this thesis is the foundational understanding needed to utilise PA as a treatment for ADHD in adults. If the findings support the theory that PA reduces ADHD symptoms in adults and help determine the circumstances under which this effect is most significant, this would provide evidence for the use of PA as a possible treatment approach. Importantly though, even if PA is found to reduce ADHD symptoms in adults, the research's potential positive impact might be limited without accompanying research into how this effect can be effectively translated into real world treatment. However, an additional consideration is to ensure that the potential use of any such treatment is kept in proportion alongside existing treatments. Due to the low cost of PA as a treatment, it might be considered as a replacement for existing, more expensive treatments, but potentially more effective treatments.

Furthermore, there are potential dangers of over-exercising such as increased risk of acute cardiovascular events and musculoskeletal complications (Franklin & Billecke, 2012; Gkaliagkousi et al., 2015). As there is a high comorbidity with anorexia and eating disorders in adults with ADHD (Nazar et al., 2016; Yao et al., 2019), combined with multiple ADHD medications also working as appetite suppressants, there is a danger that the encouragement of exercise could lead to unhealthy calorie deficits in some individuals. Consequently, the use of PA as a treatment should be considered alongside relevant medical histories, medication use, and other relevant factors to mitigate potential risks.

If the findings do not support the theory that PA reduces ADHD symptoms in adults, efforts should be taken to understand why. A potential negative implication could be that the effect does exist but was not found due to methodological issues, thereby increasing the risk that a potentially beneficial treatment is dismissed. Analysis should be performed to understand if this finding was potentially down to methodological issues and if so, how to address them in future research. Alternatively, such findings could also highlight fundamental differences in how PA might affect ADHD symptoms differently in children versus adults. Investigating such discrepancies could inform our understanding of the development and life course of ADHD, informing tailored treatment approaches.

Regardless of the findings of this thesis, it should not be viewed as definitive. Further research would be needed in order to optimise the potential positive impacts of PA while minimising any associated risks.

2. Chapter Two: Underlying Associations Between PA and ADHD

2.1. Chapter Overview

As outlined in Chapter One, existing literature into the relationship between PA and ADHD symptoms suggests there is a negative correlation, but it is limited, with several gaps in the research (such as limited research on: certain demographic groups; whether the apparent positive effects of PA on ADHD-associated symptoms vary based on formal diagnosis; and potential moderating). Therefore, the aim of this chapter is to investigate the relationship between levels of PA and ADHD symptoms in adults, while exploring the effects of potential moderating variables. A further aim is to investigate relationships among participants who may not have a formal diagnosis, but who may reach psychometrically defined subclinical thresholds for ADHD. This chapter highlights the relevance and utility of different methods of measurement for variables investigated in this research area, and provides greater foundational understanding of multiple variables, offering insights for further exploration in this thesis.

2.2. Introduction

As covered in Chapter One, current treatments for ADHD include both pharmacological and non-pharmacological approaches (see section 1.5.6.), with most guidelines recommending a mixture of both (NICE, 2018). However, due to limitations with both pharmacological (e.g., diminishing efficacy, relatively high non-response rate) (Banaschewski et al., 2004; J. Parker et al., 2013) and non- pharmacological treatments (e.g., reduced efficacy and cost-effectiveness) (Philipsen et al., 2015; E. Q. Wu et al., 2012), research has increasingly explored alternative and/or complementary treatments, such as PA.

Recent evidence suggests that PA/PE may help alleviate cognitive deficits (i.e., attention, information processing), reduce socio-emotional difficulties, and improve physical/motor symptoms (Den Heijer et al., 2017; Vysniauske et al., 2020) (see section 1.5.). In male adults with ADHD (or those expressing elevated ADHD symptoms), a 20-minute bout of exercise was found to improve motivation for cognitive tasks and increase feelings of energy (Fritz & O'Connor, 2016), and a positive association between PA and reduced ADHD symptoms has also been reported (Abramovitch et al., 2013).

However, despite accumulating evidence that PA may have beneficial effects, the literature itself is limited, with several gaps in the research. As highlighted previously (sections 1.5.3.; 1.5.4.) one of those shortcomings is a lack of research exploring certain demographic groups such as adults; females; and those without a formal diagnosis.

Additionally, it is unclear whether PA may differentially impact on specific subtypes and ADHD symptom expression. Current findings are equivocal, with some studies suggesting that PA leads to greater positive effects on ADHD-associated symptoms for individuals with ADHD (Fuermaier et al., 2014; Pontifex et al., 2013; Tantillo et al., 2002), while others suggest the opposite effect (Wigal et al., 2003). Mixed findings could be due to studies using a dichotomous classification of ADHD based solely on the presence/absence of a *clinical* diagnosis. This approach might result in undiagnosed individuals with ADHD either being missing from the ADHD group and/or contained within the non-ADHD group and further overlooks how PA may have varying impacts on individuals with specific symptoms of ADHD. Determining whether the relationship between PA and ADHD symptomatology is different between ADHD and non-ADHD diagnosed individuals, alongside exploring under-researched demographics such as age and gender, is essential. Such insights are crucial for informing potential PA based treatments and determining which populations may benefit most from the treatment and in what way.

Furthermore, research into potential moderating factors on the effect of PA on ADHD symptoms has received scant attention, including motivation for PE (C. H. Huang et al., 2007) and form of PE (Neudecker et al., 2019; Silveira et al., 2013). Previous research has suggested that motivation can affect participation in PE (Duncan et al., 2010; C. H. Huang et al., 2007) (with frequency, intensity, and duration of exercise all positively correlated with a more autonomous sense of motivation) (Duncan et al., 2010) and that the form and combination of PE can affect ADHD symptoms differently (Neudecker et al., 2019; Silveira et al., 2013).

Given the above, the aim of this study was to investigate the relationship between levels of PA and ADHD symptoms in adults, while exploring the effects of potential moderating variables (e.g., form of PE, comorbidities, motivation). To overcome some of the problems noted above relating to adults and female representation, a further aim was to investigate relationships among participants who may not have a formal diagnosis, but who may reach psychometrically-defined subclinical thresholds for ADHD. This approach aims to provide greater foundational understanding of multiple variables, offering insights for further exploration in this thesis. Based on the previous literature, it was hypothesised that: 1) there would be a significant negative correlation between PA level and ADHD symptomatology; 2) there would be no significant difference between the relationship between PA level and ADHD symptomatology in participants with and without a subclinical, subclinical diagnosis of ADHD; 3) there would be a significant difference in PA level based on motivation for exercise; and 4) there would be a significant difference in ADHD symptomatology based on main form of PE.

2.3. Method

2.3.1. Participants

Participants were recruited online via social media adverts, email invitations, Survey Circle (SurveyCircle, 2016), and a University Psychology participant pool. The study was advertised as: '*Physical exercise: Links with attention, organisation and behavioural inhibition in adults*', and participants were not offered any financial reimbursement or compensation for taking part. Following a detailed information page, participants provided informed consent via an electronic consent page with Yes/No check boxes. Participants who did not agree to all consent statements were redirected to the end of the survey and their data was not used. To be eligible to take part, participants had to be at least 18 years of age and a resident of the United Kingdom. Further exclusion criteria - applied after data was collected - included: not completing the study in full; having duplicate responses to another respondent with same IP address (likely same participant responding twice); having unusable International Physical Activity Questionnaire – Long Format (IPAQ-L) data (e.g., answers filled in incorrectly; scoring above the maximum limit for the IPAQ-L; having repeated answers for questionnaires (suggesting automatic selection and invalid responses); counting as extreme outliers in the IPAQ-L (defined as exceeding the 3rd quartile of IPAQ-L score + 3*IQR), and counting as an outlier in Total Forms of Exercise (TFE) done in the past week (defined as exceeding the 3rd quartile of TFE score + 3*IQR). No further inclusion/exclusion criteria were applied.

Participants were recruited between 19/12/2020 and 08/05/2021. Initially, 389 participants accessed the survey, although 121 were subsequently excluded for the following reasons: not providing consent (n=13); being under 18 years old (n=1); not being a resident of the UK (n=42); not completing the study in full (n=33); having duplicate responses to another respondent with same IP address (likely same participant responding twice; n=12); having unusable IPAQ-L data (e.g., answers filled in incorrectly; *n*=6); scoring above the maximum limit for the IPAQ-L (*n*=7); having repeated answers for questionnaires (*n*=3); counting as extreme outliers in the IPAQ-L (*n*=3), and counting as an outlier in TFE done in the past week (*n*=1).

This left 268 participants, of whom 200 (74.63%) were female. Age ranged from 18 to 71 (M = 25.88, SD = 9.08) years, with further demographic information presented in Table 4. Options for the Gender and Ethnicity question (Appendix A) were based on the categories recommended for use by the UK government (Race Disparity Unit, 2021) with gender referring to the socially constructed roles, behaviours, and identities of female, male and gender-diverse people.

Table 4

*Demographic Information of the Study Sample (*N*=268)*

Demographics	n (%)
Gender	
Male	65 (24.25)
Female	200 (74.63)
Other	2 (0.75)
Prefer not to say	1 (0.37)
Ethnicity	
White/English/Scottish/Northern Irish/British	167 (62.31)
Irish	9 (3.36)
Any other white background	41 (15.3)
White and black Caribbean	3 (1.12)
White and Asian	6 (2.24)
Any other Mixed/Multiple ethnic background	3 (1.12)
Indian	8 (2.99)
Pakistani	5 (1.87)
Bangladeshi	3 (1.12)
Chinese	3 (1.12)
Any other Asian background	7 (2.61)
African	6 (2.24)
Caribbean	2 (0.75)
Any other Black/African/Caribbean background	2 (0.75)
Other	3 (1.12)
Highest Level of education	
No formal education	1 (0.37)
Secondary/Highschool (e.g. GCSE's) or equivalent	6 (2.24)
College/Sixth form (e.g. BTEC, A-Levels) or equivalent	68 (25.37)

University (e.g. BSc, BA, Degree)	126 (47.01)
Masters (e.g. MSC, MA)	53 (19.78)
PhD/Doctorate	12 (4.48)
Other	2 (0.75)
Employment Status	
Full-time employment	48 (17.91)
Part-time employment	33 (12.21)
Unemployed as unable to work	1 (0.27)
Currently unemployed but looking for work	3 (1.11)
Retired	1 (0.37)
Unpaid family work/Homemaker/Carer	1 (0.37)
Full-time student	172 (64.55)
Part-time student	4 (1.49)
Unpaid voluntary work	1 (0.37)
Other	3 (1.12)

Note. GCSE = General Certificate of Secondary Education; BTEC = business and Technology Education Council; A-level = Advanced level qualification; BSc = Bachelor of Sciences; BA = Bachelor of Arts; MSC = Master of Sciences; MA = Master of Arts; PhD = Doctorate of Philosophy.

G-Power calculations indicated that for 95% power, with a rejection criterion of $p < .05$, and medium effect size ($f' = .15$), that 184 participants would be needed for a multiple regression with 12 potential predictors. Any potentially identifiable information (e.g., IP address, location data) was removed during initial data screening and prior to formal analysis.

2.3.2. Apparatus and Materials

The survey was conducted online using Qualtrics (2005). Participants were asked to supply standard demographic details (age, gender, ethnicity, education, employment) (Appendix A) and to details about their: (1) physical fitness (height, weight, hours of sleep); (2) potential comorbid conditions and medication (e.g., "*Have you ever been diagnosed with* *any of the following conditions/disorders*" [10 options, such as: none; mood disorder; sleep disorders; other; etc], "*If so do you take any prescribed medication?*") (Appendix B); (3) what forms of PE they performed ("*In the last 7 days which forms of exercise listed here have you done?*" [37 options, such as: none, archery, climbing, football, other, etc]) (Appendix C); (4) use of fitness trackers ("*Do you use any fitness trackers? If so, what?*") (Appendix C); and (5) motivation for exercise ("*What is your main reason / motivation for exercising?*" [options = don't exercise; for my appearance; self-defence; for social reasons; to lose weight; fitness and health; other]) (Appendix C). In addition, the survey contained the following standardised questionnaires:

The Adult ADHD Self Report Scale – 6 (ASRS-6) (Gray et al., 2014; Kessler et al., 2005) (Appendix D): The ASRS-6 was used to classify the subclinical diagnostic status of participants in the current study. It is a 6-item scale listing different symptoms of ADHD and is used as a screening tool for subclinical diagnosis levels of ADHD in adults. Respondents are required to use a 5-item Likert scale to indicate the frequency of occurrence of symptoms (0 = *never* to 4 = *very often*). If a respondent has 4 or more scores equal and above 2 for items 1-3, and equal and above scale 3 in items 4-6, then they are considered to have symptoms highly consistent with ADHD (i.e., subclinical diagnostic group). The scale has good concordance (k=.76), sensitivity (.69), and specificity (.99), and has established reliability for the sample targeted (Gray et al., 2014). Within the current study, internal consistency fell just below the commonly adopted threshold for 'acceptable' levels (Cronbach α = .69).

The ADHD Rating Scale – IV with Adult prompts (ADHD-RS-IV with Adult Prompts) (Adler et al., 2009) (Appendix E): The ASRS-IV was used to measure Total ADHD Symptomatology (ADHD-T), Inattentive ADHD Symptomatology (ADHD-I); and Hyperactive ADHD Symptomatology (ADHD-H). It is an 18-item self-report questionnaire based on DSM-IV criteria that assesses the severity and frequency of ADHD symptoms in adults (ADHD symptomatology). Each item comprises a collection of prompts (e.g. "*Do you rush through work or activities?*") relating to a specific symptom of ADHD (e.g. carelessness). Respondents respond to each item by how much the prompts affect them on a scale of 0-3 (0 = None; 1= Mild; 2= Moderate; 3 = Severe). Each item is given the highest score generated by any of its prompts (e.g. if one prompt generates 3, but the rest 2, the score for the item is 3). Responses are then summed to provide a compositive total score (ADHD-T) ranging from 0-54, where higher scores indicate greater severity of ADHD symptoms. The questionnaire can also be broken down into 2 subscales (comprised of 9 items each): inattentive ADHD symptoms (ADHD-I), and hyperactive ADHD symptoms (ADHD-H). This measure was chosen as it is tailored for adult participants and because of its comprehensive measurement of a range of ADHD symptoms. Good levels of internal reliability were found in the present study (inattentive section [items one-nine] α= .83; hyperactive section [items 10-18] α = .85; total [items 1-18] α = .89).

The International Physical Activity Questionnaire – Long Format, last seven days, self-administered (IPAQ L7S) (Craig et al., 2003) (Appendix F): The IPAQ-L was used to measure PA level. It is a 27-item questionnaire used to measure PA over the last seven days. While a version is available that asks questions in reference to a "usual week", the "last seven days" version was used due to questions regarding recent activity having greater likelihood of being reliable (Kuh, 2001). Data can be converted to Metabolic Equivalents (MET), defined as the amount of oxygen consumed by the body while sitting at rest. The questionnaire guidelines state the maximum amount of exercise that can be done during a week is 16 hours a day, leading to a total range of 0–53760 METs. The scale can be broken down into four subscales/domains: work; travel; domestic, and leisure. This questionnaire was chosen due to it being well established in related research, the outcome variable being METs (a commonly used outcome variable allowing data to be easily compared across-studies), and its focus on a range of domains. The leisure domain/subscale was used to measure PE level. The scale has test-retest reliability clustered around .80, and criterion validity correlation of about .30, which matches with other self-report scales (Craig et al., 2003).

Other Questionnaires: To investigate potential moderators, additional variables were examined using various measures such as Body Mass Index (to measure physical fitness); and self-devised questionnaires were developed to measure average hours slept (e.g., "*How many hours of sleep a day do you get on average?).* However, as these variables were not found to have significant links with key study variables, they were not included in any further analysis and are not described in detail here.

2.3.3. Design

The study was a cross-sectional observational study. The primary variables of interest were PA, ADHD symptomatology, and subclinical ADHD diagnosis. Potential moderating variables were demographic variables (e.g., age; gender), and comorbidities. Further variables of interest were forms of PE, motivation for PE, and fitness tracking use.

2.3.4. Procedure

The research was approved by the Swansea University Psychology Department Research Ethics Committee (Reference number 5003) (Appendix G). Participants accessed the survey online via Qualtrics and were first presented with a detailed information sheet. They were then asked to indicate their consent via an electronic (Yes/No) check-box. Participants who did not consent to participate were directed to the end of the survey. Consenting participants were then asked to complete a series of demographic questions followed by the ASRS-6. After this, participants were presented with the questions on physical fitness, then questions on comorbid conditions and medication. Participants then were presented with the ADHD-RS-IV with Adult Prompts. Next, participants were presented with the IPAQ-L, depending on answers to certain questions, participants would skip other questions (as per the measures instructions). After that, participants were presented with the questions about what types of PE they performed, use of fitness trackers and motivation for PE. Finally, participants were presented with a debrief form. All survey sections required a response (except for the questions in the IPAQ-L a participant would have skipped), ensuring the survey was fully completed. There was no time limit, and after excluding outliers (defined as exceeding the 3rd quartile of total duration + 3*IQR), average completion time was 14 minutes, 37 seconds.

2.3.5. Data processing and Statistical Analysis

All statistical analyses were carried out using IBM SPSS Statistics version 28 (IBM Corp, 2021) and PROCESS v4.0 (Hayes, 2018).

IPAQ-L data was cleaned in accordance with the guidelines set out by the IPAQ group. BMI data was also generated from height and weight data; however, some datasets were unusable due to the height and weight questions being filled out incorrectly. The usable datasets of BMI were tested to see if it would have a significant correlation (Spearman's rho) with either IPAQ-L score or ADHD-RS-IV score. As it was not found to have significant relationship with either, data sets with unusable BMI data were retained for all other analysis. Data on comorbidities and forms of exercise were converted to ordinal data, by measuring them as 'Total Number of Comorbidities' (TNC) and 'Total Forms of Exercise' (TFE) respectively. Based on ASRS-6 scores, participants were categorised into either a non-ADHD or subclinical ADHD diagnostic group (participants who met the threshold of having symptoms highly consistent with ADHD, as outlined in the materials subsection, were counted as subclinical ADHD diagnostic participants) (Sub-ADHD). Answers for fitness tracker use were analysed and grouped into 9 categories (None, Apple Watch, Smart watch, Fitbit, Garmin; Strava; Smartphone App; Smart Watch; Other; Multiple) based on collating answers numbering two responses or more.

In terms of the statistical approach adopted, none of the variables were normally distributed, so non-parametric analyses were utilised, with median and IQR used as measures of central tendency and dispersion respectively. Correlations between key variables (ADHD symptomatology; PA level; TNC; TFE) were performed using Spearman's Rank correlation. Additionally, when investigating relationships between demographic variables and the two main variables of interest (ADHD symptomatology and PA level), Kruskal-Wallis tests (for education, ethnicity and employment), Mann Whitney U tests (for gender), and Spearman's Rank correlations (for age) were performed. To investigate the relationship between subclinical diagnostic group and gender, a chi square test of association was performed.

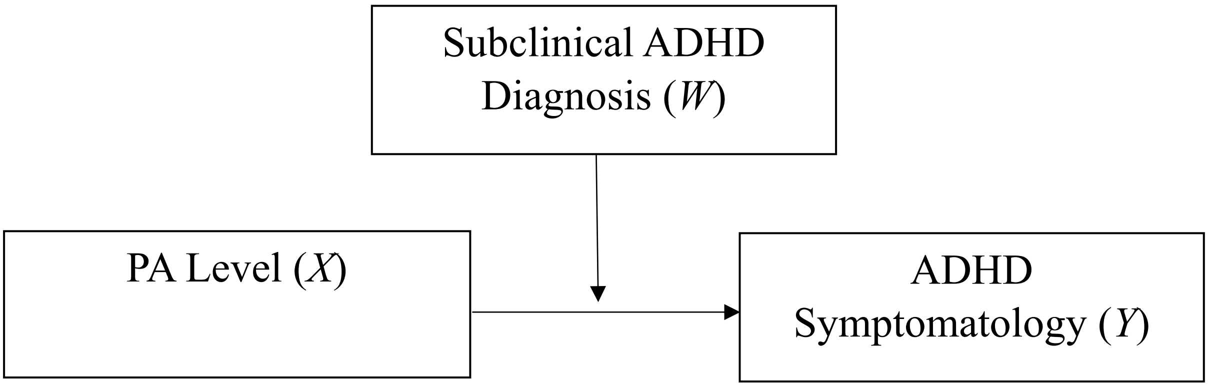
To investigate whether there was a significant negative correlation between PA level and ADHD symptomatology (hypothesis 1), a three-stage multiple hierarchical regression was conducted. ADHD symptomatology was the variable being predicted and PA level, age and TNC were entered as predictor variables. The relevant assumptions of this statistical analysis were tested. Firstly, a sample size of 268 was considered sufficient for 3 independent variables to be included in the analysis. The assumption of singularity was found to be met by checking Durbin-Watson significance values. The assumption of multicollinearity was deemed to have been met as an examination of correlations revealed that no independent variables were highly correlated with one another, and collinearity statistics (i.e. tolerance and VIF) were all within acceptable limits. In addition, residual and scatter plots indicated that the assumptions of normality, linearity and homoscedasticity were all met.

A series of Spearman's rho correlations were also performed within the different subgroups (gender and subclinical diagnostic groups) to further investigate the relationships between PA and ADHD symptom subtypes.

A moderation analysis was then employed to investigate whether the relationship between PA level and ADHD symptomatology differed in participants with or without a subclinical diagnosis of ADHD (hypothesis 2). PA level was entered as the dependant variable (Y), ADHD symptomatology as the independent variable (X), and subclinical ADHD diagnosis as the moderator (W) (see Figure 1).

Figure 1

Model for the Moderation Effect of Subclinical ADHD Diagnosis Between PA level and ADHD Symptomatology



To determine whether there was a significant difference in PA level based on motivation for exercise (hypothesis 3), a Kruskal-Wallis Test was conducted. Finally, a Spearman's rank correlation was performed to assess the relationship between TFE and ADHD, allowing examination of whether ADHD symptomatology differed based on main form of PE (hypothesis 4). A regression analysis was additionally performed to ensure that findings were not affected by PA level acting as a mediator between TFE and ADHD symptomatology (as PA level and TFE had a high level of correlation).

As an exploratory analysis on the use of fitness trackers to potentially inform future study methodology, a Kruskal-Wallis Test was conducted to examine the differences of PA level according to the type of fitness tracker used.

2.4. Results

2.4.1. Descriptive and Demographic Statistics

Table 5 shows the mean (standard deviations) for the variables.

Table 5

Descriptive Statistics for Study Variables

	Sample/Group								
	Total Sample (N= 268)			Non-ADHD Group (n=164)			Sub-ADHD Group (n=104)		
Variables	Mean (SD)	Min	Max	Mean (SD)	Min	Max	Mean (SD)	Min	Max
Age	25.88 (9.08)	18	71	27.37 (10.34)	18	71	23.54 (5.95)	18	58
ASRS-6	11.94 (4.08)	2	24	9.49 (2.62)	2	15	15.81 (2.75)	11	24
ADHD-T	18.42 (9.54)	0	46	14.54 (7.99)	0	37	24.53 (8.57)	8	46
ADHD-I	10.03 (5.19)	0	22	7.81 (4.33)	0	18	13.53 (4.48)	5	22
ADHD-H	8.39 (5.53)	0	25	6.73 (4.92)	0	22	11 (5.45)	0	25
PA level	3578.47 (3437.25)	0	173739	3772.61 (3521.99)	0	17379	3272.33 (3292.65)	0	16458
TNC	0.66 (1.02)	0	5	0.54 (0.91)	0	4	0.87 (1.15)	0	5
TFE	1.75 (1.42)	0	7	1.84 (1.38)	0	7	1.61 (1.48)	0	7

Note. ASRS-6= The Adult ADHD Self Report Scale score – 6; PA = Physical Activity; T-ADHD-S = Total ADHD Symptomatology; I-ADHD-S = Inattentive ADHD Symptomatology; H-ADHD-S = Hyperactive ADHD Symptomatology; TNC = Total Number of Comorbidities; TFE = Total Forms of Exercise.

Regarding demographic variables and their relationships with the two main variables (ADHD symptomology and PA level), no significant correlation was found between age and PA level (r = .097; p = .114), but a significant negative correlation was found between age and ADHD symptomology (r = -.178; p = .003). There was no significant difference in PA level or ADHD symptomology based on gender (U = 6443, p =.915; U = 6408, p =.864; respectively), or education (H[4]= 3.7, p = .449; H[4] = 3.44, p = .488; respectively). There was no significant difference in ADHD symptomatology based on ethnicity (H[7] = 4.01, p = .779), or employment (H [2]= 1.87, p =.392), but PA level did differ significantly based on both ethnicity (H[7] = 22.01, p = .003) and employment (H[2] = 7.92, p =.019).

Table 8 shows the median (interquartile range deviations) and correlation coefficients for study variables split by subclinical ADHD diagnosis and gender.

Table 6 shows the frequencies for Gender and Main motivation for PE split by subclinical ADHD diagnostic group.

Table 6

Frequencies of Gender and Main Motivation for PE

	Sample/Group		
	Total Sample (N= 268, 100%)	Non-ADHD Group (n=164, 61.19%)	Sub-ADHD Group (n=104, 38.81%)
Variables	n (% of total)	n (% of subgroup)	n (% of subgroup)
Gender			
Male	65 (24.25)	43 (26.22)	22 (21.15)
Female	200 (74.63)	120 (73.17)	80 (76.92)
Other	2 (0.75)	0 (0)	2 (0.75)
Prefer not to say	1 (0.37)	1 (0.37)	0 (0)
Main motivation for PE			
Fitness and health	149 (55.6)	100 (60.98)	49 (47.12)
To lose weight	41 (15.3)	24 (14.63)	17 (16.35)
For social reasons	11 (4.1)	4 (2.44)	7 (6.73)
Self defence	1 (0.37)	1 (0.61)	0 (0)
For my appearance	27 (10.45)	16 (9.76)	11 (10.58)
Do not exercise	28 (10.45)	12 (7.32)	16 (15.38)
Other	11 (4.1)	7 (4.27)	4 (3.85)

Table 6 shows that within the subclinical diagnostic group, there was a slightly higher ratio of females (76.92%), compared to the non-ADHD group (73.17%). However, a chi-square test found no significant difference in the prevalence of subclinical diagnosis of ADHD between males and females, $\chi 2(1) = 0.79$, $p = .376$, $\varphi = .054$ (three participants who selected 'other' or 'prefer not to say' were not included in the analysis due to expected cell counts being below five).

2.4.2. Relationship Between PA level and ADHD Symptomatology

To investigate the relationship between PA level and ADHD symptomatology (hypothesis 1), a three-step hierarchical multiple regression was conducted with ADHD-T as the dependant variable, and age and TNC added as control variables. Age was entered in Step one, TNC was entered in Step two, and PA level was entered in Step three (Table 7).

In Step one, age significantly contributed to the regression model, $F(1,266) = 5.22$, $p = .023$, accounting for approximately 1.9% of the variance in ADHD-T. When TNC was entered in Step two, the overall regression model remained significant, $F(2,265) = 18.15$, $p = <.001$), with TNC accounting for an additional 10.1% of the variance in ADHD-T. When PA level was entered in Step three, the overall regression model remained significant $F(3,264) = 12.2$, $p = < .001$), and accounted for 12.2% of the variance – but PA level only accounted for an additional 0.1% of variance and was not a significant unique predictor. In contrast, Age and TNC were both significant unique predictors, with the latter being the strongest overall predictor. Thus, these findings suggest that PA level and total ADHD symptomatology are not significantly associated.

Table 7.

Multiple Hierarchical Regression on Total ADHD Symptomatology

Predictor Variables	R	$R^2 \Delta$	p	B	95% CI	SE	β	t
Step 1	.14	.02*	.023					
Age			.023	-.15	[-.27, -.02]	.06*	-.14	-2.29
Step 2	.35	.1***	<.001					
Age			.034	-.13	[-.25, -.01]	.06*	-.12	-2.13
TNC			<.001	2.98	[1.92, 4.04]	.54***	.32	5.52
Step 3	.35	>.01	.536					
Age			.036	-.13	[-.25, -.01]	.06*	-.12	-2.11
TNC			<.001	2.98	[1.92, 4.04]	.54***	.32	5.51
PA level			.536	>-.01	[>-.01, <.01]	<.01	-.04	-.62

Note. Statistical significance: *$p < .05$; ***$p < .001$. TNC = Total Number of Comorbidities; PA = Physical Activity.

To investigate relationships between PA and ADHD symptom subtypes, a series of Spearman's rho correlations were performed within the different subgroups (Table 8). Results showed that although there was no significant relationship between PA and ADHD-T in the total sample (nor between PA and ADHD-H), there was a significant negative correlation between PA and ADHD-I, $r(266) = -.14$, $p = .02$ (small effect size), and a significant negative correlation between PE and ADHD-T, $r(266) = -.13$, $p = .03$ (small effect size). This suggests that while there may not be a significant relationship between overall PA level and total ADHD symptomatology, significant negative relationships emerge when PA and ADHD symptomatology is split into sub-measures, such as PE and inattentive ADHD symptoms.

Further, PA was not significantly correlated with any ADHD symptom types in the non-ADHD group, but there were significant negative correlations between PA and ADHD-I in the subclinical diagnostic group $r(102) = -.24$, $p = .016$. Similarly, while PA was not significantly correlated with any ADHD symptom types in males, there was a significant negative correlation between PA and ADHD-I in females $r(198) = -.18$, $p = .01$). This suggests that that any significant negative correlations between PA and inattentive ADHD symptomatology might be specific to subclinical ADHD individuals and females.

Table 8

Descriptive Statistics and Correlation Coefficients (Spearman's rho) for ADHD Symptomatology and PA Subtypes, Split by Subclinical ADHD Diagnosis and Gender

Variable	Median	IQR	1	2	3	4	5
Total Sample (N=268)							
1. ADHD-T	17	13	-				
2. ADHD-I	10	8	.88***	-			
3. ADHD-H	7	7	.87***	.55***	-		
4. PA level	2574.25	4031.25	-.07	-.14*	.03	-	
5. PE level	594	1608.75	-.13*	-.2**	-.03	.69***	-
Non-ADHD (n=164)							
1. ADHD-T	14	9	-				
2. ADHD-I	8	7	.82***	-			
3. ADHD-H	6	7	.84***	.41***	-		
4. PA level	2712	4211.25	.01	-.08	.1	-	
5. PE level	619	1864.13	-.06	-.17*	.09	.72***	-
Sub-ADHD group (n=104)							
1. ADHD-T	24	11.75	-				
2. ADHD-I	13	7	.83***	-			
3. ADHD-H	11	8	.86***	.45***	-		
4. PA level	2388.75	3244.88	-.11	-.24*	.04	-	
5. PE level	429	1358.63	-.19	-.23*	-.1	.63***	-
Male (n=65)							

1. ADHD-T	17	9	-				
2. ADHD-I	10	6.5	.77***	-			
3. ADHD-H	8	6.5	.8***	.29*	-		
4. PA level	2760	4080	.1	-.05	.24	-	
5. PE level	396	1456.5	-.02	>.01	>.01	.71***	-
Female (n=200)							
1. ADHD-T	17	15	-				
2. ADHD-I	10	8	.9***	-			
3. ADHD-H	7	8	.89***	.61***	-		
4. PA level	2574.25	4016.25	-.13	-.18**	-.04	-	
5. PE level	594	1642.5	-.18*	-.27***	-.05	.68***	-

Note. Statistical significance: *$p < .05$; **$p < .01$; ***$p < .001$.

ADHD-T = Total ADHD Symptomatology; ADHD-I = Inattentive ADHD Symptomatology; ADHD-H = Hyperactive ADHD Symptomatology; PA = Physical Activity; PE = Physical Exercise.

2.4.3. Effect of Subclinical ADHD Diagnostic Status on the Relationship Between PA Level and ADHD Symptomatology

The moderating role of subclinical diagnosis of ADHD on the relationship between PA level and ADHD symptomatology (hypothesis 2) was assessed to determine if the strength of the correlation was different between Sub-ADHD participants and non-ADHD participants. A test of unconditional interaction was performed using PROCESS macro (model 1) (with subclinical ADHD diagnosis as moderator, PA level as predictor, and ADHD-T as the outcome), with the change in R^2 due to interaction of predictor and moderator (Table 9). Altogether, 26.12% of the variability in ADHD-T was predicted by the variables, R^2 =.26, F(3,264) = 31.11, p<.001. The interaction (shown in Figure 2) was not significant, as the impact of PA level on ADHD-T in non-ADHD participants was not significantly different from Sub-ADHD participants (b = 0, 95% C.I. [>-.01, <.01], t = .242, p

= .809). Table 10 presents the conditional effect of PA at the two levels of subclinical ADHD diagnosis. This suggests that the relationship between PA and ADHD symptomatology is not significantly different based on subclinical ADHD diagnostic status.

Figure 2

Interaction Between Total ADHD Symptomatology and PA Level Based on Subclinical ADHD Diagnosis

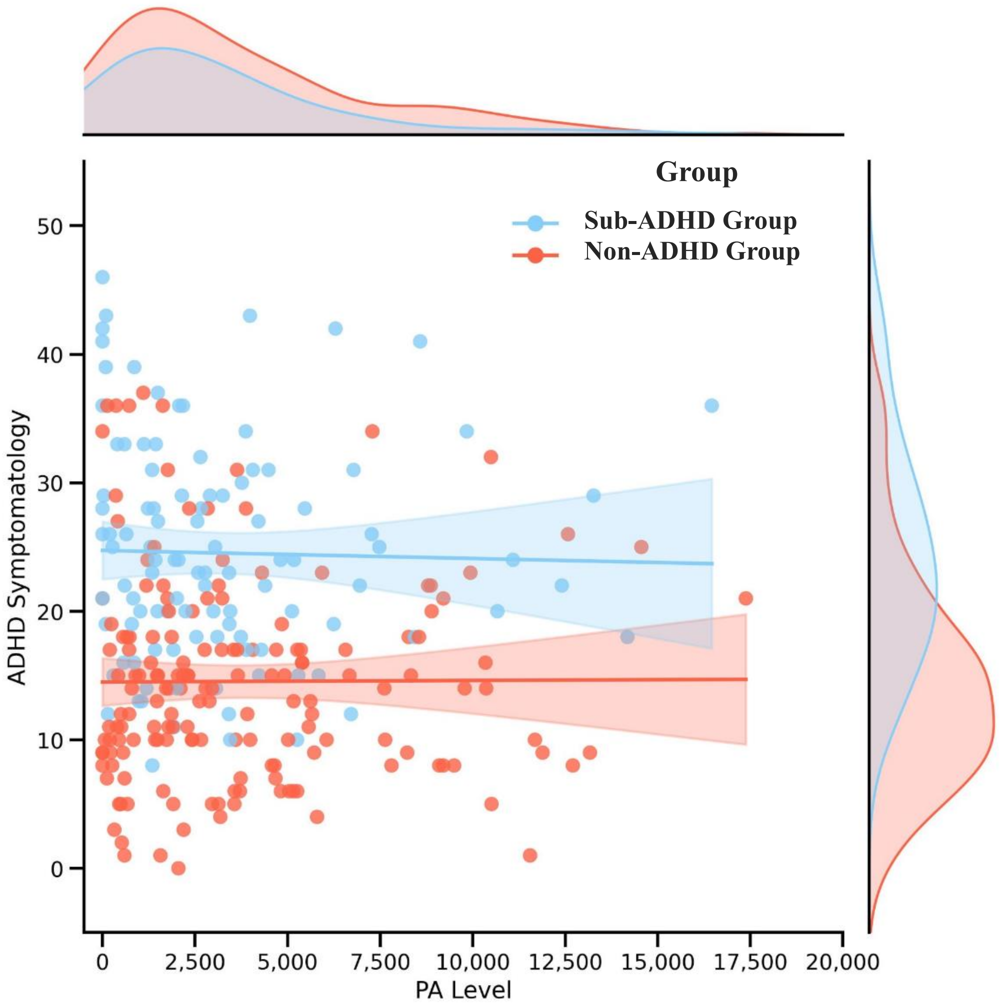


Table 9

Moderated Regression Analysis Predicting ADHD Symptomatology

Predictor	B	SE	*t*	*p*	95% CI
Constant	14.54	0.65	22.54	<.001	[13.27, 15.81]
PA Level	<.01	<.01	0.06	.949	[>-.01, <.01]
SAD	9.97	1.04	9.61	<.001	[7.92, 12.01]
PA Level*SAD	>-.01	<.01	-0.24	.809	[>-.01, <.01]

Note. PA = Physical Activity; SAD=Subclinical ADHD Diagnosis.

Table 10

Conditional Effects of PA Level Across Subclinical ADHD Diagnosis

SAD	Effect	SE	*t*	*p*	95% CI
Non-ADHD	<.01	<.01	0.06	.949	[>-.01, <.01]
Sub-ADHD	>-0.01	<.01	-0.25	.8	[>-.01, <.01]

Note. SAD=Subclinical ADHD Diagnosis.

2.4.4. Effect of Motivation for Exercise on PA Level

To determine whether there was a significant difference in PA level based on the main form of motivation for PE (e.g., "For social reasons", "For my appearance"), a Kruskal-Wallis Test was conducted (hypothesis 3). No significant differences, $H(5) = 5.10$, $p = .404$) were found across the five categories of participants. Therefore, this suggests that PA level does not differ based on an individual's main form of motivation for PE.

2.4.5. Relationship Between Forms of Exercise and ADHD Symptomatology

Next, in relation to whether ADHD symptomatology differed based on main form of PE (hypothesis 4), a Spearman's rank correlation confirmed that there was no significant correlation between TFE and ADHD-T, $r_S(266) = -.114$, $p = .063$. However, to ensure that the findings were not affected by PA level acting as a mediator between TFE and ADHD-T (as PA level and TFE had a high level of correlation), PA level was also controlled for in a regression analysis. Specifically, a two-stage hierarchical multiple regression was conducted, with ADHD-T as the dependent variable (Table 11). PA level was entered in Step one, and TFE entered in Step two. In Step one, PA did not contribute significantly to the regression model, F (1,266) = 0.48, p =.498, and accounted for only 0.2% of the variation in ADHD-T. When TFE was entered in Step two, it accounted of for an additional 0.9% of the variance in ADHD-T, and the overall model was not significant, F(1,265) = 2.50, p = .115). In total, the final model accounted for 1.1% of the variance in ADHD-T, which was not significant. As such, this suggests that there is no significant relationship between total ADHD symptomatology and the number of forms of exercise engaged in (after controlling for PA level).

Table 11

Multiple Hierarchical Regression on Total ADHD Symptomatology

Predictor Variables	R	$R^2\Delta$	p	B	95% CI	SE	β	t
Step 1	.04	>.01	.498					
PA level			.498	>-.01	[>-.01, <.01]	<.01	-.04	-.68
Step 2	.11	.01	.115					
PA level			.899	<.01	[>-.01, <.01]	<.01	.01	.13
TFE			.115	-.73	[-1.64, .18]	.46	-.11	-1.58

Note. PA = Physical Activity; TFE = Total Forms of Exercise.

2.4.6. Fitness Tracker Use

A Mann-Whitney test indicated that PA level was significantly greater for people who used fitness tracking tools (Mdn = 3438.75, IQR = 4560), than for those who did not (Mdn = 1915.5, IQR= 3348.75), $U = 5667$, $r_{rb} = .354$, $p < .001$ (medium effect size). A Kruskal-Wallis Test was conducted to examine the differences of PA level according to the type of fitness tracker used. A significant difference, $H(8) = 34.13$, $p = .001$, was found among the nine categories of participants (e.g., None, Apple Watch, etc). Post hoc pairwise comparison tests found that PA level was significantly lower in the no fitness app category (Median = 1915.5 IQR= 3348.75) in comparison to the Fitbit (Median = 4290, IQR = 4335.75; $p = .01$), and Garmin categories (Median = 6177, IQR = 6483; $p = .003$).

2.5. Discussion

Building on initial research primarily conducted with children (Archer & Kostrzewa, 2012; Den Heijer et al., 2017; Gapin et al., 2011; Neudecker et al., 2019; Vysniauske et al., 2020) (see section 1.5.), the overarching aim of this study was to investigate the relationship between levels of PA and ADHD symptoms in adults, while exploring the effects of potential moderating variables. Addressing some of the limitations of prior research in this area (see section 1.6.), a further aim was to investigate the relation between PA and ADHD symptoms among participants who may not have a formal diagnosis, but who may reach psychometrically-defined subclinical thresholds for ADHD. In contrast to prior research (Abramovitch et al., 2013; Archer & Kostrzewa, 2012; Den Heijer et al., 2017; Gapin et al., 2011), there was no significant correlation between ADHD symptom severity or PA level. There was also no significant difference in the strength of correlation between ADHD symptom severity or PA level based on subclinical ADHD diagnosis. There was, however, a significant negative correlation between inattentive ADHD symptom severity and PA level, and between ADHD symptom severity and PA level in the leisure domain. Extending prior research (Duncan et al., 2010; Neudecker et al., 2019; Silveira et al., 2013) no significant difference in PA level based on motivation for exercise was found, and there was also no significant difference in ADHD symptomatology based on main form of PE. This means that hypothesis 1 was partially supported; hypothesis 2 was supported, and hypotheses 3 and 4 were not supported. The main findings of the study are discussed further below.

Based on prior literature (Abramovitch et al., 2013; Archer & Kostrzewa, 2012; Den Heijer et al., 2017; Gapin et al., 2011), it was hypothesised that there would be a significant negative correlation between PA level and ADHD symptomatology (hypothesis 1). In contrast to this, no significant correlation between PA level and total ADHD symptomatology was found in the sample as a whole. This contrasts with previous research by Abramovitch et al. (2013) who found that individuals engaging in high levels of PA reported significantly fewer ADHD symptoms (i.e., behavioural impulsivity and worrisome and intrusive thoughts). When spilt by subclinical ADHD subtype in this study though, PA was found to have a significant (small) negative correlation with inattentive ADHD symptomatology, and a positive (albeit not significant) relationship with hyperactive ADHD symptomatology. The difference between the strength of these two correlations was found to be statistically significant also (Lenhard, W. & Lenhard, 2014), potentially suggesting that PA may only have a significant effect on reducing inattentive ADHD symptoms, and not hyperactive ones. This is supported by previous research that has found PA interventions to have a greater effect on inattentive ADHD symptoms than hyperactive ones (Xie et al., 2021). The other possibility though is that individuals with predominantly hyperactive ADHD symptoms are more likely to engage in PA than individuals with predominantly inattentive ADHD symptoms. This would align with prior research findings that inattentive symptoms in childhood predicted reduced PA in adolescence, whilst the opposite was true for hyperactive symptoms (Selinus et al., 2021), and that individuals with hyperactive presentations may engage with PA as a way of coping and self-treating their symptoms. However, these possible explanations are not mutually exclusive (and both could potentially be contributing to the observed findings) and would need to be investigated further via alternative experimental designs before drawing more definitive conclusions.

Furthermore, greater understanding can also come from breaking down the PA measurement into more specific subcategories, with PE showing a significant negative correlation with general ADHD symptoms and inattentive symptoms, but a positive (non-significant) correlation with hyperactive ADHD symptoms. This could suggest that any positive effects of PA on ADHD symptoms in adults may be reserved to PE, rather than other forms of PA. This view is supported by existing research that has found increased benefits of voluntary exercise (which would likely be the case in the leisure domain of the IPAQ-L), compared to involuntary and forced exercise (which would be more similar to the other domains) (Arnold et al., 2020; Ke et al., 2011; Leasure & Jones, 2008). It is also worth noting that most of the existing evidence around the positive effects of PA on ADHD symptoms (suggesting a negative correlation) are based on PE specifically (Archer & Kostrzewa, 2012; Den Heijer et al., 2017; Neudecker et al., 2019; Vysniauske et al., 2020; Xie et al., 2021), rather than PA in general, as due to the nature of experimental/intervention studies the PA interventions used are planned, structured and repetitive (making them PE, see section 1.4.1.). Alternatively, this finding could also support the earlier suggestion that individuals with predominantly hyperactive ADHD symptoms are more likely to engage in PA than individuals with predominantly inattentive ADHD symptoms. Either way though, these nuanced findings highlight the importance of distinguishing between PA versus PE when exploring the relationship between PA level and ADHD symptomatology.

However, current findings lend support for the second hypothesis, that there would be no significant difference between the strength of relationship between PA level and ADHD symptomatology in participants with and without a subclinical ADHD diagnosis. Again, the findings initially appear to contradict existing research reporting that the rate of improvement of PA on ADHD symptomatology is slightly greater in ADHD subjects (Fuermaier et al., 2014; Pontifex et al., 2013; Tantillo et al., 2002). For example, Pontifex et al. (2013) concluded that only children with diagnosed ADHD exhibited exercise-induced facilitations in action monitoring processes, and regulatory adjustments in behaviour, after exercise. One explanation for the apparent difference in findings, is that previous research only observed a significant *acute* effect of PA on ADHD. In contrast, the measure of ADHD symptomatology in this study would likely only reflect a *chronic* effect of PA. If the differences in effect size between ADHD and non-ADHD subjects is due to acute and not chronic term effects, then this could not be reflected in a correlation study such as this. Additionally, Wigal et al. (2003) found that exercise caused a significantly greater increase in DA, norepinephrine and epinephrine for children without than with ADHD. It is also important to note, that when looking at hyperactive or inattentive ADHD symptoms specifically when split by subclinical diagnosis, the only significant correlation was a negative one between inattentive ADHD symptoms and PA level in Sub-ADHD participants. This could suggest that any positive relationships between, and potential effects of PA on ADHD symptomatology, were not only exclusive to inattentive ADHD symptoms, but also only reached a significant level for subjects with a subclinical level of ADHD. This could also partially explain initial differences in findings highlighted earlier with Abramovitch et al. (2013), as they only sampled individuals with ADHD. However, owing to the correlational design of the current study, these findings could also suggest that only subjects with a subclinical diagnosis of ADHD as well as predominantly inattentive symptoms, are significantly less likely to engage in PA than other subjects (subjects without a subclinical diagnosis of ADHD; and subjects with a subclinical diagnosis but with predominantly hyperactive symptoms). However, a groupwise correlation analysis found that there was no significant difference in the strength of correlation between PA level and inattentive ADHD symptoms when split by subclinical ADHD diagnosis (despite one correlation being significant, and one being non-significant), suggesting that not too much weight should be given to this possibility without further research.

It was also hypothesised that there would be a significant difference in PA level based on motivation for exercise (hypothesis 3), which was not supported by the current data. No significant difference was found in PA level based on motivation type, which is partially supported by previous research from Cash et al. (1994) who found that there was no significant correlation between PE frequency and *most* reasons for PE. However, direct comparison is difficult as their sample was exclusively female and they also used different measurement tools (e.g., motivation was measured using the Reasons for Exercise Inventory and PA was measured by weekly PE frequency). Additionally, current findings conflict with research from Duncan et al. (2010), who found that greater frequency, duration, and intensity of PE were correlated with more autonomous than controlling regulations. Reasons for this discrepancy are likely due to differences in the measurement of motivation: while the current study based different motivation types around potential different reasons, Duncan et al. (2010) based it around Self-Determination Theory (e.g., intrinsic; identified; introjected; and external). This could suggest that while the precise reasons for motivation may not be important for improving PA engagement (and any potential PA based intervention), their source (internal versus external) may be. This could be particularly relevant to adults with ADHD as the extrinsic motivations for children to engage in interventions (e.g., compelled to by parents/school) would be less present for adults who would rely more on intrinsic motivations (Weiss et al., 2008).

Unfortunately, it was not possible to fully explore the hypothesis that there would be a significant difference on ADHD symptomatology based on main form of PE (hypothesis 4), as it was not possible to effectively group different forms of exercise. Therefore, the total number of different forms of exercise performed by an individual were instead investigated. Previous literature has suggested that more combined based PA interventions (involving both aerobic and strength training) can lead to more positive benefits than singular based interventions (Neudecker et al., 2019; Silveira et al., 2013). Current findings seem to conflict with this as there was no significant correlation between total forms of exercise performed by a participant and ADHD symptomatology. However, like the main relationship between PA level and ADHD symptomatology, when ADHD symptomatology was split by type, it was found that hyperactive ADHD symptoms had a non-significant positive correlation with TFE, whereas inattentive symptoms had a significant negative correlation. Hypothetically, this could suggest that any positive effects of combining different exercise types are only found in inattentive ADHD symptoms/subtypes; and/or individuals with predominantly inattentive ADHD symptoms are less likely to try out different forms of exercise. However, note that the exact direction and nature of any such effects would have to be determined via additional work with an alternative study design.

In relation to the exploratory research aims, the finding that fitness tracker use was positively correlated with PA level aligns with previous research showing a positive effect of fitness tracker use on PA (Ferguson et al., 2022; Lynch et al., 2020). This finding was expected, as fitness tracker use could both encourage PA and be more commonly used by individuals already engaging in relatively high levels of PA. However, further analysis of different fitness tracker types revealed that the significant correlation was likely attributable to participants using Fitbit or Garmin devices, who reported higher levels of PA compared to non-users. In contrast, participants using other fitness trackers did not engage in significantly different levels of PA compared to non-users. These findings could be interpreted in one of two ways: either that specific fitness tracker types are more effective in promoting PA, and/or they are more likely to be used by those who are already engaging in higher levels of PA. However, given the scope of this study, no further conclusions can be drawn regarding these possibilities.

Another unexpected finding was the lack of any significant difference in subclinical diagnostic rates of ADHD when split by gender. As already outlined, previous research has focused largely on males due to higher diagnosis rates, potentially overlooking a large sample of females with ADHD due to underdiagnosis. The findings of the study potentially support the claim of female underdiagnosis in ADHD (Quinn & Madhoo, 2014) and suggest that the prevalence rate is much more even across males and females. Of particular interest was the finding that when the data was split by gender, the negative correlation between inattentive ADHD symptoms and PA level was not significant in males but reached a high level of significance in females (p=.01).

One possible implication of our findings to policy and practice, is that efforts to incorporate exercise into treatment regimens for adult ADHD may benefit from being focused towards individuals with the predominantly inattentive presentation of ADHD than other presentations (combined or hyperactive), either because: the positive effects of exercise are most significant in inattentive ADHD symptoms; and/or individuals with predominantly inattentive ADHD are less likely to already be engaged in exercise than those with other presentations. However, owing to the correlational nature of our design, it should be acknowledged that our findings could also suggest instead that individuals with hyperactive ADHD may be more open and likely to engage with exercise-based interventions. This could then imply the opposite: that exercise treatments could have greater effect when focused on individuals with hyperactive than inattentive symptomatology. Thus, a dual approach may be beneficial: encouraging exercise among individuals with a predominantly inattentive subtype, whilst leveraging the tendency for those with hyperactive presentations to perhaps already engage in PA.

As there was no significant difference between motivation types on PA level, this also suggests that motivation might not be a variable of importance when designing potential PE based interventions. Instead, it suggests that if an individual can be motivated in some way, and this motivation is primarily internal rather than external, this should lead to increased commitment with any interventions (Duncan et al., 2010). Therefore, rather than interventions focusing their promotion of exercise for a particular reason (e.g., focusing on specifically the health benefits, or social aspects, or appearance etc), which might not be important or relevant to individuals (and act as external regulations), professionals may benefit from adopting an individualistic approach: taking time with individuals to find out what potential motivations are the most important to them specifically (acting as internal regulations), and focusing on those to promote exercise. That is, interventions should be personalised, identifying and fostering the most relevant motivations for each individual. In turn, this could enhance adherence to, and potentially the effectiveness of, PA-based interventions, particularly as research has shown intrinsic motivations to be positively associate with PA adherence (Ryan et al., 1997; Thøgersen-Ntoumani et al., 2016). It is important to note though, that the current study was not able to differentiate between the different forms of exercise and consequently, it is unclear if any particular form of PE should be promoted over others.

The current study has a number of limitations that should be taken into account when considering its implications for practice (i.e., intervention design) and suggestions for further research. Data collection occurred between December 2021 and March 2022, at a time when COVID-19 lockdown conditions were largely in place in the UK. This could have affected participants answers on the IPAQ-L, as they might not have been able to engage in as much PA as normal. The sample was also biased towards females, students, and younger adults. This may have contributed towards the main measures of PA and ADHD symptomatology not being normally distributed as students may engage in less PA than the general population, thus leading to the negative skew in the IPAQ-L. Therefore, given the composition of the sample and study context, our findings may not be generalisable to a more diverse population. A lack of specificity in some measurement types also limited the amount of analysis possible. Thus, future studies would benefit from utilising more detailed and specific measures (i.e., forms of exercise, motivation) where practicable and feasible, to allow a more nuanced analysis and understanding of their potential effects.

To enable further evaluation of the potential effectiveness of PA on ADHD symptomatology, and/or the likelihood of those with ADHD fruitfully engaging with PA, future work may also wish to explore different types of ADHD symptoms and presentations, and to also differentiate between inattentive and hyperactive subtypes, rather than treat ADHD as a monolith category. In turn, additional insights gained could help improve the efficacy and potential cost-effectiveness of any interventions also (e.g., by allowing for greater determination on who would benefit the most from/be more likely to engage with any treatments).

Similarly, the findings highlight the importance of further addressing ADHD in females in this area. Using subclinical diagnostic measures might allow for a much higher rate of female participation, as well as supporting future research to more easily reach sufficient sample sizes for robust analysis. Secondly, the findings suggest that the correlation between PA and ADHD symptomatology is different between genders. Whether this is due to the effect of PA being different in females, or because ADHD in females makes them less inclined to perform PA than males, is currently unclear and warrants further investigation. As such, future research should try to distinguish between demographic factors such as gender and ADHD presentation type, as failing to do so may lead to overlooking potentially significant differences among individuals with ADHD. Indeed, considering the nature of ADHD and its potential interactions with various external factors, it is important that future research more broadly considers potential confounding variables throughout the research process. For instance, PA preferences and energy levels may vary across age, comorbidities may interact with ADHD symptoms and affect individuals' motivation or ability to engage in PA, and lockdown circumstances may result in decreased PA levels.

2.5.1. Conclusions

To conclude, the findings of this study suggest that the relationship between PA and ADHD symptomatology is complex, and may need to be broken down into smaller, more specific factors to be properly understood. Specifically, while there was no significant relationship between PA level and total ADHD symptomatology, further analysis suggests that significant relationships may exist between specific subtypes of PA (such as physical exercise) and ADHD (such as inattentive ADHD symptoms), as well as within specific subgroups (such as females and individuals with ADHD). Furthermore, analysis of certain variables, primarily motivation, was limited and could be improved by modifying the measurement approach. This underscores the need for additional detailed investigations to further elucidate the relationship between PA level and ADHD symptomatology in adults, and to enable evaluation of the potential effectiveness of PA as a potential adjunct therapeutic option.

Chapter Two: Key Messages

- This study aimed to investigate the relationship between levels of PA and ADHD symptoms in adults, while exploring the effects of potential moderating variables, with particular emphasis placed on researching demographics typically underrepresented in previous research (e.g., adults; females; those lacking formal diagnosis).
- This study found no significant correlation between PA level and total ADHD symptomatology; the strength of relationship between PA level and ADHD symptomatology did not differ based on subclinical ADHD diagnosis; PA level did not significantly differ based on motivation type; or by forms of exercise performed.
- However further analysis found significant negative correlations between PA and ADHD symptomatology, dependent on specific subtypes of PA (such as PE) and ADHD (such as inattentive ADHD symptoms), as well as within specific subgroups (such as females and individuals with subclinical ADHD).
- Additionally, analysis into forms of exercise and motivation type were limited potentially due to form of measurement. Adopting established frameworks, such as Self Determination Theory, could enable more comprehensive analysis.
- Current findings guide the refinement and improvement of methodology for this thesis by: (1) differentiating variable subtypes/subgroups to capture crucial distinctions, and (2) Using self-determination theory for measuring and understanding motivation.

3. Chapter Three: Understanding the Link Between Physical Exercise, Autonomous Motivation, Exercise Dependence, and Adult ADHD Symptoms

3.1. Chapter Overview

Findings from Chapter Two suggested that the relationship between ADHD and PA/PE may be more complicated than originally thought, with further research giving greater consideration of PA and ADHD subtypes and investigating the role of motivation from a SDT perspective. Consequently, this chapter aims to further investigate these directions, while also exploring potential connections with Exercise Dependence (ED)/Exercise Addiction (EA). The overarching goal of this chapter is to investigate the relationship between these key variables (PE; ADHD; motivation; ED) to provide greater understanding behind the underlying psychological motivations for PE and highlight potential risks related to ADHD.

3.2. Introduction

Chapter Two established a foundation by identifying key subgroups and variable subtypes that influence the primary relationship between PA and ADHD, but a number of issues and new research directions emerged that warrant investigation. In particular, these involved: 1) investigating the primary relationship between PA and ADHD symptomatology with greater consideration of PA and ADHD symptom subgroups/types - as using single monolith categories could lead to critical distinctions/findings being missed; and 2) investigating more nuanced dimensions of motivation aligned with a self-determination theory. Namely, Chapter Two utilised methods to categorise motivation into potential ‘types’, whereas self-determination perspectives emphasise extrinsic versus intrinsic motivation. In turn, expanding the research to explore motivation provides opportunity to investigate potential connections between PA motivation and Exercise Dependence (ED)/Exercise Addiction (EA) due to suggestions that motivation may be a key factor in identifying those at greatest risk of EA (Freimuth et al., 2011; Landolfi, 2013).

Within Self Determination Theory (SDT), expressions of motivation are framed as lying on a scale from autonomous/intrinsic motivations (self-determined motivations/freely initiated by the individual) and controlling/extrinsic motivation (motivations based on external factors even if they have been internalised) (K. A. Miller et al., 1988). Applying SDT to PA, more autonomous motivations have been linked with greater exercise frequency, duration, intensity (Duncan et al., 2010), and adherence (Teixeira et al., 2012). Motivation is also recognised as critical factor for ADHD interventions, enhancing engagement (Alabdulakareem & Jamjoom, 2020) and intervention effectiveness (Van der Oord & Tripp, 2020; Weiss et al., 2008), and intrinsic motivation has been identified as a critical component in enhancing intervention effectiveness in general (Medalia & Saperstein, 2011). Notably, individuals with ADHD typically have lower intrinsic motivation in academic related work (Smith & Langberg, 2018) and motivation in general (Modesto-Lowe et al., 2013) (see section 1.3.6.) but the relationship between intrinsic motivation and PA within ADHD remains unexplored.

Further research into motivation would also provide an opportunity to investigate potential links with Exercise Dependence (ED)/Exercise Addiction (EA), as motivation can be directly linked to both increased PA (Ryan et al., 1997; Teixeira et al., 2012; Thøgersen-Ntoumani et al., 2016) and ED (Edmunds et al., 2006; Hamer et al., 2002). As defined previously (see section 1.4.3.), ED refers to a state in which a person exercises excessively/obsessively to a point of dependence, whereas EA is defined as dysfunctional behaviour marked by exaggerated training, loss of control over exercise behaviour, and negative impacts on daily life (P. M. Miller, 2013). Whilst the rate of EA among general exercisers has been found to be around 8.1% (Trott et al., 2020), rates may be higher in individuals with ADHD. Indeed, there is an established association between ADHD and risk of addictions, including behavioural ones (Starcevic & Khazaal, 2017), and Colledge et al., (2022) found that individuals deemed "at-risk" of exercise addiction reported significantly higher symptoms of ADHD. Similarly, Popat et al., (2021) found that medicated individuals with ADHD reported higher levels of exercise withdrawal and fixation levels, although ED total scores did not differ significantly from healthy controls. Further, regardless of medication status, those with ADHD were more likely to be symptomatic non-dependant (showing some symptoms but not meeting the diagnostic threshold for ED) than healthy controls, suggesting increased risk even if diagnostic thresholds are not met. This is further supported by Ramji et al., (2024) who also found a relatively high rate of symptomatic non-dependence for ED in ADHD individuals (38.9%), although the rate was slightly lower than what was found in Popat et al., (2021) (54.2%). Nevertheless, owing to limited research, the underlying mechanisms and nature of the relationship between ADHD and ED, remain unclear, warranting further investigation.

Referring back to motivation, links have been found between motivation and ED, with higher levels of introjected motivation (a form of extrinsic motivation) positively correlated with higher levels of ED (Hamer et al., 2002), and being a significant predictor of ED (Edmunds et al., 2006). Understanding this link within ADHD is therefore important to understand any link between ADHD and ED, as well as to better inform potential exercise interventions for ADHD so that they do not inadvertently increase ED as a negative consequence.

Such research is also particularly important for adults with ADHD, where motivation plays a key role in their engagement with interventions (Weiss et al., 2008). Unlike children, adults with ADHD may lack extrinsic motivations and structural systems such as parental or school oversight, necessitating greater reliance on intrinsic motivations to sustain engagement and participation. Additionally, adulthood has been identified as a critical stage for ED risk to manifest (Costa et al., 2013), yet the relationship between PA and ADHD in adults remains largely underexplored (Vysniauske et al., 2020).

Therefore, the aim of this study was to investigate the relationships between ADHD symptomatology, motivation, and ED within an adult population. Based on previous literature, it was hypothesised: 1) there would be a significant positive correlation between ADHD symptomatology and ED (one-tailed); 2) there would be a significant correlation between ADHD symptomatology and autonomous exercise motivation (two-tailed); 3) there would be a significant correlation between ED and autonomous exercise motivation (two-tailed).

3.3. Methods

3.3.1. Participants

Participants were recruited online via social media adverts, email invitations, Survey Circle (SurveyCircle, 2016), and a University Psychology participant pool system. The study was advertised as *"Physical activity, motivation and behaviour in adults",* and participants were not offered any reimbursement or financial compensation for taking part. To be eligible to take part, participants had to be at least 18 years of age and resident in the United Kingdom. G-Power calculations indicated that for 95% power, with a rejection criterion of *p*

< .05, and medium effect size (r = .3), a minimum sample size of 138 participants was required.

Of the 207 participants who accessed the survey, 55 were subsequently excluded for the following reasons: not being a resident of the UK (n=8); not completing the study in full (n=17); not correctly answering attentional control checks (n=13); having duplicate responses to another respondent with same IP address (likely same participant responding twice; n=3); scoring above the maximum limit for the IPAQ-L (n=10); and counting as extreme outliers for the IPAQ-L Leisure domain score (defined as exceeding the 3rd quartile of TFE score + 3*IQR; n=4).

This left 152 participants, of whom 122 (77.63%) were female. Ages ranged from 18 to 62 (M = 21.59, SD = 5.74) years, with further demographic information presented in Table 12. Options for the Gender and Ethnicity question were based on the categories recommended by the UK government (Race Disparity Unit, 2021).

Table 12

*Demographic Information of the Study Sample (*N*=152)*

Demographics	*n* (%)
Gender	
Male	22 (14.47)
Female	118 (77.63)
Other	9 (5.92)
Prefer not to say	3 (1.97)
Ethnicity	
White/English/Scottish/Northern Irish/British	109 (71.71)
Arab	3 (1.97)
Any other white background	14 (9.21)
White and Black African	1 (0.66)
White and Asian	5 (3.29)
Any other Mixed/Multiple ethnic background	3 (1.97)
Indian	5 (3.29)
Pakistani	3 (1.97)
Bangladeshi	3 (1.97)
Chinese	3 (1.97)
African	3 (1.97)
Highest Level of education	
Secondary/Highschool (e.g. GCSE's) or equivalent	3 (1.97)
College/Sixth form (e.g. BTEC, A-Levels) or equivalent	82 (53.95)
University (e.g. BSc, BA, Degree)	53 (34.87)
Masters (e.g. MSC, MA)	10 (6.58)
PhD/Doctorate	2 (1.32)
Other	2 (1.32)
Employment Status	

Full-time employment	12 (7.89)
Part-time employment	19 (12.5)
Unemployed as unable to work	1 (0.66)
Currently unemployed but looking for work	4 (2.63)
Full-time student	107 (70.39)
Part-time student	6 (3.95)
Unpaid voluntary work	1 (0.66)
Other	2 (1.32)

Note: GCSE = General Certificate of Secondary Education; BTEC = business and Technology Education Council; A-level = Advanced level qualification; BSc = Bachelor of Sciences; BA = Bachelor of Arts; MSC = Master of Sciences; MA = Master of Arts; PhD = Doctorate of Philosophy.

3.3.2. Apparatus and Materials

The survey was administered online using Qualtrics (Qualtrics, 2005). Participants supplied standard demographic details (e.g., age, gender, ethnicity) and responded to questions about comorbid conditions (Appendix A and B). If English was not their first language, participants were also asked to rate their language proficiency in reading, writing, and speaking on a five-point scale ranging from 'Weak' to 'Excellent' (Appendix H). Standardised questionnaires were also included:

The ADHD Rating Scale – IV with Adult prompts (ADHD-RS-IV) (Adler et al., 2009) (Appendix E) was used to measure ADHD symptomatology (see section 2.3.2 for details). Within the current sample, the ADHD-RS-IV demonstrated good to excellent levels of internal reliability, with Cronbach's Alpha coefficients of .88 for inattentive (items one-nine), .85 for hyperactive (items 10-18), and .9 for ADHD-T (items 1-18).

The International Physical Activity Questionnaire – Long Format, last seven days, self-administered (IPAQ-L) (Craig et al., 2003) (Appendix F): Total IPAQ-L score (sum of all four domain sub scores) measured PA level, while the Leisure domain indexed PE level (see section 2.3.2. for details).

Behavioural Regulation in Exercise Questionnaire – version 3 (BREQ-3) (Wilson et al., 2006) (Appendix I): A 24 item self-report questionnaire assessing external, introjected, identified, and intrinsic forms of regulation of exercise behaviour and motivation. Participants rate statements about their exercise attitudes (e.g. *"I feel guilty when I don't exercise"*) on a four-point scale (0 = not true of me, 4 = very true of me). Mean scores for set items generate scores for six subscales: 1) Amotivation (lacking any intention to engage in exercise); 2) External Regulation (exercise only done to comply with external pressures e.g., being instructed to by someone in authority); 3) Introjected Regulation (external pressures are internalised, e.g., exercising to avoid judgment of others); 4) Identified Regulation (conscious acceptance of exercise as important for personally valued outcomes e.g., identifying exercise being important for good health); 5) Integrated Regulation (internalisation of Identified Regulation, so exercise is confluent with one's sense of self e.g., exercising to improve health willingly with no coercion); and 6) Intrinsic Regulation (exercise is appreciated for the experience and extrinsic outcomes are not concerned e.g., simply exercising out of enjoyment of the experience itself). Each subscale score can then be weighted to generate the Relative Autonomy Index (RAI), indicating the degree of self-determination. Subscale scores range from 0-4, and RAI ranges from -24 to 24. The BREQ-3 has adequate internal consistency (McDonald's Ω ranging between .73 to .91) (Rocchi et al., 2023), with good to excellent levels in the current sample also (Cronbach α range .84 to .94).

Exercise Dependence Scale – Revised (EDS-R) (Downs et al., 2004) (Appendix J): A 21-item self-report questionnaire assessing the degree of exercise dependence based on DSM-IV criteria for substance dependence. Participants rate statements regarding their beliefs and behaviours with exercise (e.g., *"I exercise longer than I expect"*) over the past three months on a six-point Likert scale (1 = never, 6 = always). Ratings provide a total ED score (EDS-T), which comprises the sum of ratings for seven subscales: 1) Withdrawal (manifested by withdrawal symptoms for exercise); 2) Continuance (Exercise continues even though a problem is likely to have been caused/exacerbated by exercise); 3) Tolerance (need for increased amounts of exercise to achieve desired effect, or experiencing diminished effects with same amount of exercise); 4) Lack of Control (desire/unsuccessful effort to reduce/control exercise); 5) Reductions in Other Activities (ROA) (reduction or abandonment of activities due to exercise); 6) Time (amount of time engaging in exercise); and 7) Intention effects (exercising in larger amounts/over a longer period than intended). Subscale scores range from 3-18 and 21-126 for EDS-T. The scale has excellent test-retest reliability (r=.95), and most subscales show adequate to excellent internal consistency (Cronbach α ranging between .78 to .92) (Downs et al., 2004). Within the current study, internal consistency was excellent (Cronbach α = .96).

The Adult ADHD Self Report Scale – v1.2 (ASRS-5) (Ustun et al., 2017) (Appendix K): A six-item self-report questionnaire used as a screening tool to assess subclinical levels of ADHD in adults using the DSM-5 criteria and derived from the ASRS v1.1 (Kessler et al., 2005) which was based on DSM-IV criteria (see section 2.3.2.). Respondents are required to use a five-item Likert scale to indicate the frequency of occurrence of symptoms (0 = *never* to 4 = *very often*), resulting in a range of scores from 0-24. The ASRS-5 score can act as a continuous predictor of ADHD or as a subclinical diagnostic tool, with a score of 14 or higher suggestive of ADHD. The ASRS-5 has shown excellent validity, with a sensitivity rate of 91.4% and specificity rate of 96% (Ustun et al., 2017). Within the current study, internal consistency was acceptable (Cronbach α = .7). Although included in the survey, data from the ASRS-5 was not utilised in the analysis as the

ADHD-RS-IV generated usable subclinical ADHD subgroups (with greater sensitivity) including those based on subtype.

3.3.3. Design

The study was a cross-sectional observational study. The primary variables of interest were ED (EDS-T); motivation (RAI); ADHD symptomatology (ADHD-T, ADHD-I, ADHD-H) and PE Level. In the semi-partial correlational analyses involving ADHD symptomatology, ADHD symptomatology was the independent variable, and the other variable involved (Motivation or ED) was the dependent variable. In the semi-partial correlational analysis between Motivation or ED, motivation was the independent variable, and ED was the dependent variable. PE served as the covariate for all semi-partial correlational analyses.

3.3.4. Procedure

The research was approved by the Swansea University Psychology Department Research Ethics Committee (Approval Number: 1 2023 6008 5223) (Appendix L). Participants accessed the survey via Qualtrics and were presented with a detailed information page, followed by an electronic consent page (Yes/No checkbox). Non-consenting participants were directed to the end of the survey and were excluded from data analysis. This ensured that all participants included within data analysis were 18 years old or over and had provided informed consent. Consenting participants then completed demographic questions, followed by questions on comorbidities, and then the ASRS-5. They were then presented with the ADHD-RS-IV; BREQ-3; EDS-R; and IPAQ-L in a randomised order. Finally, participants were presented with a debrief page. All survey sections required a response (except for the questions in the IPAQ-L a participant would have skipped given responses), ensuring complete participation. There was no time limit, and the average completion time, excluding outliers, was 15 minutes and 34 seconds.

3.3.5. Data Processing and Statistical Analysis

Statistical analyses were carried out using IBM SPSS Statistics version 28.0 and version 29.0 (IBM Corp, 2021; IBM Corp., 2023), PROCESS v4.0 (Hayes, 2018), and JASP 0.18.0 (JASP Team, 2023).

Attentional check items were included in the ASRS-5, BREQ-3, and EDS-R (e.g., "Please select option "4"). Participants who failed these simple attentional check items were excluded from further analysis.

IPAQ-L data underwent cleaning following guidelines set by the IPAQ group. Participants were also grouped into non-ADHD or subclinical ADHD participants based on their ADHD-RS-IV scores, adhering to established procedures (Döpfner et al., 2006; Mattingly et al., 2012): participants responding 2-3 on 6 or more inattentive prompts but 5 or less hyperactive prompts were categorised as meeting the subclinical threshold for inattentive ADHD diagnosis (Sub-Inattentive). The reverse was applied for hyperactive ADHD (Sub-Hyperactive). Participants meeting both thresholds were categorised as combined ADHD (Sub-Combined), while those meeting neither were categorised as Non-ADHD. A final group comprised participants who met any subclinical ADHD threshold (Sub-ADHD). Additionally, as the ADHD-RS-IV generated usable subclinical ADHD subgroups (that could also be split by subtype) and (from comparing diagnosed rates of ADHD measured on the comorbidity questionnaire) had greater sensitivity than the ASRS-5, data from the ASRS-5 was not used to generate subgroups.

Most study variables (ADHD-T, ADHD-I, ADHD-H, RAI) were normally distributed (skewness, histograms). However, EDS-T and PA level required transformation (EDS-T by logarithmic transformation; PA level by square root transformation) to meet normal distribution assumptions. Despite transformation, PE, and BREQ-3 and EDS-R subscales remained non-normally distributed. Therefore, analyses involving these variables utilised nonparametric tests with the untransformed variables. Additionally, demographic factors (age; gender; ethnicity; education; and employment) and comorbidities did not show significant correlations/differences with multiple key variables, so were not used as control variables.

Pearson's correlations were performed to assess relationships between normally distributed variables. Correlations between ED/Motivation and ADHD symptomatology were then controlled for by PE level (semi-partial correlations), to ensure any correlations ED/Motivation and ADHD symptomatology were not a result of PE level. For correlations involving non-normally distributed data or controlling for PE, non-parametric semi-partial correlations were utilised. This involved generating residuals of independent variables from PE level and then performing Kendall Tau's correlations between the residual independent and dependent variables. Additionally, to account for multiple comparisons, Bonferroni-Holm corrections were applied to correlations between ADHD symptomatology and both ED (seven) and Motivation (six) subscales.

Finally, to compare the strength in relationships between ED and RAI across subclinical ADHD groups, a moderation analyses was performed, with RAI entered as the independent variable (X), EDS-T as the dependent variable (Y), and subclinical ADHD diagnosis as the moderator (W). Originally this was planned to be conducted with all four ADHD subgroup levels (Non-ADHD; Sub-Inattentive; Sub-Inattentive; and Sub-Combined) but due to limited numbers of some ADHD subgroups (see Table 14) subclinical ADHD diagnosis was only set to two levels (Non-ADHD; Sub-ADHD). The relevant assumptions of this statistical analysis were tested. The assumption of singularity was found to be met by checking Durbin-Watson significance values. The assumption of multicollinearity was deemed to have been met as an examination of correlations revealed that no independent variables were highly correlated with one another, and collinearity statistics (i.e. tolerance and VIF) were all within acceptable limits. In addition, residual and scatter plots indicated that the assumptions of normality, linearity and homoscedasticity were all met.

Significance levels for correlations between ADHD symptomatology and ED (hypothesis 1) were set for one-tailed, whereas significance levels between ADHD symptomatology and autonomous exercise motivation (hypothesis 2), and between ED and autonomous exercise motivation (hypothesis 3), were set for two-tailed.

As per Cohen (Cohen J., 1988) the effect size for Pearson's r and Spearman's rho were defined as: .1 = small effect size; .3= medium; .5 = large. To account for Kendall tau having smaller values, the effect sizes were corrected the by .9 (.09 = small; .27 = medium; .45 = large).

3.4. Results

3.4.1. Descriptive Results

Descriptives are presented in Table 13. Significant correlations were observed between most key variables, including significant positive correlations between: PA level and ADHD-H (small effect size), RAI (small effect size), and EDS-T (medium effect size); between PE level and ADHD symptomatology (Total and Hyperactive) (small effect sizes), RAI (medium effect size), and EDS-T (medium effect size); between RAI and EDS-T (large effect size); and between EDS-T and ADHD symptomatology (Total and Hyperactive) (small and medium effect sizes respectively). Additionally, a significant negative correlation was found between RAI and Inattentive ADHD symptomatology (small effect size).

Table 13

Descriptive Statistics and Correlation Coefficients (Pearson's r*) for Study Variables Split By Subclinical ADHD Diagnosis)*

Variable	*M*	*SD*	1	2	3	4	5[a]	6
Total Sample (*n*=152)								
1. ADHD-T	22.84	10.61	-	-	-	-	-	-
2. ADHD-I	12.27	6.05	.89***	-	-	-	-	-
3. ADHD-H	10.57	5.87	.89***	.59***	-	-	-	-
4. PA level	65.33	37.79	.14	>.01	.24**	-	-	-
	(3702.5)[b]	(7490.63)[b]						
5. PE level[a]	(594)[b]	(1334.5)[b]	.19*	.05	.27***	.71***	-	-
6. RAI	7.71	7.75	-.11	-.19*	-.01	.18*	.34***	-
7. EDS-T	1.67	0.18	.23**	.1	.31***	.34***	.47***	.59***
	(47)[b]	(31)[b]						
Non-ADHD (*n*=95)								
1. ADHD-T	16.66	6.75	-	-	-	-	-	-
2. ADHD-I	8.84	3.86	.86***	-	-	-	-	-
3. ADHD-H	7.82	3.86	.87***	.49***	-	-	-	-
4. PA level	64.83	38.19	.28**	.11	.36***	-	-	-
	(3334.5)[b]	(8161.5.)[b]						
5. PE level[a]	(495)[b]	(1485)[b]	.29**	.14	.32**	.72***	-	-
6. RAI	8.51	7.14	-.19	-.25*	-.07	.04	.28**	-
7. EDS-T	1.66	0.18	.28**	.15	.34***	.25*	.45***	.57***
	(47)[b]	(31)[b]						
Sub-ADHD (*n*=57)								
1. ADHD-T	33.14	7.37	-	-	-	-	-	-
2. ADHD-I	17.98	4.52	.64***	-	-	-	-	-
3. ADHD-H	15.16	5.69	.79***	.03	-	-	-	-
4. PA level	66.16	37.44	.06	-.19	.23	-	-	-
	(4304)[b]	(5976.5)[b]						

5. PE level[a]	(792)[b]	(1252.25)[b]	.14	-.12	.26	.69***	-	-
6. RAI	6.38	8.57	.19	.01	.24	.39**	.47***	-
7. EDS-T	1.68 (45)[b]	0.19 (30.5)[b]	.26	-.02	.35**	.49***	.49***	.65***

Note. Statistical significance: **p* < .05; ***p* < .01, ****p* < .01 .

Brackets represent the median and *IQR* of untransformed variables below the mean and *SD* of the transformed variable. ADHD-T = Total ADHD Symptomatology; ADHD-I = Inattentive ADHD Symptomatology; ADHD-H = Hyperactive ADHD Symptomatology; PA = Physical Activity; PE = Physical Exercise; RAI = Relative Autonomy Index; EDS-T = Exercise Dependence Score-Total

[a] Correlation coefficients represent Pearson's *r*, except for coefficients with PE level which represent Spearman's rho.

[b] Brackets represent the median and *IQR* of non-normally distributed variables/untransformed variables below the mean and *SD* of the transformed variable.

Table 14

Distribution of Subclinical Diagnosis of ADHD in Relation to Gender

Gender	Non-ADHD	Sub-ADHD	Sub-Inattentive	Sub-Hyperactive	Sub-Combined
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
Male	12 (54.55)	10 (45.45)	7 (31.82)	0 (0)	3 (13.64)
Female	79 (73.75)	39 (33.05)	17 (14.41)	8 (6.78)	14 (11.86)
Other	4 (44.44)	5 (55.56)	1 (11.11)	1 (11.11)	3 (33.33)
Prefer not to say	0 (0)	3 (100)	2 (66.67)	0 (0)	1 (33.33)
Total	95 (62.5)	57 (37.5)	27 (17.76)	9 (5.92)	21 (13.82)

As shown in Table 14, a slightly higher proportion of males (45.45%) had subclinical ADHD compared to females (33.05%), although this difference was not statistically significant, $\chi 2(1) = 1.25$, $p = .263$ (12 participants who selected 'other' or 'prefer not to say' were excluded from this analysis). Additionally, Sub-inattentive subtype had the highest prevalence (17.76%), followed by Sub-combined (13.82%), and then Sub-hyperactive (5.92%).

3.4.2. ADHD Links with Exercise Dependence

A semi-partial correlation was conducted to determine the relationship between EDS-T (dependant variable) and ADHD symptomatology (independent variable), whilst controlling for PE (hypothesis 1). There was a significant positive semi-partial correlation between EDS-T and ADHD-T (τ_b [149] = .1, p =.038) (small effect size); a non-significant positive semi-partial correlation between EDS-T and ADHD-I (τ_b [149] = .05, p =.189); and a significant positive semi-partial correlation between EDS-T and ADHD-H (τ_b [149] = .14, p =.005) (small effect size).

Table 15.

Semi-Partial Correlations (Kendall's Tau) Between ED, ADHD Symptomatology and RAI While Controlling for PE

Variable	ADHD-T	ADHD-I	ADHD-H	RAI
EDS-T	.1*	.05	.14**	. 37***
Withdrawal	.15*	.08	.2**	.32***
Continuance	.19**	.14*	.22***	.18**
Tolerance	-.02	-.07	.06	.42***
Lack of Control	.13*	.12	.14*	.24***
ROA	.14*	.1	.16*	.29***
Time	.02	-.03	.08	.41***
Intention Effects	.1	.05	.14*	.27***

Note. Statistical significance: *$p < .05$; **$p < .01$, ***$p < .001$ (after corrections have been applied as mentioned in the Methods).

ADHD-T = Total ADHD Symptomatology; ADHD-I = Inattentive ADHD Symptomatology; ADHD-H = Hyperactive ADHD Symptomatology; RAI = Relative Autonomy Index; EDS-T = Exercise Dependence Score-Total; ROA = Reductions in Other Activities

Table 15 presents the semi-partial correlations between ED (and its subscales) and ADHD symptomatology, while controlling for PE. Notably, ADHD-H was consistently more positively correlated with all ED subscales compared to ADHD-I. Among the subscales, Tolerance and Time were the only subscales not significantly positively correlated with ADHD-H, and ADHD-T was also not significantly positively correlated with Intention Effects. Conversely, ADHD-I was only significantly positively correlated with Continuance.

3.4.3. ADHD Links with Motivation

A semi-partial correlation was conducted to determine the relationship between RAI (dependant variable) and ADHD symptomatology (independent variable), whilst controlling for PE (hypothesis 2). Significant negative semi-partial correlations were found between RAI and both ADHD-T (τ_b [149] = -.13, p =.023) (small effect size) and ADHD-I (τ_b [149] = -.15, p =.008) (small effect size). A non-significant negative correlation was found between EDS-T and ADHD-H (τ_b [149] = -.06, p =.275).

Table 16

Semi-partial Correlations (Kendall's Tau) Between Motivation, ADHD Symptomatology and EDS-T While Controlling for PE

Variable	ADHD-T	ADHD-I	ADHD-H	EDS-T
RAI	-.13*	-.15**	-.06	.37***
Amotivation	.1	.11	.07	-.09
External Regulation	.16*	.14	.15	.08
Introjected Regulation	.08	.07	.05	.28***
Identified Regulation	.01	-.02	.04	.45***
Integrated Regulation	-.08	-.12	<-.01	.46***
Intrinsic Regulation	-.08	-.09	-.02	.38***

Note. Statistical significance: *p < .05; **p < .01, ***p < .001 (this is after corrections have been applied as mentioned in the Methods).

ADHD-T = Total ADHD Symptomatology; ADHD-I = Inattentive ADHD Symptomatology; ADHD-H = Hyperactive ADHD Symptomatology; RAI = Relative Autonomy Index; EDS-T = Exercise Dependence Score-Total

Table 16 shows the partial correlations between motivation (and subscales) and ADHD symptomatology, while being controlled for by PE. After controlling for PE, the negative correlation between ADHD-T and RAI became significant, contrasting to the correlation without control (Table 13). ADHD-H was consistently more positively correlated with motivation subscales positively contributing to relative autonomy (Identified, Integrated and Intrinsic Regulation) than ADHD-I was, while being generally more negatively correlated with subscales that negatively contribute to relative autonomy (Introjected Regulation and Amotivation). However, External Regulation was the only subscale significantly correlated with ADHD symptomatology, with a significant positive correlation with ADHD-T but not ADHD-I or ADHD-H.

3.4.4. Exercise Dependence Links with Motivation

A semi-partial correlation was conducted to determine the relationship between EDS-T (dependant variable) and RAI (independent variable) whilst controlling for PE (hypothesis 3). There was a significant positive partial correlation between EDS-T and RAI (τ_b [149] = .37, p <.001) (medium effect size). Further, all motivation subscales were significantly positively correlated with EDS-T (with medium to large effect sizes), except for Amotivation and External Motivation (Table 16). Additionally, all ED subscales were significantly positively correlated with RAI (with small to medium effect sizes), (Table 15).

To determine if the relationship between RAI and EDS-T was different based on subclinical ADHD diagnosis, a moderation analysis was performed using PROCESS macro (model 1), with RAI entered as the independent variable (X), EDS-T as the dependent variable (Y), and subclinical ADHD diagnosis as the moderator (W). Altogether, the final model was significant, with 26.76% of the variability in ADHD-T predicted by the variables, $R^2 = .27$, $F(3,148) = 18.03$, $p < .001$. The interaction was not significant, as the impact of

RAI on EDS-T in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ =.37, $b < .01$, $t = .61$, $p = .542$).

3.5. Discussion

The aim of this study was to investigate the relationships between ADHD symptomatology with motivation and ED. After controlling for PE, the current study found positive correlations between ADHD symptomatology (total and hyperactive) and ED; negative correlations between ADHD symptomatology (total and inattentive) and autonomous PE motivation; and a positive correlation between ED and autonomous PE motivation. This means that hypotheses 1, 2 and 3 were supported. The main findings of the study are discussed further below.

Based on previous literature (Colledge et al., 2022; Popat et al., 2021), it was hypothesised that there would be a significant positive correlation between ADHD symptomatology and ED. The current findings support this, as evidenced by the significant positive correlation between EDS-T and both ADHD-H and ADHD-T, albeit with only a small effect size (along with a non-significant positive correlation with ADHD-I). The small magnitude of these effects is similar to previous findings (Popat et al., 2021; Ramji et al., 2024) that did not find a significant difference in (classification) rates of ED, but did find a significant difference in rates of symptomatic nondependent. Similar to Popat et al., (2021) who found ADHD individuals had significantly higher withdrawal scores than healthy controls, a significant positive correlation was found between ADHD symptoms and Withdrawal. However, in our study, significant positive correlations were found between ADHD-T and total ED, Continuance, Lack of control, and ROA, as well as intention effects with ADHD-H specifically (again, all with small effect sizes). This suggests that measuring ADHD symptoms on a continuous scale provides greater insight compared to simply testing mean differences between groups. Additionally, subdividing ADHD symptomatology by subtype enabled a more nuanced analysis, revealing a stronger positive correlation between ED and hyperactive ADHD symptoms over inattentive symptoms, supporting previous findings by Ramji et al., (2024). This finding cannot solely be attributed to hyperactive symptoms being linked to higher exercise level (as PE was controlled for), suggesting that hyperactive symptoms may be more commonly linked with addictive behaviours (De Alwis et al., 2014) and different motivations.

In support of hypothesis two and aligning with prior work (Carlson et al., 2002; Smith & Langberg, 2018), significant negative correlations were observed between RAI and both ADHD-T and ADHD-I symptoms (but only of small effect sizes). Further analysis of subscales suggests that this may be largely attributable to a significant positive correlation between the External Regulation subscale (an extrinsic motivation) and total ADHD symptomatology. Regarding ADHD symptom presentation, autonomous/intrinsic exercise motivations generally demonstrated negative correlations with inattentive ADHD symptoms, while displaying slightly more positive/less negative correlations with hyperactive ADHD symptoms. Conversely, extrinsic motivations (except External Regulation) showed a reverse pattern. This suggests that previous findings of a negative association between ADHD and intrinsic motivation - in an academic context - (Carlson et al., 2002; Smith & Langberg, 2018), can also be extended to other contexts such as PA engagement. Additionally, most previous literature has primarily only investigated differences/associations with ADHD overall, not investigating potential differences between ADHD symptomatology presentation (inattention versus hyperactive). The findings that intrinsic PE motivations are more negatively associated with inattentive ADHD symptoms than hyperactive ADHD symptoms are novel, and further research should be conducted to investigate if this extends to other contexts (e.g., academic, occupational). The finding that hyperactive symptoms are less negatively associated with intrinsic PE motivation could also partially explain hyperactive symptoms having a more positive relationship with ED, as RAI was also found to have positive correlations with ED.

Regarding hypothesis three, ED was positively associated with autonomous exercise motivations, with significant positive correlations observed between EDS-T and RAI (with a medium effect size), as well as most motivation subscales (with medium to large effect sizes). This contrasts previous work (Edmunds et al., 2006; Hamer et al., 2002) reporting that greater introjected motivation specifically was the main or only predictor of ED, which would then also potentially suggest a negative correlation between ED and autonomous motivation (e.g., RAI; due to Introjected Regulation counting as an extrinsic motivation, that is negatively weighted in RAI). Additionally, while Introjected Regulation was positively correlated with ED, it was less positively correlated than all three intrinsic motivation forms (Identified, Integrated and Intrinsic Regulation) and had a smaller effect size (medium) than Identified and Intrinsic (large). However, Hamer et al., (2002) previously noted Identified Regulation (an intrinsic motivation) as the second biggest predictor of ED after Introjected, potentially balancing out the correlation between ED and RAI. Indeed, in this study, Identified Regulation had a strong correlation with ED, although the strongest correlation (albeit marginally) was observed for Integrated.

One possible explanation for the discrepancy in findings, could be differences in sample demographics. Unlike Hamer et al. (2002) who recruited endurance athletes, participants from the general population were sampled here. It is plausible that endurance athletes had reached a “ceiling effect” with their engagement and motivations, where positive associations become harder to detect. Additionally, the older version of the BREQ (Mullan et al., 1997) was used which did not include Integrated Regulation, precluding comparison with data from the current study. Regarding Edmunds et al. (2006), their research also treated ED as a categorical rather than a continuous variable and lacked enough participants categorised as “at risk” to perform analyses on all three groups (at risk, nondependent-symptomatic, nondependent-asymptomatic). Additionally, neither study controlled for the total amount of PE performed, meaning any positive relationships found between ED and motivation forms might be due to the form of motivation being more likely to increase PE level (acting as a mediator), which could then be the direct factor leading to increased ED risk (and vice versa). This means that an analysis of the different motivation forms when PE level is held constant cannot be performed.

An unexpected finding in the current study was the positive correlation between PA level and ADHD symptomatology, which contrasts with the findings of Chapter Two and previous literature (Abramovitch et al., 2013). This relationship remained when assessed specifically through exercise (using the leisure domain score of the IPAQ instead of total score) and did not significantly change when split by sub-group. Notably, correlations between PA and ADHD symptomatology within the Sub-ADHD group were lower and lost significance, but ADHD-I had a negative, although non-significant, correlation with PA (see Table 13). One partial explanation for differences from Chapter Two could rest with sample composition. The current study recruited a slightly higher proportion of students (who generally expressed a more positive correlation between PA and ADHD than the general sample) and a slightly lower proportion of full-time workers (who generally expressed a more negative correlation between PA and ADHD than the general sample). However, the difference in demographics is not statistically significant and therefore does not provide a viable full explanation for the change.

Another notable difference is the significantly higher median PA level in the current study (Mdn =3702.5) compared to Chapter Two (Mdn = 2574.25). If the nature of the relationship between PA and ADHD symptomatology was non-linear and changes as PA increases, this could partially explain the different findings. However, scatter plots analysis suggests that this is unlikely to be a significant factor, as no notable changes in dispersion were observed amongst higher PA level scores.

A more viable explanation may relate to the context of data collection. Chapter Two data was collected during early 2021 in the UK when COVID-19 lockdown restrictions were in place. These restrictions significantly reduced opportunities for PA, including reduced occupational and leisure travel, reduced work, and gym and social exercise activity closures, leading to reduced levels of PA (Stockwell et al., 2021). For individuals with ADHD, whose symptoms may involve difficulty initiative and planning activities, the lockdown context may have exacerbated such barriers and difficulties. Indeed, research has shown that COVID-19 lockdowns may have exacerbated ADHD symptoms and co-occurring difficulties (Hollingdale et al., 2021). As such, this could have led to the more negative correlation between PA and ADHD symptoms found in Chapter Two. This hypothesis also aligns with current findings, evidenced by ADHD symptomatology's negative correlation with RAI, and positive correlation with external regulation. Post Lockdown restrictions, external pressures/motivations for PA may then have had a disproportionately strong impact on individuals with ADHD, potentially leading to higher levels of PA compared to the general population. COVID-19 lockdowns were also found to have potentially exacerbated EA symptoms (Caponnetto et al., 2021; Lim, 2021), and if ADHD is positively associated with ED (as suggested by the current study findings), then this could have led to a particular increase in PA/PE level for individuals with ADHD once PA opportunities were available again, post lockdown restrictions. However, as there is limited research into this area looking at pre-post pandemic effects, it is very difficult to confirm without qualitative data and/or further research conducted post pandemic.

Another difference to the findings of Chapter Two was that subclinical diagnosis of ADHD was higher in males compared to females in the current study, whereas the reverse pattern was observed in Chapter Two. However, there was still no significant difference in subclinical diagnosis rate between males and females, which still stands in contrast to existing literature reporting a much higher diagnostic rate in males (Nøvik et al., 2006; Willcutt et al., 2012), and supports the theory that ADHD in females may be underdiagnosed (Quinn & Madhoo, 2014; Young et al., 2020). The prevalence of the ADHD subgroups mostly conforms to rates reported in the literature, with hyperactive presentation having the lowest prevalence (5.63%) (Faraone et al., 1998; Wilens et al., 2009). However, a slightly higher prevalence of Sub-Inattentive (17.76%) compared to Sub-Combined (13.82%) was found in the current study, whereas most literature report the combined presentation to be the most prevalent (Faraone et al., 1998; Wilens et al., 2009). These findings could support the theory that the inattentive presentation is more likely to be underdiagnosed due to its less disruptive nature, making it less likely to be noticed compared to the combined presentation (Quinn & Madhoo, 2014). In relation to gender differences, females had a lower proportion of the Sub-Inattentive presentation compared to males, which is in contrast to research showing that females are more likely than boys to be reported as having the inattentive presentation (Biederman et al., 2002; Willcutt et al., 2012). However further research suggests that any differences in presentation between males and females reduces and diminishes post-adolescence (Biederman et al., 2004). This is consistent with the current findings, as all participants were 18 years old or older.

The findings of this study have significant implications, particularly regarding the potential risks associated with using PE as an intervention for ADHD. Higher levels of ADHD symptoms in this adult sample were found to be linked with higher risks of ED. While the magnitude of effect was small, any potential implementation of exercise as an intervention for ADHD, particularly hyperactive, should consider the potential benefits against possible low-level risks of ED and associated harms. While the potential risk appears to be comparatively lower for inattentive ADHD, combined or hyperactive presentations warrant additional consideration, as ADHD-H was positively correlated with all subscales but Tolerance and Time. Such findings underscore the importance of regularly monitoring such interventions to offset the risk of unhealthy behaviours developing. Additionally, considering an individual's background and motivations is also important, as these factors may also influence ED risk.

The findings regarding the relationship between RAI and ADHD symptomatology suggest that the lower intrinsic motivation observed in children with ADHD, as seen in academic settings (Smith & Langberg, 2018), may also extend to other contexts (i.e., exercise) and across different age groups. As intrinsic motivation appears to be lower within ADHD subjects (and that it has a positive link with PE), efforts focused around increasing intrinsic exercise motivations for individuals with ADHD could effectively increase exercise engagement. This suggests that intervention techniques suggested by Smith and Langberg (2018) to enhance intrinsic motivation for academic tasks, could also be applied to exercise interventions for adults, particularly those with the inattentive presentation.

However, caution is needed as while this study found that RAI was positively correlated with higher PE level, it was also positively correlated with EDS-T, even after controlling for PE. This suggests that while increasing intrinsic motivations might lead to greater engagement with any exercise intervention, it might also elevate risk of ED development. Therefore, if exercise interventions seek to enhance engagement by improving autonomous motivation, caution should be exercised concerning ED risk, with careful monitoring and more thorough analysis to discern their suitability for prospective individuals, taking into consideration relevant risk factors (Gori et al., 2021). It should be noted that subclinical ADHD diagnosis did not moderate the relationship between RAI and EDS-T, suggesting that individuals with ADHD would not be more or less prone to the risk of this link than the general population.

However, the viability of any potential PE intervention primarily depends on whether exercise reduces ADHD symptoms and yields positive effects. The positive correlation between ADHD symptomatology and PE level could imply the opposite, that PA and PE might increase ADHD symptoms. Although, due to the correlational nature of this study, causation cannot be determined. Furthermore, the possibility that PE may exacerbate symptoms of ADHD contradicts much of the literature (Den Heijer et al., 2017; Vysniauske et al., 2020). Such an effect would also contrast most existing literature where there is aetiological evidence supporting the beneficial, rather than detrimental, effects of PA/PE on ADHD symptoms (Ding et al., 2006). An alternative explanation could be that individuals with greater ADHD symptoms are more likely to engage in PA, and while this contrasts with findings from previous literature (Abramovitch et al., 2013), there is less conflicting evidence, and this could be a partial result of post-pandemic changes. While this would mean that the positive effect of PE on ADHD symptomatology would still be present, it could mean that individuals with ADHD are already exercising more than the general population, making any possible exercise intervention redundant, or elevating the potential risk of overexercising and ED. However, without further analysis and research on the topic post-pandemic, it is hard to determine such implications with confidence.

Additionally, the current study is not without limitations. Some changes were made to the data collection methods for some measures (compared to Chapter Two), particularly the IPAQ-L (mainly focused around reducing the chances of participants entering incorrect/unusable data and a clearer flow). While this may have improved the reliability of such measures, it means that data from the current study might not be directly comparable to data from Chapter Two.

However, the current study also shared some limitations with Chapter Two. For instance, the sample in this study was again biased towards females, students, and younger individuals, which may limit the generalisability of the findings to the general population, as students are generally found to have higher rates of ADHD (Gray et al., 2014). Further, the smaller sample size of males made comparison between males and females harder to conduct, potentially lacking sufficient statistical power to detect true differences. Additionally, the correlational nature of the study means that causation between study variables cannot be determined. Whilst significant associations were identified, the nature of these relationships, as well as the potential mechanisms underlying each, remain speculative. Consequently, the implications of the current study would benefit from further empirical validation via more experimental designs. As requisite examples, future research endeavours could focus on developing interventions tailored to improve/develop intrinsic exercise motivation, possibly via motivational interviewing, as previously explored with individuals with ADHD (Sibley et al., 2016). Such interventions could be designed to monitor their impact on both PA level and ED. Research could also investigate ways in which intrinsic exercise motivation could be encouraged/improved, without increasing the risk of ED in individuals with ADHD (and possibly individuals with hyperactive ADHD particularly). To maximise the efficacy and safety of such interventions, it would be beneficial to consider and address potential risk factors (e.g., body dissatisfaction, drive for thinness, bulimia), while supporting and increasing protective factors (e.g., self-esteem) (Gori et al., 2021).

In terms of measures used, limitations of the EDS-R in accurately estimating the prevalence of ED have been noted (Egorov & Szabo, 2013; Müller et al., 2014; Szabo et al., 2015). Comparisons between ED diagnosis using the EDS-R (translated to German) and structured clinical interviews have shown fair to moderate agreement, with the EDS-R having a higher rate of false-positive classification (Müller et al., 2014). This likely reflects difficulty in distinguishing between 'at risk' individuals and those with the disorder, as self-report measures without clinical interviews can lead to an overestimated prevalence rates. This issue may be particularly pronounced in athletic populations or those with highly active occupations, where high scores may reflect professional demands than addiction. For example, an athlete may endorse item four of the EDS-R, "I am unable to reduce how long I exercise" as exercise duration may reflect professional demands rather than addiction. Thus, athletic populations may score highly on ED self-report measures because of occupational requirements rather than it being reflective of exercise dependence (Szabo et al., 2015). This suggests that the ED findings in this study, especially given small effect sizes, should be interpreted with caution. Future research should employ clinical interviews to better establish diagnostic validity.

The use of using RAI as a continuum scale for self-determination has also been criticised (Chemolli & Gagné, 2014), with theoretical and statistical limitations regarding the reduction of different dimensions into a single scale. Therefore, analysis of the individual motivation subscales would have provided greater insight and accuracy. Although, analysis of individual the BREQ-3 subscales largely support the overall findings and implications of the current study. There was a significant negative correlation between External Regulation and total ADHD symptomatology, while all three intrinsic forms of motivation were positively correlated with ED (Table 16) and PE (Appendix M). However, the positive correlation between External Regulation and ADHD-I was not significant (in contrast to RAI which had a significant negative correlation with both ADHD-T and ADHD-I), suggesting that differences between inattentive and hyperactive symptoms might be less pronounced when solely considering RAI. Additionally Introjected Regulation (an extrinsic motivation) was also significantly correlated with ED and PE, albeit weaker compared to the three intrinsic forms, underscoring the risk of treating all extrinsic motivations as equivalent, as Extrinsic and Introjected Regulation might have different relationships and effects.

Finally, this study did not measure possible barriers to PE, meaning no analysis could be performed on how these factors could have influenced the relationship between ADHD, PE level and exercise motivation. This could be particularly relevant as intrinsic motivations can act as a key mediator between environmental factors and behavioural outcomes for individuals with ADHD (Morsink et al., 2022), and ADHD is associated with higher rates of barriers to exercise (Harvey et al., 2014; Ogrodnik et al., 2023). Future research could measure different barriers to exercise to investigate whether they are associated with ADHD and whether intrinsic motivation acts a significant mediator between barriers and PE engagement, providing greater understanding on intrinsic motivation’s importance within potential interventions.

3.5.1. Conclusions

In conclusion, the findings of this study suggest that ADHD symptomatology in adults is linked with reduced intrinsic exercise motivation and higher risks of ED. Additionally, while intrinsic exercise motivation may be linked with increased PE level, it is also linked with increased ED, suggesting that caution should be applied to any intervention focused around increasing intrinsic exercise motivation. Finally, the relationship between ADHD and PE may be more complex than previously understood, especially considering the potential impact of post-Covid-19 effects. Therefore, while there is the suggestion of effectively increasing exercise engagement within ADHD by focusing on intrinsic exercise motivation, any such intervention needs to be carefully considered and monitored to reduce risks and optimise effectiveness. Additionally, PE interventions based around boosting autonomous motivation could be limited due to other barriers to PE, warranting further research into what barriers individuals with ADHD experience and how they may interact with motivation and ED.

Chapter Three: Key Messages

- In light of findings from Chapter one, this study aimed to investigate the links between PE and motivation from a SDT perspective, with a particular focus on distinguishing between ADHD subtypes/subgroups. The study also examined links with ED.
- This study found positive correlations between ADHD symptomatology (total and hyperactive) and ED; negative correlations between ADHD symptomatology (total and inattentive) and autonomous exercise motivation; and a positive correlation between ED and autonomous exercise motivation.
- Results suggests that promoting intrinsic exercise motivation in adults with ADHD could potentially increase PE engagement. However, caution is advised, as intrinsic motivation was also positively associated with ED.
- Interventions seeking to boost autonomous motivation could be limited due to barriers to PE. This highlights the need for further research to identify relevant barriers and understand their interaction with motivation and ED.

4. Chapter Four: Understanding Barriers and Facilitators of Physical Exercise in Adults with ADHD Symptoms

4.1. Chapter Overview

Chapter Three investigated the links between PA; ADHD; motivation and ED, finding that intrinsic PE motivation is associated with increased PE and that ADHD symptomatology is associated with reduced intrinsic PE motivation and heightened risk of ED. This suggests that efforts focused around increasing intrinsic PE motivation for people with ADHD could lead to increased PE engagement. Such findings raise important questions concerning how intrinsic motivation might be expressed and influenced by exercise facilitators and/or barriers (determinants), and whether any of these determinants are linked to increased risk of ED. The aim of this chapter is to identify determinants/barriers to PE that are experienced by individuals with ADHD (while also exploring possible links with ED). This chapter highlights environmental, social and personal determinants that inhibit individuals with ADHD from engaging with PE and explores whether any of these determinants are more influential to PE engagement to individuals with ADHD compared to the general population.

4.2. Introduction

The findings from Chapter Three suggested that ADHD symptomatology is associated with reduced intrinsic motivation PE (Physical Exercise) and heightened risk of ED. Such findings raise important questions concerning how intrinsic motivation might be expressed and influenced by exercise facilitators and/or barriers (determinants), and whether any of these determinants are linked to increased risk of ED. Moreover, to eventually design and effectively implement any potential PA/PE based interventions, it is first important to establish the specific Determinants of Exercise (DE) and barriers to PA/PE that are relevant to individuals with ADHD, who may face unique challenges (see section 1.5.6.). Indeed, the

Behaviour Change Wheel (Michie et al., 2011), a framework for characterising and designing behaviour change interventions and linking them to the targeted behaviour, considers sources of behaviour (e.g., opportunity, capability, motivation; COM-B model) as a key step when designing and maximising the effectiveness of any behavioural based intervention (Michie et al., 2011).

Additionally, an unresolved question remains regarding why the central correlation between ADHD symptomatology and PA level changed between Chapter Two and Chapter Three. Investigating DE provides an opportunity to address this question, as changes during and after the COVID-19 pandemic could have conceivably influenced exercise barriers and behaviours.

In relation to DE, most research has utilised the Theoretical Domains Framework (TDF) (C. Brown et al., 2024; Weatherson et al., 2017; Zhen et al., 2020); a theoretical implementation framework for examining influences on behaviour, grouped into 14 domains (Atkins et al., 2017; Michie et al., 2005): Knowledge; Skills; Social/Professional Role and Identity; Beliefs about Capabilities; Beliefs about Consequences; Memory, Attention and Decision Processes; Environmental Context and Resources; Social influences; Emotion; Behavioural Regulation; Optimism; Reinforcement; Intentions; and Goals. In a review of 39 studies, with a total of 17,771 student participants, C. Brown et al., (2024) found that Environmental Context and Resources (e.g., time constraints; accessible exercise options); Social Influences (e.g., socialising with others); and Goals (e.g., prioritisation of PA over other activities; stress management) were of greatest relative importance to PA. Conversely, no barriers or facilitators were identified in the domains of Memory, Attention and Decision Processes, or Optimism. This can be used to help inform any potential PA interventions for ADHD, but it is also important to consider whether the DE would be different for individuals with ADHD compared to the general population.

Differences in DE could be present as certain ADHD symptoms could lead to increased barriers to exercise, or potentially, certain exercise facilitators being utilised more effectively (Pontifex et al., 2014), and there is also evidence that PA and PE engagement by individuals with ADHD tends to be lower than their neurotypical peers (Kim et al., 2011). Increased barriers to PE have been found for common comorbidities of ADHD such as anxiety (Sabourin et al., 2011) and mood disorders (particularly around the Emotion TDF domain) (Firth et al., 2016; Glowacki et al., 2017), and ADHD could lead to further challenges/barriers unique to certain symptoms (see section 1.5.2.). This could also explain differences in the relationship between PA levels and Hyperactive versus Inattentive ADHD symptoms (Chapter Two) (Xie et al., 2021). For example, certain inattentive symptoms could lead to increased barriers, such as reduced motivation which is linked with reduced PE engagement (Frederick et al., 1996). Conversely, certain hyperactive symptoms could lead to increased facilitators, such as physical activity being perceived as part of an individual with Hyperactive ADHD's identity, with social identity linked with PA engagement (Stevens et al., 2017). Additionally, if ADHD is also linked with reduced intrinsic PE motivation (as suggested given the findings of Chapter Three), this could influence certain DE, such as Social/professional role and identity (Waterman, 2004); Emotion (Shin et al., 2014); and Belief in consequences and capabilities (Oman & McAuley, 1993).

Despite this, few studies have explored the barriers and facilitators of PA and PE in those with ADHD, despite the importance of such insights for designing and implementing interventions and supporting behaviour change (Harvey et al., 2014; Ogrodnik et al., 2023). Harvey et al. (2014) found that children with ADHD expressed several barriers to PA, such as financial cost, lack of time, lack of community resources and equipment (Environmental Context and Resources), and performance anxiety (Beliefs about Capabilities and Emotion). Conversely, facilitators of PA engagement included enjoying the social element from friends and family (Social Influences), developing friendships and enjoying the activity itself (Social Influences and Beliefs about Consequences), and having positive environmental conditions (Environmental Context and Resources). Further, in another qualitative investigation in adults self-reporting a formal diagnosis of ADHD, Ogrodnik et al. (2023) identified several barriers that interfered with the initiation and maintenance of PA. These included a lack of knowledge regarding the benefits of activity, executive dysfunction, poor self-esteem, and lack of motivation. For example, although participants noted benefits to their EF following engagement with PA, the presence of executive dysfunction made it difficult to initiate the activity owing to problems with forgetfulness, sustained focus, and time management. In contrast, reported facilitators included group or team-based activities (i.e., enjoying a sense of community; being active with others), perceived improvements in physical health (e.g., fitness, weight management) and mood (e.g., mental clarity and focus), and having access to transportation, time, and activity space (e.g., accessibility and convenience).

However, both studies outlined in the preceding paragraph (Harvey et al., 2014; Ogrodnik et al., 2023) lack a non-ADHD control group, preventing any comparison to identify potential differences in determinants of PA and PE between individuals with and without ADHD. Similarly, as both employed qualitative methodologies, it is not possible to perform quantitative comparisons or meta-analyses with other studies. Additionally, neither investigated whether determinants of PA and PE may differ depending on ADHD symptom subtype (which could lead to important distinctions being missed, see section 2.5.) and Ogrodnik et al. (2023) also interviewed participants during the COVID-19 pandemic, which may have impacted both PA and reported determinants of behaviour.

Moreover, in addition to understanding the facilitators and barriers to PE experienced by individuals with ADHD, it is also important to investigate which DE are actually important to them. For instance, certain barriers might be experienced frequently but not significantly impact PE engagement. Therefore, targeting the removal of such barriers might not be as effective as targeting others that are more important. Alternatively, individuals with ADHD might experience barriers for a determinant at the same rate as the general population, but those barriers could be particularly important to increasing PE engagement for individuals with ADHD and thus deserve specific attention. For instance, both Ogrodnik et al. (2023) and Harvey et al. (2014) identified exercising with others as an important aspect of PE for individuals with ADHD. Therefore, even if this barrier is similarly experienced by those without ADHD, cultivating social support in PE based interventions for individuals with ADHD might be particularly effective.

Overall, research in this area remains limited, undermining the development of effective, tailored interventions for enhancing PE engagement in individuals with ADHD. Addressing these gaps and gaining a better understanding of the barriers and facilitators of PE in relation to ADHD is important for developing potential PA and PE based interventions (Pontifex et al., 2014), and addressing key barriers and effectively utilising key facilitators (Hussein et al., 2021). Indeed, identifying the sources of behaviour, represented by the TDF domains, is the first step in developing behaviour change interventions before moving on to intervention function and design (Michie et al., 2011). This is particularly important for demographics that are under-researched in relation to ADHD and PE, such as females and adults (Vysniauske et al., 2020).

However, due to the potential increased risk of ED in individuals with ADHD (as suggested in Chapter Three and existing research (Colledge et al., 2022; Popat et al., 2021; Ramji et al., 2024), careful concern should be paid towards which DE are linked with ED. Potential efforts to overcome barriers/encourage facilitators could lead to greater risks of ED in an already at-risk population, meaning the relationship between the potential DE and ED should be investigated. Indeed, research suggests that risk factors for ED and exercise addiction (EA) include a drive for thinness (potentially linked to TDF domains such as Beliefs about consequences and Goals), body satisfaction (Gori et al., 2021), excessive use of exercise as a coping mechanism for stress (related to TDF domains such as Emotion and Nature of Behaviour) (Berczik et al., 2012; Landolfi, 2013), and the degree and nature of motivation (linked to the TDF domain of Motivation) (Landolfi, 2013).

Therefore, the aim of this study was to investigate the relationships between ADHD symptomatology with DE and ED in an adult population. Based on previous literature, it was hypothesised that: 1) there would be a significant difference in the strength of barriers faced between sub-ADHD and non-ADHD participants (two-tailed); 2) there would be significant correlations between DE and ED (two-tailed); and 3) Subclinical ADHD diagnosis would moderate the relationship between DE and level of PE (two-tailed).

4.3. Method

4.3.1. Participants

Participants were recruited via online social media adverts, e-mail invitations, Survey Circle (SurveyCircle, 2016), SurveySwap (SurveySwap, 2019) and a University Psychology participant pool system. The study was advertised as '*Physical activity in adults: Barriers and Facilitators*', and participants were not offered any reimbursement or compensation for taking part. To be eligible to take part, participants had to be at least 18 years of age and resident in the United Kingdom. G-Power calculations indicated that that 102 participants would be needed for each group (204 overall) for a Mann-Whitney U test; 145 participants for a correlation; and 125 participants for a moderation analysis. These calculations were performed accounting for 80% power, with a rejection criterion of $p < .0045$ (using a Bonferroni correction of 11 tests; .05 ÷ 11), and medium effect size (Mann-Whitney U: $d = .5$; correlation: $\rho = .3$; moderation analysis: $f^2 = .15$).

Initially, 604 participants accessed the survey. However, in addition to the upfront eligibility criteria outlined above, predefined data screening criteria (listed below) were then applied to support analysis of high-quality data. This resulted in 242 participants being excluded from the analysis for the following reasons: not providing consent (n=24); not completing the study in full (*n*=90); not being a resident of the UK (*n*=60); not correctly answering basic attentional control checks (*n*=29); having duplicate responses to another respondent with same IP address (likely same participant responding twice; *n*=2); having consistently repeated answers for questionnaires (indicating that questions were potentially not being read/answered truthfully, n=4); having unusable IPAQ-L data (e.g., answers filled in incorrectly; *n*=11); scoring above the maximum limit for the IPAQ-L (e.g., answers suggesting that over 16 hours per day were spent doing PA; *n*=10); self-rating their English Language proficiency as either weak or very weak (*n*=3); and counting as extreme outliers (defined as exceeding the 3rd quartile of score + 3*IQR) in the total IPAQ-L score (*n*=4) and/or IPAQ-L Leisure domain score (*n*=4).

This left 362 participants, of whom 279 (77.07%) were female. Ages ranged from 18 to 68 (M = 25.41, SD = 8.72) years, and further demographic information is presented in Table 17. Options for the Gender and Ethnicity question were based on the categories recommended for use by the UK government (Race Disparity Unit, 2021)

Table 17

*Demographic Information of the Study Sample (*N*=362)*

Demographics	*n* (%)
Gender	
Male	73 (20.17)
Female	279 (77.01)
Other	8 (2.21)
Prefer not to say	2 (0.55)
Ethnicity	
White/English/Scottish/Northern Irish/British	239 (66.02)
Arab	3 (0.83)
Any other white background	45 (12.43)
White and Black African	2 (0.55)
White and Asian	6 (1.66)
Any other Mixed/Multiple ethnic background	5 (1.38)
Indian	11 (3.04)
Pakistani	5 (1.38)
Bangladeshi	4 (1.12)
Chinese	8 (2.21)
African	10 (2.76)
Any other Asian background	2 (0.55)
Any other Black/African/Caribbean background	3 (0.83)
Caribbean	2 (0.55)
Gypsy or Irish Traveller	2 (0.55)
Irish	5 (1.38)
White and Black Caribbean	5 (1.38)
Other	5 (1.38)
Highest Level of education	
No formal education	1 (0.28)

Secondary/Highschool (e.g. GCSE's) or equivalent	10 (2.76)
College/Sixth form (e.g. BTEC, A-Levels) or equivalent	132 (36.46)
University (e.g. BSc, BA, Degree)	149 (41.16)
Masters (e.g. MSC, MA)	57 (15.75)
PhD/Doctorate	12 (3.32)
Other	1 (0.28)
Employment Status	
Full-time employment	60 (16.58)
Part-time employment	60 (16.58)
Unemployed as unable to work	3 (0.83)
Currently unemployed but looking for work	15 (4.14)
Full-time student	209 (57.74)
Part-time student	8 (2.21)
Unpaid voluntary work	1 (0.28)
Other	5 (1.38)

Note. GCSE = General Certificate of Secondary Education; BTEC = business and Technology Education Council; A-level = Advanced level qualification; BSc = Bachelor of Sciences; BA = Bachelor of Arts; MSC = Master of Sciences; MA = Master of Arts; PhD = Doctorate of Philosophy.

4.3.2. Apparatus and Materials

The online survey was conducted online using Qualtrics (Qualtrics, 2005). Participants were asked to supply standard demographic details (e.g., age, gender) and were also asked questions about their potential comorbid conditions and medication (Appendix A and B). If English was not their first language, participants were also asked to rate their language proficiency in reading, writing, and speaking on a five-point scale ranging from 'Weak' to 'Excellent' (Appendix H). In addition, the survey contained the following standardised questionnaires:

The ADHD Rating Scale – IV with Adult prompts (ADHD-RS-IV with Adult Prompts) (Adler et al., 2009) (Appendix E) was used to measure ADHD symptomatology (see section 2.3.2 for details). Within this study, the ADHD-RS-IV demonstrated good to excellent internal reliability with a Cronbach's Alpha of .89 for Inattentive, .88 for Hyperactive, and .92 for ADHD-T.

The International Physical Activity Questionnaire – Long Format, last seven days, self-administered (IPAQ-L7S) (Craig et al., 2003) (Appendix F) was used to measure PA Level (sum of all four domain sub scores) and PE level (Leisure domain) (see section 2.3.2. for details).

Behavioural Regulation in Exercise Questionnaire – version 3 (BREQ-3) (Wilson et al., 2006) (Appendix I) was used to measure motivation (see section 3.3.2 for details). The internal reliability of the EDR-S in the present sample was excellent (Cronbach α = .94). It demonstrated good to excellent levels of internal consistency within the current sample, with Cronbach's alphas for the subscales ranging from .82 to .93.

Exercise Dependence Scale – Revised (EDS-R) (Downs et al., 2004) (Appendix J) was used to measure ED (see section 3.3.2 for details). The internal reliability of the EDR-R in the present sample was excellent (Cronbach α = .94).

Determinants of Physical Activity Questionnaire (DPAQ) (Taylor et al., 2013) (Appendix N): A 34-item self-report questionnaire used to access 11 determinants (domains) of PA/PE, based on TDF: 1) Knowledge (An awareness of the existence of something); 2) Environment Context and Resources (circumstance of an individual's situation/environment that discourages or encourages the development of skills and abilities, independence, social competence and adaptive behaviour); 3) Motivation and Goals (resolve to act in a certain way/Mental representations of outcomes that an individual wants to achieve); 4) Beliefs about Capabilities (acceptance of the truth/reality/validity about an ability/talent/facility that an individual can put to constructive use); 5) Skills (ability/proficiency acquired through practice); 6) Emotion (complex reaction pattern involving experiential/behavioural/physiological elements, by which an individual attempt to deal with a personally significant matter/event); 7) Social Influences (interpersonal processes that can cause individuals to change thoughts, feelings, or behaviours); 8) Beliefs about Consequences (acceptance of truth/reality/validity about outcomes of a behaviour in a situation); 9) Action Planning (anything aimed at managing/changing objectively observed/measured actions); 10) Coping Planning (anticipating barriers, mental simulation of success scenarios); and 11) Goal Conflict (when multiple goals compete and conflict). Participants rate statements (e.g., "*Facilities are available to help me to do physical activity*") on a seven-point Likert scale (1= Strongly Disagree, 7 = Strongly Agree). All negatively phrased items were reverse scored. Scores for each of the 11 domains are generated by summing the mean scores of three items (four for Action Planning), resulting in a range of scores from 1-7 for each domain. Higher scores indicate greater levels of the corresponding domain, reflecting reduced barriers. In the current study, internal consistency for most domains ranged from acceptable to excellent (Cronbach α = .64 to .9). In addition to the existing 11 domains, the measure was modified with an additional 12 items to measure a further four factors identified in the study by Ogrodnik et al., (2023) as being particularly salient for individuals with ADHD: Identity; Memory, Attention, and Decision Process; Behavioural Regulation; and Nature of the Behaviours.

Personal Values Questionnaire II (PVQ-II) (Blackledge et al., 2010) (Appendix O) – is a self-report questionnaire used to assess measures of patient values across different domains (nine provided in the original questionnaire), with a five question/nine item section for each domain. As none of the original nine domains adequately matched our research aim, the domain of "Engaging in Physical Activity/Exercise" was chosen and put into the PVQ-II section format with nine items rated on a five-point scale. There are four subscales: Intrinsically held Choice (individual's own commitment to the value); "Aversive-controlled value choice (degree of external regulation of the value); and "Value Related Behaviour" (degree to which the value is acted upon) (PVQ-S) (with higher scores representing greater motivation strength); and the manner in which the value is held (PVQ-T) (calculated by subtracting the mean score for Aversive Choice from the mean score for Intrinsic Choice, higher scores representing more intrinsically held motivations). This measure was chosen as it would allow use to more effectively distinguish between the strength of an individual's motivation (PVQ-S) and the degree to which their motivation is extrinsic or intrinsic (PVQ-T) compared to the BREQ-3, and providing an alternative measure to address the issues previously mentioned regarding use of the RAI as a continuum scale for self-determination (Chemolli & Gagné, 2014) (see section 3.5.). The PVQ-II has acceptable to good internal consistency (Cronbach α = .72 to .8) (Blackledge et al., 2010). Within this study it demonstrated questionable to good reliability with a Cronbach's Alpha of .53 to .82

In addition to the standardised Questionnaires above, two attentional control checks were embedded, with one in the BREQ-3 and one in the EDS-R (e.g., "Please select option "2 - Sometimes true for me" "). Participants who failed one or more of these basic attentional checks were excluded from the analysis *a priori*.

4.3.3. Design

The study was a cross-sectional observational study. The primary variables of interest were DE (DPAQ domains); Exercise Dependence (EDS-T); Motivation (RAI, PVQ-S, PVQ-T); ADHD symptomatology (ADHD-T, ADHD-I, ADHD-H); Subclinical ADHD diagnosis (Sub-ADHD vs Non-ADHD); PA (PA-Level); and PE (PE-level). For the analyses on differences in barriers to PE between Non-ADHD and Sub-ADHD participants, Subclinical ADHD diagnosis served as the independent variable, while barriers to PE (DE domains) were the dependent variables. In the analysis exploring the relationship between DPAQ domains and EDS-T, DE domains were the independent variables, ED was the dependent variable, and PE served as the covariate. For the moderation analyses assessing the effect of Subclinical ADHD diagnosis on the relationship between barriers to exercise (DE) and PE levels, DE were the independent variables, PE level was the dependent variable, and subclinical ADHD diagnosis was the moderator.

4.3.4. Procedure

The research was approved by a Psychology School Research Ethics Committee (Approval Number: 1 2023 7799 6755) (Appendix O). Participants accessed the survey online via Qualtrics and were presented with a detailed information page. They were then asked to provide informed consent via an electronic (Yes/No) checkbox. Participants who did not consent to participate were directed to the end of the survey. Consenting participants completed a series of demographic questions followed by questions on comorbidities. They were then presented with the ADHD-RS-IV with Adult Prompts; BREQ-3; EDS-R; IPAQ-L; DPAQ; and PVQ-II in a randomised order. All survey sections required a response (except for the questions in the IPAQ-L a participant would have skipped given their responses), ensuring the survey was fully completed. Finally, participants were presented with a debrief page. There was no time limit, and after excluding outliers, average completion time was 21 minutes and 11 seconds.

4.3.5. Data Processing and Statistical Analysis

All statistical analyses were carried out using IBM SPSS Statistics version 29.0 (IBM Corp., 2023), PROCESS v4.0 (Hayes, 2018) and JASP 0.18.3 (JASP Team, 2024).

Data on comorbidities was converted to ordinal data, by measuring it as ‘Total Number of Comorbidities’ (TNC) (ranging from 0 – 5, *Mdn*=0, *IQR*=2). IPAQ-L data was cleaned in accordance with the guidelines set out by the IPAQ group. Participants were also grouped into non-ADHD or Subclinical ADHD participants, based on their ADHD-RS-IV scores: participants who responded 2-3 on 6 or more inattentive prompts, but 5 or less hyperactive prompts were grouped as meeting the subclinical threshold for inattentive ADHD diagnosis (Sub-Inattentive). The reverse was applied for hyperactive ADHD (Sub-Hyperactive). If a participant met both thresholds, they were categorised as combined ADHD (Sub-Combined), while if they met neither were categorised as Non-ADHD. A final group was created by capturing participants who met any subclinical ADHD threshold (Sub-ADHD).While there were initial plans to measure a further four DE (Identity; Memory, Attention, and Decision Process; Behavioural Regulation; and Nature of the Behaviours) by modifying the DPAQ with additional items, it was found that the reliability of these scores was very low, with Cronbach's Alphas reaching as low as -.07. Due to this, these factors were removed from further analysis and only the original 11 domains were included.

ADHD-T; ADHD-I; ADHD-H; RAI; PVQ-S and PVQ-T were deemed to be normally distributed (skewness, histograms). However, EDS-T and PA level required transformation (square root) to meet normal distribution assumptions. Despite transformation attempts, PE level, DPAQ Domains, and EDS-R subscales remained non-normally distributed. Therefore, analyses involving these variables used nonparametric tests with the untransformed variables (except for PE level in the moderation and mediation analyses specifically, as detailed below). Additionally, demographic factors and TNC were not found to have significant correlations/differences with multiple key variables, so were not used as control variables.

Pearson's r correlations were performed to assess relationships between normally distributed variables, whereas Spearman's rho was used for non-normally distributed variables. Due to DPAQ factors not meeting parametric requirements, Mann Whitney U tests were performed to test for differences in DPAQ factor scores between Non-ADHD and Sub-ADHD participants (hypothesis 1). Additionally for these tests of difference, Bonferroni-

Holm corrections were applied (Gaetano, 2018) to control for multiple comparisons (of which there were 11).

Correlations between ED and DPAQ Domains, (hypothesis 2) were then controlled for by PE level (semi-partial correlations), to ensure that any correlations found between ED and DPAQ Domains, were not a result of PE level. Non -parametric semi-partial correlations were performed due to the DPAQ Domain scores being non normally distributed. This was done by generating residuals of the independent variables from PE level and then performing Kendall Tau's correlations between the residual independent variables and the dependent variables. Additionally, Bonferroni-Holm corrections were applied to control for multiple comparisons (11).

To investigate the effect of Subclinical ADHD diagnosis on the relationship between DE and PE level (hypothesis 3), a series of 11 moderation analyses were performed. DPAQ domains were entered as the independent variable (X), PE as the dependent variable (Y), and subclinical ADHD diagnosis as the moderator (W). The assumptions of homoscedasticity and normality were found to be violated in multiple models. However, all statistical assumptions were met when the square root transformation was applied to the outcome variable (PE level). Therefore, the square root transformation of PE level was used for these moderation analyses, specifically. As previous, Bonferroni-Holm corrections were also applied to control for multiple comparisons (of which there were 11).

Finally, to investigate the role of intrinsic motivation as a mediator on the relationship between DE and PE level, a series of 10 mediation analyses were performed. DPAQ domains were entered as the independent variable (with the exception of Motivation as this violated the assumption of multi-collinearity as it was partially measuring the same underlying factor as the mediator) (X), PE as the dependent variable (Y), and PVQ-T as the mediator (M). To compare differences in the level of mediation effect based on subclinical ADHD diagnosis, this was also repeated for both the Non-ADHD and Sub-ADHD groups. However this analysis was not deemed appropriate to be confirmatory for two reasons: 1) comparisons between subgroups was based purely on comparing whether the findings were significant or not (not directly testing if the differences themselves were statistically significant); and 2) significance of mediation was tested via seeing if bootstrapped 95% confidence intervals crossed 0, not p values (meaning Bonferroni-Holm corrections were not able to be applied to control for multiple comparison). Due to this, this analysis was explicitly exploratory.

4.4. Results

4.4.1. Descriptive Results

Descriptives and correlations between study variables are presented in Table 18. Significant correlations were observed between most key variables, including significant positive correlations between: ADHD-T and PA level; ADHD-H and PA level and EDS-T; PA level and PE level, EDS-T, RAI, PVQ-S, and PVQ-T; and PE level and EDS-T, RAI, PVQ-S and PVQ-T. Additionally, significant negative correlations were found between: ADHD-symptomatology (ADHD-T and ADHD-I) and RAI, PVQ-S and PVQ-T; and ADHD-I and PE Level.

Table 18

Descriptive Statistics and Correlation Coefficients (Pearson's r*) for Study Variables Split by Subclinical ADHD Diagnosis*

Variable	*M*	*SD*	1	2	3	4	5[a]
Total Sample (N=362)							
1. ADHD-T	21.95	11.55	-	-	-	-	-
2. ADHD-I	11.77	6.46	.91***	-	-	-	-
3. ADHD-H	10.18	6.31	.9***	.64***	-	-	-
4. PA level	62.87	28.64	.12*	.03	.18***	-	-
	(3503.25)[b]	(4859.63)[b]					
5. PE level[a]	(627.8)[b]	(1479.55)[b]	-.09	-.15**	-.01	.44***	-
6. EDS-T	6.96	1.32	.08	-.07	.21***	.35***	.32***
	(50)[b]	(26)[b]					
7. RAI	7.21	6.63	-.19***	-.28***	-.06	.29***	.36***
8. PVQ-S	21.93	5.53	-.21***	-.3***	-.08	.28***	.41***
9. PVQ-T	1.43	1.26	-.17**	-.22***	-.08	.28***	.18***
Non-ADHD (*n*=240)							
1. ADHD-T	15.58	7.01	-	-	-	-	-
2. ADHD-I	8.42	4.25	.86***	-	-	-	-
3. ADHD-H	7.15	4	.84***	.45***	-	-	-
4. PA level	61.6	29.05	.14*	.04	.21***	-	-
	(3280.2)[b]	(4702.65)[b]					
5. PE level[a]	(720)[b]	(1440.75)[b]	-.03	-.11	.07	.49***	-
6. EDS-T	6.9	1.81	.07	-.04	.17**	.35***	.31***
	(49)[b]	(25)[b]					
7. RAI	7.74	6.92	-.21**	-.28**	-.07	.29**	.38**
8. PVQ-S	22.43	5.65	-.24**	-.29**	-.12	.27**	.42**
9. PVQ-T	1.49	1.31	-.23**	-.27**	-.11	.08	.14*
Sub-ADHD (*n*=122)							
1. ADHD-T	34.48	7.88	-	-	-	-	-
2. ADHD-I	18.36	4.79	.69***	-	-	-	-

3. ADHD-H	16.12	5.77	.8***	.11	-	-	-
4. PA level	65.37	27.77	.04	-.15	.18	-	-
	(4074)[b]	(5287.88)[b]					
5. PE level[a]	(480)[b]	(1485)[b]	-.06	-.21*	.05	.36***	-
6. EDS-T	7.06	1.38	.03	-.34***	.32***	.35***	.36***
	(51)[b]	(26.25)[b]					
7. RAI	6.16	5.91	-.05	-.3***	.19*	.31***	.31***
8. PVQ-S	20.96	5.18	-.07	-.34***	.18*	.33***	.39***
9. PVQ-T	1.3	1.14	-.07	-.21*	.08	.25**	.25**

Note. Statistical significance: **p* < .05; ***p* < .01; ****p* < .001.

ADHD-T = Total ADHD Symptomatology; ADHD-I = Inattentive ADHD Symptomatology; ADHD-H = Hyperactive ADHD Symptomatology; PA = Physical Activity; PE = Physical Exercise; RAI = Relative Autonomy Index; EDS-T = Exercise Dependence Score-Total; PVQ-S = Motivation Strength; PVQ-T = Motivation Type

[a] Correlation coefficients represent Pearson's *r*, except for coefficients with PE level which represent Spearman's rho.

[b] Brackets represent the median and *IQR* of non-normally distributed variables/untransformed variables below the mean and *SD* of the transformed variable.

As shown in Table 19, a slightly higher proportion of males (38.36%) had Subclinical ADHD compared to females (31.18%), although this difference was not statistically significant, $\chi2(1) = 1.35$, $p = .245$ (10 participants who selected 'other' or 'prefer not to say' were excluded from this analysis due to expected cell counts being below five). Additionally, the Sub-Combined subtype had the highest prevalence (14.92%), followed by Sub-Inattentive (13.54%), and then Sub-Hyperactive (5.25%).

Table 19

Distribution of Subclinical Diagnosis of ADHD in Relation to Gender

Gender	Non-ADHD	Sub-ADHD	Sub-Inattentive	Sub-Hyperactive	Sub-Combined
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
Male	45 (61.64)	28 (38.36)	8 (10.96)	4 (5.48)	16 (21.92)
Female	192 (68.82)	87 (31.18)	37 (13.26)	14 (5.02)	36 (12.9)
Other	3 (37.5)	5 (62.5)	2 (25)	1 (12.5)	2 (25)
Prefer not to say	0 (0)	2 (100)	2 (100)	0 (0)	0 (0)
Total	240 (66.3)	122 (33.7)	49 (13.54)	19 (5.25)	54 (14.92)

Table 20 shows the median (interquartile range) for the DPAQ domains split by subclinical diagnosis (Non-ADHD, Sub-ADHD and Total sample), as well as their correlations with other key variables. The medians of the DPAQ domains were consistently lower in the Sub-ADHD group compared to the Non-ADHD group. Significant positive correlations were found between several DPAQ domains and both PA and PE in both groups. Correlations between DPAQ domains and ADHD-T Scores were generally negative, but they were stronger and only significant within the Non-ADHD group. This is likely due to correlations between DPAQ domains and ADHD-H Scores being much more positive within the Sub-ADHD Group than the Non-ADHD group (particularly Beliefs in about Capabilities and Skills). Additionally, correlations between DPAQ domains and ADHD-I Scores were generally more negative than with ADHD-H Scores in both groups. Correlations between DPAQ Domains and ADHD symptoms for the total sample generally fell between those observed within the two subgroups, with a few exceptions (e.g., Emotion, Coping Planning), which were more negative than in the Non-ADHD group. This may be due to the potential bias towards null correlations within subgroups, as group classification and ADHD symptoms were both assessed using the same measure (ADHD-RS-IV).

Table 20

Descriptive Statistics and Correlation Coefficients (Spearman's rho) Between DPAQ Domains and Study Variables

Variable	***Mdn***	***IQR***	**PA**	**PE**	**ADHD-T**	**ADHD-I**	**ADHD-H**
Non ADHD (*n*=240)							
Knowledge	5	1.67	-.03	.12	-.18**	-.22***	-.09
E Context	6	1.33	.04	.13*	-.24***	-.23***	-.2**
Motivation	5	2.33	.29***	.41***	-.25***	-.34***	-.07
BCap	4.33	3	.17**	.21**	-.35***	-.37***	-.2**
Skills	5.33	2	.21**	.27***	-.26***	-.29***	-.15*
Emotion	5.17	2.33	.17*	.29***	-.36***	-.41***	-.2**
Social Influences	5.33	2.08	.04	.11	-.31***	-.31***	-.2**
BCon	6.33	1.33	.03	.16*	-.18**	-.11	-.2**
Action Planning	5.25	2	.18**	.29***	-.18**	-.17**	-.15*
Coping Planning	4	2	.24***	.35***	-.27***	-.4***	-.07
Goal Conflict	3.5	2	.21**	.19**	-.09	-.18**	.04
Sub ADHD (*n*=122)							
Knowledge	4.67	2	>-.01	.08	-.07	-.04	-.04
E Context	5.67	2.17	.14	.26**	.04	-.06	.15
Motivation	4.67	1.33	.28**	.35***	-.08	-.28**	.15
BCap	3.33	2.5	.25**	.31***	.12	-.09	.26**
Skills	5	1.92	.27**	.36***	.1	-.18*	.33***
Emotion	4.17	2	.25**	.29**	-.17	-.25**	-.01
Social Influences	4.67	2.25	.11	.24**	-.02	-.1	.03
BCon	6	1.33	-.02	.18*	-.07	-.01	-.01
Action Planning	5	2	.12	.23*	-.02	-.22*	.12
Coping Planning	3	1.67	.25**	.26**	-.05	-.26**	.15

Goal Conflict	3.33	1.58	.9	.18*	-.05	-.15	.09
Total Sample (N=362)							
Knowledge	4.67	1.67	-.03	.12*	-.17**	-.18***	-.12*
E Context	6	1.67	.07	.19***	-.19***	-.21***	-.14*
Motivation	5	2	.27***	.39***	-.24***	-.34***	-.1
BCap	4	3.25	.18***	.26***	-.29***	-.35***	-.16**
Skills	5.33	2	.22***	.3***	-.19***	-.27***	-.07
Emotion	5	2.33	.17**	.3***	-.37***	-.41***	-.25***
Social Influences	5	2	.06	.16**	-.24***	-.25***	-.16**
BCon	6.33	1.33	.01	.17**	-.13*	-.09	-.16**
Action Planning	5.13	2	.15**	.28***	-.16**	-.19***	-.09
Coping Planning	3.67	2	.2***	.32***	-.33***	-.44***	-.16**
Goal Conflict	3.33	1.67	.16**	.19***	-.1	-.18***	>.01

Note. Statistical significance: $*p < .05$; $**p < .01$; $***p < .001$.

PA = Physical Activity; PE = Physical Exercise; ADHD-T = Total ADHD Symptomatology; ADHD-I = Inattentive ADHD Symptomatology; ADHD-H = Hyperactive ADHD Symptomatology; E Context = Environmental Context; BCap = Beliefs about Capabilities; BCon = Belief in Consequences.

4.4.2. Differences in Barriers to PE Between Non-ADHD and Sub-ADHD Participants

To investigate differences in barriers to PE (the 11 DPAQ domains) between Non-ADHD and Sub-ADHD participants (hypothesis 1), a series of Mann-Whitney U tests were conducted. To correct for familywise errors, the Holm-Bonferroni correction was applied. Compared to Sub-ADHD participants, Non-ADHD participants scored significantly higher in the Coping Planning ($U = 9836.5$, $r_{rb} = .33$, $p < .001$) (medium effect size), Emotion ($U = 10619$, $r_{rb} = .28$, $p < .001$) (small effect size), Beliefs about Capability ($U = 11204$, $r_{rb} = .24$, $p = .002$) (small effect size); and Motivation domains ($U = 11982$, $r_{rb} = .18$, $p = .037$) (small effect size). No significant differences were found between Non-ADHD and Sub-ADHD participants in the Environmental Context (U = 12583, p =.196), Skills (U = 12607, p =.196), Social Influences (U = 12681, p =.196), Action Planning (U = 12973.5, p =.304), Knowledge (U = 13020.5, p =.304), Goal Conflict (U = 13603.5, p =.538) and Beliefs about Consequences (U = 13770, p =.538) domains.

4.4.3. DPAQ Links with Exercise Dependence

A series of semi-partial correlations (Kendall's Tau) determined the relationship between DPAQ domains (independent variable) and EDS-T (dependent variable) whilst controlling for PE (hypothesis 2) (see Table 21). Significant positive correlations were found between EDS-T and several DPAQ domains, including Motivation (medium effect size), Beliefs about Capabilities (small effect size), Skills (small effect size), Emotion (small effect size), Action Planning (small effect size), Coping Planning (medium effect size), and Goal Conflict (small effect size). Correlations between Motivation, ADHD symptomatology and DPAQ Domains were included for further exploratory analysis (Table 21). Similar to that shown in Table 20, there were negative correlations between DPAQ Domains and ADHD symptomatology, with more negative correlations generally found with ADHD-I than ADHD-H. Significant positive correlations were consistently between Motivation variables and all DPAQ domains.

Table 21

Semi-partial Correlations (Kendall's Tau) Between DPAQ Domains, ADHD Symptomatology, and EDS-T, While Controlling for PE Level

Variable	ADHD-T	ADHD-I	ADHD-H	RAI	PVQ-S	PVQ-T	EDS-T
Knowledge	-.11**	-.11**	-.09	.1**	.09**	.01**	-.02
E Context	-.13**	-.13**	-.1*	.19***	.17***	.19***	.06
Motivation	-.16***	-.21***	-.08	.5***	.47***	.28***	.33***
B Cap	-.19***	-.23***	-.12*	.36***	.3***	.26***	.18***
Skills	-.12**	-.17***	-.05	.44***	.36***	.32***	.22***
Emotion	-.25***	-.28***	-.18***	.4***	.33***	.3***	.19***
Social Influences	-.15***	-.16***	-.11*	.19***	.18***	.14***	.09
B Con	-.08	-.04	-.11*	.2***	.18***	.18***	-.01
Action Planning	-.1*	-.11**	-.07	.22***	.2***	.11**	.14**
Coping Planning	-.23***	-.3***	-.12**	.39***	.37***	.22***	.3***
Goal Conflict	-.06	-.11**	<.01	.28***	.29***	.18***	.26***

Note. Statistical significance: **p* < .05; ***p* < .01; ****p* < .001 (this is after corrections have been applied as mentioned in the methods).

ADHD-T = Total ADHD Symptomatology; ADHD-I = Inattentive ADHD Symptomatology; ADHD-H = Hyperactive ADHD Symptomatology; PE = Physical Exercise; RAI = Relative Autonomy Index; PVQ-S = Motivation Strength; PVQ-T = Motivation Type; EDS-T = Exercise Dependence Score-Total; E Context = Environmental Context; BCap = Beliefs about Capabilities; BCon = Belief in Consequences.

4.4.4. Moderation of Subclinical ADHD Diagnosis on the Relationship Between DPAQ Domains and PE Levels

The moderating role of subclinical diagnosis of ADHD on the relationship between DE and PE level was assessed to determine if the strength of the correlation was different between subclinical ADHD participants and non-ADHD participants (hypothesis 3). A series of tests of unconditional interaction was performed using PROCESS macro (model 1), with subclinical ADHD diagnosis as moderator, DPAQ domains as predictor, and PE level as the outcome, and with the change in R^2 due to interaction of predictor and moderator. With the exception of the DPAQ domain Knowledge, all models were found to be significant overall (i.e., Environmental Context; Motivation; Beliefs about Capabilities; Skills; Emotions; Social Influences; Beliefs about Consequences; Action planning; Coping Planning; and Goal Conflict), but none of the interactions were significant. Full results are shown below.

In each of the following models the DE domain in the respective subheading was the dependent variable/predictor (Y), PE Level was the independent variable/outcome variable (X) and Subclinical ADHD diagnosis was the moderator (W).

Knowledge

Altogether, the final model was not significant, with 1.96% of the variability in PE predicted by the variables, R2 =.02, F(3,358) = 2.39, p = .068. The interaction was not significant, as the impact of Knowledge on PE Level in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ =.14, b = -.6, t = -.37, p = .713).

Environmental Context

The final model was significant, with 4.19% of the variability in PE predicted by the variables, R2 =.04, F(3,358) = 5.22, p = .002. The interaction was not significant, as the impact of Environmental Context on PE Level in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ =.41, b = 1.14, t = .64, p = .524).

Motivation

The final model was significant, with 15.78% of the variability in PE predicted by the variables, R2 =.16, F(3,358) = 22.36, p <.001. The interaction was not significant, as the impact of Motivation on PE Level in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ <.01, b = -.04, t = -.02, p = .984).

Beliefs about Capabilities

The final model was significant, with 7.36% of the variability in PE predicted by the variables, R2 =.07, F(3,358) = 9.48, p <.001. The interaction was not significant, as the impact of Beliefs about Capabilities on PE Level in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ =1.08, b = 1.28, t = 1.04, p = .3).

Skills

The final model was significant, with 9.46% of the variability in PE predicted by the variables, R2 =.09, F(3,358) = 12.47, p <.001. The interaction was not significant, as the impact of Skills on PE Level in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ =.28, b = .79, t = .53, p = .599).

Emotion

The final model was significant, with 9.11% of the variability in PE predicted by the variables, R2 =.09, F(3,358) = 11.96, p <.001. The interaction was not significant, as the impact of Emotion on PE Level in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ <.01, b = .09, t = .06, p = .95).

Social Influences

The final model was significant, with 3.61% of the variability in PE predicted by the variables, R2 =.04, F(3,358) = 4.47, p = .004. The interaction was not significant, as the impact of Social Influences on PE Level in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ =1.31, b = 1.81, t = 1.14, p = .254).

Beliefs about Consequences

The final model was significant, with 4.09% of the variability in PE predicted by the variables, R2 =.04, F(3,358) = 5.09, p = .002. The interaction was not significant, as the impact of Beliefs about Consequences on PE Level in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ =.17, b = .95, t = .41, p = .684).

Action Planning

The final model was significant, with 7.29% of the variability in PE predicted by the variables, R2 =.07, F(3,358) = 9.39, p < .001. The interaction was not significant, as the impact of Action Planning on PE Level in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ =1.09, b = -1.64, t = -1.04, p = .298).

Coping Planning

The final model was significant, with 11.49% of the variability in PE predicted by the variables, R2 =.12, F(3,358) = 15.49, p < .001. The interaction was not significant, as the impact of Coping Planning on PE Level in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ =.73, b = -1.4, t = -.86, p = .392).

Goal Conflict

The final model was significant, with 4.51% of the variability in PE predicted by the variables, R2 =.5, F(3,358) = 5.64, p = .001. The interaction was not significant, as the impact of Goal Conflict on PE Level in non-ADHD participants was not significantly different from Sub-ADHD participants (FΔ =.01, b = -.15, t = -.09, p = .932).

4.4.5. Mediation of Motivation on the Relationship Between DPAQ Domains and PE Levels

The mediating role of intrinsic motivation on the relationship between DE and PE level was assessed to determine if the correlation was mediated by intrinsic motivation. A series of mediation tests were performed using PROCESS macro (model 4), with subclinical PVQ-T as mediator, DPAQ domains as predictor, and PE level as the outcome. Within the total sample, PVQ-T was found to act as full mediator (to PE level) for Knowledge (β =0.44, 95% CI = [0.14, 0.86]), and as a partial mediator for Environmental Context (β =0.72, 95%

CI = [0.24, 1.29]); Beliefs about Capabilities (β =0.49, 95% CI = [0.41, 0.96]); Social Influences (β =0.56, 95% CI = [0.21, 0.99]); Beliefs about Consequences (β =1.04, 95% CI = [0.32, 1.92]); Action Planning (β =0.45, 95% CI = [0.14, 0.86]); and Goal Conflict (β =0.72, 95% CI = [0.24, 1.27]). PVQ-T did not act as a significant mediator for any of the remaining DPAQ domains. Within the Non-ADHD sample, PVQ-T was found to act as full mediator (to PE level) for Knowledge (β =0.48, 95% CI = [0.83, 1.03]), Environmental Context (β =0.61, 95% CI = [0.63, 1.3]); and Social Influences (β =0.46, 95% CI = [0.07, 0.99]); and as a partial mediator for Goal Conflict (β =0.5, 95% CI = [0.02, 1.06]). PVQ-T did not act as a significant mediator for any of the remaining DPAQ domains.

Within the Sub-ADHD sample, PVQ-T was found to act as full mediator (to PE level) for Environmental Context (β =0.94, 95% CI = [0.05, 2.17]); Beliefs about Consequences (β =0.97, 95% CI = [0.01, 2.67]); Action Planning (β =0.59, 95% CI = [0.01, 1.46]); and Goal Conflict (β =1.34, 95% CI = [0.22, 2.63]); and as a partial mediator for Social Influences (β =0.73, 95% CI = [0.06, 1.71]); and Coping Planning (β =0.81, 95% CI = [0.05, 1.85]). PVQ-T did not act as a significant mediator for any of the remaining DPAQ domains.

4.5. Discussion

The aim of this study was to investigate the relationships between ADHD symptomatology and both DE and ED. Significant differences were found in the levels of barriers to PE (Coping Planning; Emotion; Belief in Capability; and Motivation) based on subclinical ADHD diagnosis, with Sub-ADHD participants experiencing more. Additionally, significant positive correlations were observed between DE and ED (Motivation; Beliefs about Capabilities; Skills; Emotion; Action planning; Coping planning; Goal conflict; Social Influences). Subclinical ADHD diagnosis did not significantly moderate the relationship between any of the DE and PE level. This means that hypotheses 1 and 2 were supported, but hypothesis 3 was not supported. The main findings of the study are discussed further below.

Based on previous literature (Harvey et al., 2014; Ogrodnik et al., 2023; Pontifex et al., 2014), it was hypothesised that there would be a significant difference in the strength of barriers faced between sub-ADHD and non-ADHD participants. The current findings support this suggestion, as non-ADHD participants reported fewer barriers for Coping Planning, Emotion, Beliefs about Capabilities, and Motivation than Sub-ADHD participants. This is consistent with evidence suggesting that individuals with ADHD may be more likely to have maladaptive coping strategies (Wise et al., 2019), leading to reduced Coping Planning; experience higher rates of emotional dysregulation (Retz et al., 2012) and comorbidities (such as depression and anxiety), increasing emotional barriers; have higher rates of obesity (Kim et al., 2011), which could lead to reduced belief in ones capability for exercise; and have deficits in motivation (Volkow et al., 2011), which could manifest as reduced motivation for engaging in exercise.

Supporting hypothesis two, significant positive correlations were observed between ED and DE: Motivation; Beliefs about Capabilities; Skills; Emotion; Action Planning; Coping Planning; and Goal Conflict. This partially aligns with previous literature suggesting that certain DE could serve as risk factors for ED, such as Motivation (Chapter Three: Landolfi, 2013), and Emotion (Berczik et al., 2012; Gori et al., 2021; Landolfi, 2013). However, the absence of a significant association between ED and Belief in Consequences partially contradicts the findings of Gori et al., (2021) who found that a drive for thinness (which could be considered as a Belief in Consequences) was a risk factor for ED/EA. Nevertheless, such discrepancies could reflect prior studies not specifically exploring associations between ED and the determinants outlined in the TDF.

Contrary to hypothesis three, Subclinical ADHD diagnosis did not moderate relationships between DE and PE level. This finding contrasts somewhat with prior literature (Harvey et al., 2014; Ogrodnik et al., 2023), which found certain determinants as particularly important for individuals with ADHD (e.g., Social Influences; Belief about Consequences; Environmental Context). However, it is noteworthy that these previous findings were not compared with non-ADHD participants. Therefore, whilst the identified determinants were deemed important to individuals with ADHD, their relative importance and significance may not differ substantially from that in the general population.

Regarding the exploratory mediation analyses, it was found that intrinsic motivation acted as a mediator between multiple DE and PE, supporting previous literature highlighting intrinsic motivation as a mediator for behavioural outcomes (Morsink et al., 2022). Intrinsic Motivation acted as a significant mediator (to PE) for both Non-ADHD and Sub-ADHD for Environmental Context; Social Influences; and Goal Conflict DPAQ domains. However, a significant mediation effect was also found for Knowledge in Non-ADHD participants only; and Beliefs about Consequences; Action Planning; Coping planning for Sub-ADHD participants only. This suggests that certain DE may increase PE engagement via different pathways in ADHD individuals compared to non-ADHD individuals. However, the exploratory nature of this analysis means that further confirmational analysis would be needed before confident assessments could be made.

Also of note was that, in contrast to the findings of Chapter Two and Three, there was a significant positive correlation between ADHD symptomatology and PA level. It is worth noting that despite the correlation not being significant in Chapter Three, the coefficient was actually higher (.14 compared to .12), suggesting that the difference in significance was potentially due to reduced power in study three (with a sample size of 152 compared to 362). The relationship between ADHD symptomatology and PE level was a nonsignificant negative correlation for ADHD-T and ADHD-H, and a significant negative correlation with ADHD-I, making it more similar to findings in Chapter Two (which had a significant negative correlation with ADHD-T and ADHD-I), compared to Chapter Three (which had a significant positive correlation). Additionally, possible explanations for this include the fact that for its sample Chapter Three had a higher proportion of full-time students (70.39% compared to 64.55% in Chapter Two and 57.74 in Chapter Four); who typically had more positive correlations between PA/PE and ADHD symptomatology. In addition, the sample in study three also consisted of people in full time employment (7.89% compared to 17.91% in Chapter Two and 16.58 in Chapter Four); who typically had more negative correlations between PA/PE and ADHD symptomatology.

The positive correlation found between ADHD symptomatology and PA level also contrasts with prior literature (Abramovitch et al., 2013). This discrepancy may partially stem from differences in recruitment strategy: Abramovitch et al. (2013) recruited individuals with a pre-existing diagnosis of ADHD, whereas the current study recruited from the general population, potentially resulting in a more positive correlation due to the inclusion of non-ADHD participants. Within the current study, and when split by subgroup (see Table 18), the correlation between ADHD symptomatology and PA level was .14 in Non-ADHD participants, but only .04 in Sub-ADHD. Additionally, the correlation between ADHD symptomatology and PE level was negative suggesting that there is a key difference in the relationship between ADHD symptomatology with PA versus with PE.

The findings regarding the difference in strength of barriers between non-ADHD and sub-ADHD participants have implications for potential PE based interventions for ADHD. Indeed, identifying specific barriers that individuals with ADHD experience at a greater level is an important step for the development of such interventions (Hussein et al., 2021; Michie et al., 2011; Pontifex et al., 2014). Utilising the Behaviour Change Wheel (Michie et al., 2011), the TDF can be applied to the three sources of behaviour (Capability; Opportunity; Motivation) (Cane et al., 2012) to determine appropriate intervention functions. For instance, Motivation; Emotion and Belief in Capabilities would fall under the source of Motivation, while Coping Planning would fall under Capability (Cane et al., 2012). Accordingly, interventions to address barriers related to Motivation and Beliefs in Capability would benefit from incorporating educational, persuasion, incentivisation and coercion-based functions. That is, increasing knowledge and understanding of PE, using communication strategies to induce positive or negative feelings to support action, and creating clear expectations of both reward and cost. For barriers related to Emotions, intervention functions should similarly comprise persuasion, incentivisation, and coercion, but also environmental restructuring, modelling and enablement. For example, changing the physical or social context, providing examples for individuals to aspire to and/or imitate, and increasing means or reducing barriers to increase both opportunity and capability. Similarly, interventions addressing Coping Planning should focus on education, persuasion, and enablement functions. It is important to note though that these intervention strategies are based on guidance from the Behaviour Change Wheel (Michie et al., 2011), where other evidence-based approaches could alternatively be considered, such as improving motivation via motivational interviewing (Sibley et al., 2016) (see section 3.5.). Therefore, future research considering the effectiveness of these potential interventions should explore various options, being cognisant of the specific needs and challenges of the ADHD population.

In examining whether ADHD presents unique challenges/barriers to PE compared to other psychiatric conditions, this study found that the barriers linked with ADHD were similar to those linked with mood disorders, such as Emotion; Belief about Capabilities; and Motivation/Intentions (Glowacki et al., 2017). However, while mood disorders are often associated with barriers related to Environmental Context & Resources, this was not observed in ADHD which instead showed higher barriers in Coping Planning. As suggested previously (see section 1.5.6.), this suggests that ADHD could be associated with unique barriers around Coping Planning, potentially due to difficulties around maintaining routines (Wender, 1998;

Wolf & Wasserstein, 2001). However, such comparisons should be interpreted with caution without direct controlled comparisons.

The finding that intrinsic motivation acted as a mediator between several DE and PE level for Sub-ADHD participants suggests that previous recommendations for interventions based around reducing barriers to PE (see above) and increasing intrinsic motivation for PE (see section 3.5.) could be combined. Intrinsic PE motivation could potentially be increased by interventions around reducing the barriers highlighted (Environmental Context; Social Influences; Beliefs about Consequences; Action Planning; Coping Planning; Goal Conflict). Of note is Coping Planning as this was found to be a greater barrier for Sub-ADHD participants, while intrinsic PE motivation was also found to act as a partial mediator between it and PE level for Sub-ADHD participants. As highlighted previously though, these findings are purely exploratory, and further research is needed to confirm whether intrinsic motivation acts as a mediator for specific DE.

Moreover, the finding that subclinical ADHD diagnosis did not moderate the relationship between the DE and level of PE suggests that the level of experienced barriers (compared to the general population) is a key consideration in identifying behaviours to target in PE-based interventions. This suggests that the four DE domains identified as being experienced at a greater rate in subclinical ADHD participants – Coping Planning, Emotion, Beliefs about Capabilities, and Motivation - should be primary targets. However, all four DE experienced at a higher rate in individuals with subclinical ADHD were also positively correlated with ED. Similar to suggestions in Chapter Three focused around increasing intrinsic motivation, interventions focused on reducing barriers to PE should be cautious of ED risk, carefully monitoring any increased risk and discerning which prospective individuals it may be more suitable for.

This study suffers from similar limitations as the studies from Chapters Two and Three. Once again, the sample was biased with an overrepresentation of females and students, and a lower average age compared to the general population. Additionally, with a cross-sectional design, causation cannot be inferred. For the moderation analyses, it could be interpreted that the level of determinants experienced would affect PE level. However, it could in fact operate in the opposite direction. For instance, high levels of PE could motivate individuals to try to remove barriers, while those engaging in small amounts of PE may be less concerned with removing such barriers.

Moreover, the DPAQ has limitations due to inconsistencies in item wording. Most items inquire about whether a particular barrier/determinant is experienced regardless of its effect on PE engagement (e.g., "I DO NOT know the reasons why I should be meeting the nationally recommended PA guidelines"), whereas others additionally specify the impact on PE engagement (e.g., "My local area is NOT very attractive and this puts me off doing physical activity"), or only assess the importance of the barrier to PE engagement (e.g., "I FIND IT HARD to do physical activity when I see others doing well at physical activity [e.g. watching others run for a long time on the treadmill]"). This inconsistency compromises the accuracy of the measure, as the underlying variables being represented by the 11 domains might not be the same. For example, Emotion comprises two items phrased to assess whether engagement in PE is affected, whereas all three items of Knowledge focus on whether a possible barrier/facilitator is experienced, irrespective of its effect. Additionally, items focusing only on the experience of a DE could lead to flawed interpretations, where a particular potential barrier may not be important for individuals with ADHD, leading to them taking fewer steps to remove that barrier as it does not affect their PE engagement. This could then lead to them being recorded as experiencing that potential barrier to a greater degree, leading to the flawed interpretation that steps should be taken to reduce these barriers for individuals with ADHD, even though it would not affect their PE engagement. Furthermore, four domains of the 14-domain TDF are not fully measured by the DPAQ (Social/Professional Role and Identity; Memory, Attention and Decision Processes; Behavioural Regulation; Nature of Behaviours), limiting the scope of analysis in this study.

To address this, future research should try to adopt established quantitative measures of barriers to ensure consistency in findings and to identify additional barriers that individuals with ADHD may experience but are not captured by the DPAQ. Potential options include the Barriers to Being Active Quiz (Centers for Disease Control and Prevention, 2016); Barriers to Outdoor Physical Activity Questionnaire (Eronen et al., 2014); and the Corporate Exercise Barriers Scale (Aaltonen et al., 2012). However, the quantitative measurement of facilitators of PE is more challenging, as most existing tools are qualitative in nature (Mbabazi et al., 2023). Moreover, many quantitative measures fail to distinguish between: 1) the experience of a potential facilitator; 2) the personal importance of a facilitator; 3) the effect of a potential facilitator (similar to the DPAQ, see above.). Future research on facilitators of PE within ADHD could begin by adapting quantitative measures used in previous studies (Ebben & Brudzynski, 2008; Harvey et al., 2014; Ogrodnik et al., 2023). Although, quantifiable comparison with healthy controls and further meta-analysis would not be possible without further quantitative research. To address this, quantitative measures of facilitators could be developed, informed by the TDF, facilitators identified in previous studies (Eronen et al., 2014; Harvey et al., 2014; Ogrodnik et al., 2023), and insights from pilot work to capture potential facilitators not included in existing measures like the DPAQ.

4.5.1. Conclusion

In conclusion, the findings of this study suggest that individuals with subclinical ADHD experience higher levels of barriers to PE than the general population, and that the importance and significance of these barriers/determinants in influencing PE engagement is not significantly different between subclinical ADHD and non-ADHD individuals. Additionally, certain determinants are associated with increased ED, suggesting that caution should be exercised when implementing interventions aimed at reducing these barriers. Future research should focus on further exploring these barriers in individuals with ADHD to better inform the development of effective, practical interventions.

Chapter Four: Key Messages

- This study aimed to investigate the relationship between PE, ADHD symptoms, barriers/determinants of exercise, and ED.
- Significant differences were found in the levels of barriers to PE (Coping Planning; Emotion; Belief in Capability; and Motivation) based on subclinical ADHD diagnosis, with Sub-ADHD participants experiencing more. Additionally, significant positive correlations were observed between DE and ED (Motivation; Beliefs about Capabilities; Skills; Emotion; Action planning; Coping planning; Goal conflict; Social). Subclinical ADHD diagnosis did not significantly moderate the relationship between any of the DE and PE level.
- These findings suggest that individuals with ADHD experience greater levels of certain barriers to exercise, which may need to be overcome or targeted in any potential PE based intervention. However, since some of these barriers were linked with ED risk, caution should be exercised to avoid increasing ED rates further.

5. Chapter Five: Effects of Home-based Exercise Intervention on ADHD Symptoms – Executive-Function and Mood

5.1. Chapter Overview

As outlined in Chapter Four, individuals with ADHD were found to experience greater barriers to PE than individuals without ADHD. Further research should identify ways in which these barriers could be overcome and/or circumnavigated to increase PE engagement. One potential method could be through the use of home-based exercise, that would avoid certain barriers (e.g., lack of community resources/equipment; financial cost) and potentially allow for the growth in capability/confidence to overcome others (e.g., Beliefs about capabilities). The goal of this chapter is to investigate the effects of home-based exercise on specific ADHD symptoms. These symptoms were focused on EF (inhibitory control, set-shifting and working memory) and Mood.

5.2. Introduction

Findings from Chapter Four showed that ADHD was associated with greater levels of barriers to PE, suggesting that there should be particular attention paid to PA contexts/dimensions that would circumvent/address these barriers (e.g., home based PE). Findings in previous chapters have also shown potential links between exercise and reduced ADHD symptoms, particularly inattentive (Chapter Two). However, as highlighted previously (see sections 1.5. and 1.6.) more research is still needed regarding the central effects of PA on ADHD symptom, particularly in regard to different contexts/dimensions of PA (see section 1.5.2.).

As highlighted previously (see section 1.5.1.), existing literature has found that PE can reduce symptoms of ADHD, including poor mood (Fritz & O'Connor, 2016) and various aspects of EF, such as inhibitory control (Kuo et al., 2024; Ludyga et al., 2016; Piepmeier et al., 2015), set shifting (Ludyga et al., 2016; Welsch et al., 2021), and working memory (Chen et al., 2014; Ludyga et al., 2016; Welsch et al., 2021). For example, Kuo et al. (2024) found that a 30-minute session of aerobic exercise (on a stationary exercise bike) led to significant improvements in inhibitory control (measured via the Stop Signal Task) and increased short intracortical inhibition in a sample of 26 adults with ADHD, compared to a group of age- and gender-matched controls. A meta-analysis by Ludyga et al. (2016) reviewing 40 experimental studies found that moderate aerobic exercise improved inhibitory control, set shifting and working memory across a range of ages and fitness levels. Similarly, a meta-analysis by Welsch et al. (2021), which analysed 12 studies focussed on various aspects of EF in children with ADHD, found that PA had significant beneficial effects on set shifting and working memory. Even so, it is important to note that such findings are not universal. For instance, in their meta-analysis, Welsch et al., (2021) found no significant beneficial improvement on inhibition control, and a randomised controlled trial by Dinu et al. (2023) on adults with ADHD also found no effects of PE (10 minutes of either aerobic cycling or yoga) on attention (measured via Test of Variables of Attention task) or cognitive impulsivity (measured via Delay Discounting Test and Iowa Gambling Task). Conversely, Piepmeier et al. (2015) found that PE (30-min bout of aerobic exercise) led to benefits in inhibitory control (measured via Stroop test) in children with ADHD, but not in set shifting (measured via Trial Making Test). Therefore, while existing evidence generally supports the beneficial effects of PE on ADHD symptoms, findings related to specific aspects of EF are mixed, signalling the need for further research.

Additionally, and as mentioned previously, findings from Chapter Four and previous literature (e.g., Harvey et al., 2014; Ogrodnik et al., 2023) indicates that individuals with ADHD experience greater levels of barriers to exercise. Therefore, further research is needed not only to further explore whether PE in general can alleviate ADHD symptoms in adults, but also specifically whether forms of PE that circumvent these potential barriers can also produce the same effects on adult ADHD symptoms. Several barriers, such as a lack of community resources and equipment (Harvey et al., 2014), low self-esteem/confidence (Harvey et al., 2014; Ogrodnik et al., 2023), and financial cost (Harvey et al., 2014), may make it particularly challenging for individuals with ADHD to engage in outside/club-based activities like gyms and sports clubs. Further, the increased financial burden of ADHD (Pitts et al., 2015) represents an additional challenge for activities with financial costs attached, such as gym memberships, making them even less accessible. Thus, home-based exercises may be a more accessible option for individuals with ADHD, as they do not require outside/community equipment/facilities, may lower the risk of performance anxiety by avoiding observation by others, and reduce financial expenses and related pressures. Home-based PE interventions have similarly been used for other clinical populations that experience high barriers to PE engagement such as patients with heart failure (Okwose et al., 2020) and type one diabetes (Scott et al., 2020). Such home-based PE interventions have been found to lead to outcomes approximately equivalent to gym-based programmes (Jansons et al., 2017), while also being less costly (Jansons et al., 2018); increase overall PA engagement (Ransdell et al., 2004); and reduce or remove exercise barriers (Ransdell et al., 2004; Scott et al., 2020), such as requiring no travel time or membership related costs, being time efficient, and reducing embarrassment experienced by some when exercising in public. Engaging in home exercise could also help reduce barriers related to 'Beliefs about capabilities' experienced by individuals with ADHD (see Chapter Four) by supporting individuals to build their confidence so that they feel better positioned to engage in PE in the presence of others. This suggests that home exercise-based interventions for individuals with ADHD could be a more cost-effective option while maintaining comparable effectiveness.

However, not all research supports home-based exercise as comparably effective as other forms of exercise. For instance, some research suggests that home-based exercise does not match the benefits of gym-based exercise (Melo et al., 2024); supervised exercise (Liang et al., 2020); or outdoor-based exercise (Boere et al., 2023; Rueschmann, 2022). Additionally, some key facilitators for engaging with exercise amongst individuals with ADHD include social aspects, which may be missing in home-based exercise. For example, individuals often benefit from the social enjoyment of exercising with friends and family (Harvey et al., 2014); the opportunity to develop friendships (Harvey et al., 2014), and the overall enjoyment of being active with others (Ogrodnik et al., 2023). Therefore, it should not be assumed that home-based exercises will yield the same outcomes and benefits on ADHD symptoms as group-based or outside exercises. Thus, further research on the effects of home-based exercises is required to inform intervention strategies, balancing the potential benefits of home exercise (e.g., ease of access, reduced barriers) with possible limitations (e.g., reduced efficacy on ADHD symptoms).

Therefore, the aim of this study was to investigate whether PE performed in an online home-based format can lead to a significant increase in EF and mood compared to a control condition. Based on previous literature (Fritz & O’Connor, 2016; Kuo et al., 2024; Ludyga et al., 2016; Welsch et al., 2021), it was hypothesised that: 1) there would be a significant improvement in mood following exercise compared to a control; 2) there would be a significant improvement in levels of inhibitory control following exercise compared to a control; 3) there would be a significant improvement in set shifting following exercise compared to a control; 4) there would be a significant improvement in working memory following exercise compared to a control.

5.3. Methods

5.3.1. Participants

Participants were recruited online via adverts placed on the internet, social media, e-mail, and a University Psychology participant pool. The study was advertised as "*Effect of changing conditions on executive function*", and upon completion, participants were offered either eight participant pool credits or entry into an anonymous raffle to win one of four £25 amazon vouchers. To be eligible to take part, participants had to be at least 18 years of age, reside in the United Kingdom, and have no physical or health restrictions that would prevent them from performing 30 minutes of moderate exercise. Additionally, participants also needed to have access to a laptop or desktop computer to complete stages two and three of the study. A G-Power calculation indicated that for 80% power, with a rejection criterion of $p < .05$, and medium effect size ($f = .25$), that 34 participants would be needed for a 2x2 repeated measures ANOVA interaction effect.

Initially, 116 individuals expressed interest in the study and were registered on Gorilla (GORILLA, 2009) , receiving study information and an access link for the study. However, only 74 participants accessed the study, and of those, 52 were subsequently excluded for the following reasons: not completing the study in full (n=36); not starting session 3 within eight days of completing session 2 (n=9); having unusable gaps of time within the test battery (n=6); having unusable data (n=1); and reporting no perceived exertion after completing the exercise condition (scoring 0 on the BORG scale; n=1).

This left 21 participants, of whom 17 (80.95%) were female. Ages ranged from 19-36 years (M = 21.48 SD = 3.57), with further demographic information presented in Table 22. Options for the Gender and Ethnicity question were based on the categories recommended for use by the UK government

Table 22

*Demographic information of the study sample (*N=*21)*

Demographics	*n* (%)
Gender	
Male	4 (19.05)
Female	17 (80.95)
Ethnicity	
White/English/Scottish/Northern Irish/British	14 (66.67)
Any other white background	4 (19.05)
Indian	1 (4.76)
Bangladeshi	1 (4.76)
African	1 (4.76)
Highest Level of education	
College/Sixth form (e.g. BTEC, A-Levels) or equivalent	12 (57.14)
University (e.g. BSc, BA, Degree)	8 (38.1)
Masters (e.g. MSC, MA)	1 (4.76)
Employment Status	
Full-time employment	1 (4.76)
Part-time employment	5 (23.81)
Full-time student	15 (71.43)

Note: BTEC = business and Technology Education Council; A-level = Advanced level qualification; BSc = Bachelor of Sciences; BA = Bachelor of Arts; MSC = Master of Sciences; MA = Master of Arts

5.3.2. Apparatus and Materials

The online survey was conducted online using Gorilla (GORILLA, 2009).

Participants were asked to supply standard demographic details (e.g., age, gender) and answered questions about their potential comorbid conditions and medications (Appendix A and B). In addition, the survey contained the following standardised questionnaires and tasks:

ADHD Self Report Scale v1.2 (ASRS-5) (Ustun et al., 2017) (Appendix K) was used as a screening measure for ADHD (see section 3.3.2. for details). While the screening measure for ADHD was changed to the ADHD-RS-IV for Chapter Three and Four (see sections 3.3.2. and 3.3.5.), the current study was designed before those two chapters (October 2021 – February 2022). Therefore, this change in the thesis methodology had not been implemented chronologically and the ASRS-5 was chosen due to its short length. Within the current study it demonstrated an internal consistency of .48.

The International Physical Activity Questionnaire – Long Format, last seven days, self-administered (IPAQ-L7S) (Craig et al., 2003) (Appendix F) was used to measure PA Level (sum of all four domain sub scores) and PE level (Leisure domain) (see section 2.2.2. for details).

National Health Service (NHS) Exercise Video: A 48-minute long workout video featuring a compilation of low-impact exercises designed for viewers to follow at home (NHS, 2021). For the exercise intervention, viewers were directed to this video and instructed to follow along for 20 minutes. The video was used due for its moderate intensity, ease of accessibility, and prescribed use by a certified organisation (NHS) to ensure safety.

Figure 3

Screenshot of NHS Exercise Video

Figure 4

Screenshot of NHS Exercise Video

Movie for the Assessment of Social Cognition (MASC) (Dziobek et al., 2006): Typically employed to assess levels of social cognition, the MASC was used as the control condition in this study. It requires participants to watch a series of short movie/video clips of characters interacting at a dinner and when prompted, answer questions from a multiple-choice format about the characters' moods, feelings and intentions. This was chosen as a control condition as it keeps participants engaged without being cognitively demanding and has been used similarly in other studies previously (Mehren et al., 2019). The MASC took approximately 30 minutes to complete.

Borg Category-Ratio 10 Scale (Borg CR-10) (Borg, 1982, 1998) (Appendix Q): an 18-point general intensity rating scale most commonly used to measure perceived exertion. Participants are presented with instructions and the prompt "Please indicate your level of exertion" and required to select an answer from 0 ("Nothing at all") to 12 (Absolute maximum). The validity of the Borg CR-10 has been established in numerous contexts, with strong correlations with objective measures of exertion (Capodaglio, 2001; Frasie et al., 2024; O. Lee & Jung, 2016). The scale, instructions and licence to use were acquired from https://borgperception.se/.

Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988) (Appendix R): A 20-item self-report questionnaire used to assess emotion or mood. Respondents are presented with 10 positive affects (e.g., excited; enthusiastic; proud) and 10 negative affects (e.g., upset; guilty; scared) and rate how much they are currently experiencing each on a five-point scale (1= *Very slightly or not at all* to 5 = *Extremely*). The scores are then summed separately for positive and negative affects, creating a total score range of 0-50 for each. The questionnaire has shown good reliability for both Positive Affect (Cronbach α = .89) and Negative Affect (Cronbach α = .85) (Crawford & Henry, 2004).

Erikson Flanker Task (Eriksen & Eriksen, 1974): This task assesses response inhibition and sustained attention. An online fish version was used in this study, where each stimulus was comprised five fish in a row (one target in the middle and two flankers either side). Participants had to select which direction the target fish was facing (left or right). In congruent trials, the flankers faced the same direction as the target, whereas in incongruent trials, they faced in other direction. Each trial began with a fixation cross displayed for 400, 800 or 1200 milliseconds, followed by the stimulus. Participants responded by pressing "f" key (for left) or "j" key (for right). Two interference scores are then calculated: 1) Mean Reaction Time (MRT) Interference, calculated by subtracting the MRT of correct congruent trials from the MRT of correct incongruent trials; 2) Accuracy Interference, calculated by subtracting the accuracy rate of congruent trials from the accuracy rate of incongruent trials (Sanders et al., 2018). These two resultant scores represent levels of inhibitory control, with higher MRT Interference and lower Accuracy Interference representing greater inhibitory control. RTs below 150ms (0.01% of all trials) or greater than 3000ms were excluded as outliers (less than 0.01% of all trials) (Mittelstädt et al., 2023). Participants completed four practice trials followed by 120 main trials with randomised direction, fixation duration, and trail type. The task took approximately four minutes.

Wisconsin Card Sorting Task (WCST) (Berg, 1948; Grant & Berg, 1948): A psychological test used to assess set-shifting. An online electronic version was used in this study where participants were presented with four piles of cards, each containing symbols varying by number, colour, and shape. Participants are asked to match a target card to one of the piles according to one of the criteria (e.g., shape, colour, number), receiving feedback about whether their match was correct or incorrect (displayed for 700 milliseconds). After 10 consecutive correct matches, the categorisation rule then switches. The number of Preservative Errors are recorded, which represents incorrect responses made by a participant based on an incorrect or previously relevant dimension. The number of preservative Errors is then used to reflect, and index set shifting ability (Miles et al., 2021). Failure To Maintain Set (FTMS) was measured by the number of incorrect trials after five or more consecutively correct trials within the same categorisation rule (showing they have understood the rule). FTMS was then used to reflect and index distractibility (Figueroa & Youmans, 2013). The task consisted of 64 trials with randomised categorisation rules, target cards, and piles, and lasted approximately three minutes.

The N-Back test (Kirchner, 1958): A continuous performance task used to assess working memory. An online version of the task was employed, where participants were shown a sequence of items (letters or numbers), each appearing for 500 milliseconds before disappearing for 2500 milliseconds before the next item was presented (each trial being 3000 milliseconds each). Participants select whether the currently presented item matches the item that was presented either two items previously (in the case of the 2-back) or three items previously (in the case of the 3-back). Participants respond by pressing the "m' key for a match, and the "z" key for a non-match. Correctly identifying a match was considered a "hit", incorrectly identifying a non-match as a match was considered a "False Alarm" (FA). A delay of 3000ms results in a "timeout" screen and is recorded as an error. Participants were presented with 10 practice trials of the 2-back and 10 practice trials of the 3-back before starting the main task. The main task consisted of four blocks (two 2-back blocks and two 3-back blocks in a randomised order), with each block containing 30 trials. Sensitivity, the ability to discriminate targets from non-targets, was represented as D Prime (*d'*), calculated using the formula: $d' = Z_{Hit} - Z_{FA}$ (Haatveit et al., 2010). Perfect hit rates were adjusted by 1-1/160, and perfect FA rates were adjusted by 1/40. Higher *d'* scores represent greater discrimination ability (i.e., targets from non-targets). The whole task took approximately eight minutes, and of the four presentations, two blocks used numbers and two used letters (in randomised order).

Self-devised Questionnaires: To monitor potential extraneous variables such as PE performed outside of the study and order-effects, a simple measure of exercise was developed to measure the amount of PE participants had performed in the past week. Participants were asked "*In the past week how many days have you performed moderate exercise for at least 20 minutes (not including any exercise incorporated into this study)?*", with response options including "None (0)"; "One day (1)"; "Some days (2-3)"; "Most days (4-6)"; and "Every day (7)".

5.3.3. Design

This study was a 2x2 within-subjects crossover study. The within-subjects variables were intervention condition (Exercise-Condition versus Control Condition) and Time (Pre-intervention versus Post-intervention). The dependent variables were: Mood, measured as Positive Affect and Negative Affect (PANAS); Inhibitory Control, measured as MRT Interference and Accuracy Interference (Flanker task); Set-shifting, measured as Preservative Errors (WCST); and Working Memory, measured by 2-Back Sensitivity and 3-Back Sensitivity) (N-Back test). Participants were randomly assigned to one of two counterbalanced schedule groups (Exercise-Control [E-C] versus Control-Exercise [C-E]) to reduce order and practice effects.

5.3.4. Procedure

The research was approved by the Swansea University Psychology Department Research Ethics Committee (Reference number 5414) (Appendix S). The study was divided into three stages. Participants accessed the first stage online via Gorilla using an email link and individual access code (after first registering their interest through responding to emails or signing up on Participant Pool, as examples). Participants were first presented with a detailed information page and were then asked to indicate their consent via an electronic (Yes/No) checkbox. Participants who did not consent to participate were directed to the end of the survey and excluded from data analysis.

Consenting participants were asked to complete a series of demographic questions, followed by the ASRS-5; the IPAQ-L; and then questions on comorbidities. This completed the first stage, and participants were then randomly grouped into a schedule group (E-C versus C-E). Participants then had to wait at least one day before starting stage two, with a deadline of 14 days after completing stage one. Upon accessing stage two (through the same link and access code as stage one), participants were presented with a screening questionnaire. They had to confirm they had consumed no caffeine that day; had not performed strenuous PE; or experienced abnormal sleep (defined as within 1 hour of their normal amount). Participants who did not meet these criteria were instructed to restart stage two on another day. On meeting the criteria, participants were presented with the basic exercise measure (asking how much PE they had performed in the past week) and then completed the EF/mood test battery, consisting of the PANAS; Flanker task; WCST and N-back, presented in a randomised order.

Next, participants undertook one of two interventions based on their schedule group: participants in the E-C group were presented with the NHS home-based exercise video where they were instructed to follow the video for 20 minutes, followed by a 10-minutes cool-down period, and then completed the BORG-10 scale. Participants in the C-E group were presented with the MASC, which took approximately 40 minutes to complete. After the intervention (exercise or control), all participants completed the same EF/mood test battery as before (again in a randomised order), concluding stage two.

Participants then had to wait six-eight days before starting stage three, which they were instructed to complete at a similar time of day and under similar conditions as stage two. Stage three was largely the same as stage two (confirmation questionnaire; EF/mood test battery; intervention; EF/mood test battery), but participants performed the intervention they had not done in stage two (e.g., E-C group would complete the MASC; C-E group would complete the exercise video and BORG-10). After the final test battery, participants were presented with a debrief form and asked to select their preferred form of compensation. All survey sections required a response (except for the questions in the IPAQ-L a participant would have skipped), ensuring the survey was fully completed. Participants were sent email reminders as their required completion dates for stages two and three approached, to improve adherence rates.

5.3.5. Data Processing and Statistical Analysis

Data cleaning and processing were conducted using Microsoft Excel, and analyses performed using IBM SPSS Statistics version 29.0 (IBM Corp., 2023) and JASP 0.18.3 (JASP Team, 2023). IPAQ-L data was cleaned in accordance with the guidelines set out by the IPAQ group.

To investigate whether the Exercise condition led to a significant increase in EF/mood scores (from Pre-intervention to Post-intervention) compared to the control condition, a series of 2x2 Repeated Measures ANOVAs were performed, one for each dependent variable: Positive Affect (hypothesis 1); Negative Affect (hypothesis 1); MRT Interference (hypothesis 2); Accuracy Interference (hypothesis 2); Preservative errors (hypothesis 3); 2-Back Sensitivity (hypothesis 4); and 3Back Sensitivity (hypothesis 4) (a total of seven ANOVAs). The within subject's variable for each ANOVA was Time of measurement (Pre-intervention versus Post-intervention) and Condition (Control versus Exercise).

The assumption of no significant outliers was found to be violated for five of the ANOVAs (defined as exceeding the 3rd quartile of score + 3*IQR), with two significant outliers for Preservative errors; three for MRT Interaction and Accuracy Interaction; and five for 2-Back Sensitivity and 3-Back Sensitivity. These individual outliers were then excluded from their respective analyses to satisfy this assumption.

The assumption of normal distribution was found to have been met for MRT Interference; Accuracy Interference; and 3-Back Sensitivity, for all four conditions (based on observing skewness and histograms). However, Positive Affect; Negative Affect; Preservative errors; and 2-Back Sensitivity required square root transformations to meet normality assumptions. FTMS however exhibited significant non-normal distributions across multiple conditions even after transformation attempts and was therefore excluded from further analysis.

5.4. Results

5.4.1. Descriptive Results

Table 23 shows the descriptive statistics for the variables across the different Conditions and Times. The scores of participants excluded for specific ANOVA tests (as specified in Methods) were also excluded from the calculation of the Means and SDs for those respective variables to better represent the data that was analysed.

Table 23

Descriptive Statistics for Study Variables across Conditions and Time

Variable	Control Condition				Exercise Condition			
	Pre-Intervention		Post-Intervention		Pre-Intervention		Post-Intervention	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
PANAS								
Positive (n=21)	1.35	0.15	1.24	0.14	1.33	0.18	1.33	0.17
	(24)[a]	(14)[a]	(16)[a]	(10)[a]	(23)[a]	(16)[a]	(21)[a]	(13)[a]
Negative (n=21)	3.71	0.41	3.55	0.28	3.64	0.52	3.61	0.41
	(13)[a]	(6)[a]	(13)[a]	(3)[a]	(12)[a]	(6)[a]	(12)[a]	(5)[a]
Flanker								
MRT Interference (n=18)	23.87	21.09	27.7	20.71	20.49	16.19	23.77	14.9
Acc Interference (n=18)	-0.22	0.81	-0.94	1.3	-1.5	2.2	-0.72	1.27
WCST								
Preservative Errors (n=19)	0.59	0.28	0.52	0.25	0.68	0.19	0.56	0.24
	(3)[a]	(2)[a]	(2)[a]	(3)[a]	(4)[a]	(4)[a]	(3)[a]	(2)[a]
N-Back								
2-Back Sensitivity (n=17)	2.12	0.23	2.17	0.23	2.12	0.17	2.1	0.13
	(1.37) [a]	(0.94) [a]	(1.71) [a]	(1.12) [a]	(1.67) [a]	(0.67) [a]	(1.56) [a]	(0.76) [a]
3-Back Sensitivity (n=17)	1.29	0.53	1.32	0.58	1.32	0.47	1.48	0.63

Note. PANAS = Positive and Negative Affect Schedule; MRT = Mean Reaction Time; Acc = Accuracy; WCST = Wisconsin Card Sorting Task

[a] Brackets represent the median and *IQR* of non-normally distributed variables/untransformed variables below the mean and *SD* of the transformed variable.

5.4.2. Repeated Measures ANOVAs for Mood

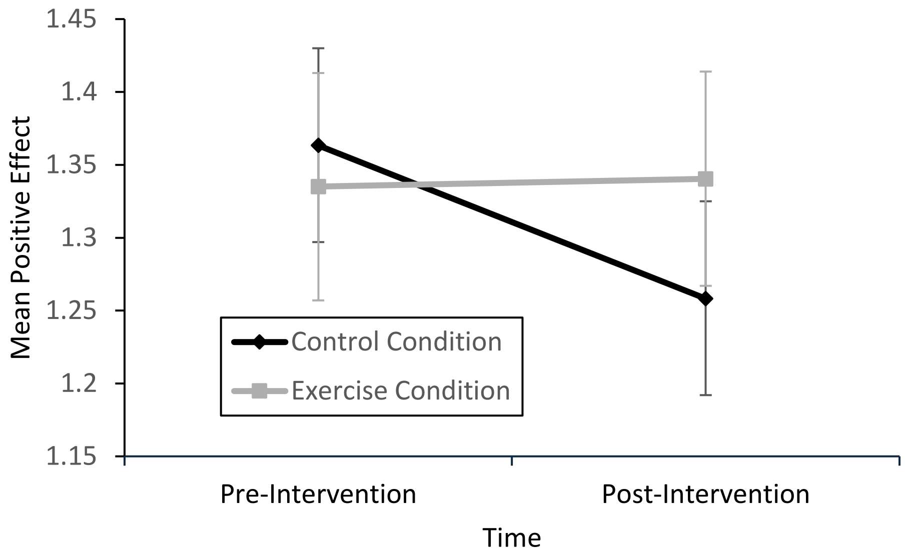
To investigate the effect of the exercise condition on mood (hypothesis 1), two 2x2 repeated ANOVAs were performed that used PANAS (Positive Affect and Negative Affect) scores as the dependent variables (see Table 23 for means). For the first ANOVA on Positive Affect, there was a significant main effect of Time $F[1,20] = 8.86$, $p = .007$, $\eta_p^2 = .31$, (large effect size) with post-intervention scores being generally lower than Pre-intervention scores (see Figure 5). Additionally, there was a significant interaction between Time and Condition, $F[1,20] = 5.92$, $p = .024$, $\eta_p^2 = .23$ (large effect size), with Positive Affect remaining relatively stable between pre-post intervention in the Exercise condition compared to the Control condition which decreased slightly. Simple main effect analysis showed that Positive Affect was significantly higher in the Exercise condition than the Control condition at post-intervention ($F= 7.89$, $p = .011$) but not at pre-intervention ($F= 0.31$, $p = .584$); and that Positive Affect was significantly lower at Pre-intervention than Post-intervention in the Control condition ($F= 13.01$, $p = .002$) but not in the Exercise condition ($F= 0.02$, $p = .883$).

However, there was no significant main effect of Condition $F[1,20] = 1.19$, $p = .289$, $\eta_p^2 = .06$.

For the second ANOVA on Negative Affect, there was no significant main effect of Condition ($F[1,20] = 0.08$, $p = .928$, $\eta_p^2 < .01$), and no significant main effect of Time ($F[1,20] = 1.77$, $p = .199$, $\eta_p^2 = .08$). Additionally, there was no significant interaction between the Time and Condition ($F[1,20] = 1.75$, $p = .201$, $\eta_p^2 = .08$).

Figure 5

Mean Positive Effect Scores Across Time and Condition



Note. Error bars represent 95% CI.

5.4.3. Repeated Measures ANOVAs for Level of Inhibitory Control

To investigate the effect of the exercise condition on inhibitory control (hypothesis 2), two 2x2 repeated ANOVAs were performed that used Flanker scores (MRT Interference and Acc Interference) scores as the Dependent variables (see Table 23). For the first ANOVA on MRT Interference, there was no significant main effect Condition, $F[1,17] = 1.34$, $p = .26$, $\eta_p^2 = .07$, or Time, $F[1,17] = 0.69$, $p = .42$, $\eta_p^2 = .04$. There was also no significant interaction between Condition and Time, $F[1,17] = 0.01$, $p = .94$, $\eta_p^2 < .01$.

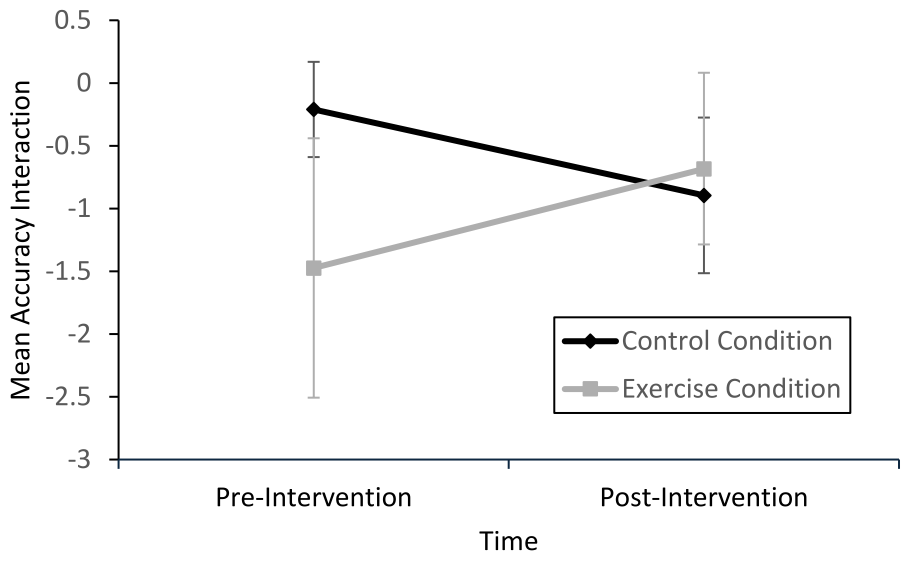
For the second ANOVA on Accuracy Interference, there was a significant interaction between Condition and Time, $F[1,17] = 4.64$, $p = .046$, $\eta_p^2 = .21$, (large effect size) with Accuracy Interference scores increasing significantly more between pre-post intervention in the Exercise condition compared to the Control condition, where Accuracy Interaction scores decreased (see Figure 6). Simple main effect analysis showed that Accuracy Interference, was significantly higher in the Control condition than the Exercise condition at pre-intervention

(F= 5.84, p = .027) but not at post intervention (F= 0.34, p = .57); and that Accuracy Interference was not significantly different between Pre-intervention and Post-intervention in the Control condition (F= 4.69, p = .055) or the Exercise condition (F= 2.27, p = .154).

However, there was no significant main effect of Condition $F[1,17] = 3.02$, p = .1, η_p^2 = .15, or Time, $F[1,17] = 0.1$, p = .92, η_p^2 = .01.

Figure 6.

Mean Accuracy Interference Scores Across Time and Condition



Note. Error bars represent 95% CI.

5.4.4. Repeated Measures ANOVA for Set Shifting

To investigate the effect of the exercise condition on set shifting (hypothesis 3), a 2x2 repeated ANOVA was performed using WCST scores (Preservative Errors) scores as the dependent variable (see Table 23 for means). There was a significant main effect of Time, $F[1,18] = 5.34$, p = .033, η_p^2 = .23 (large effect size), with post-intervention scores being consistently lower than Pre-intervention scores (see Table 23 for means). However, there was no significant main effect of Condition, $F[1,18] = 1.79$, p = .198, η_p^2 = .09, and no significant interaction between Condition and Time, $F[1,18] = 0.23$, p = .641, η_p^2 = .01.

5.4.5. Repeated Measures ANOVAs for Working Memory

To investigate the effect of the exercise condition on working memory (hypothesis 4), two 2x2 repeated ANOVAs were performed that used 2-Back 3-Back Sensitivity scores as the dependent variables (see Table 23 for means). For the first ANOVA on 2-Back Sensitivity, there was no significant main effect Condition, $F[1,16] = 0.64$, $p = .436$, $\eta_p^2 = .04$, or Time, $F[1,16] = 0.48$, $p = .498$, $\eta_p^2 = .03$. The interaction between Condition and Time was also not significant, $F[1,16] = 0.35$, $p = .562$, $\eta_p^2 = .02$.

For the second ANOVA on 3-Back Sensitivity, there was no significant main effect Condition, $F[1,16] = 1.15$, $p = .3$, $\eta_p^2 = .07$, or Time, $F[1,16] = 0.8$, $p = .786$, $\eta_p^2 = .05$. The interaction between Condition and Time was also not significant, , $F[1,16] = 0.33$, $p = .576$, $\eta_p^2 = .02$).

5.5. Discussion

The aim of the current study was to investigate whether PE performed in an online home-based format can lead to a significant increase in EF and mood compared to a control condition. Based on previous literature, it was hypothesised that: 1) there would be a significant improvement in mood; 2) there would be a significant improvement in levels of inhibitory control; 3) there would be a significant improvement in set shifting; 4) there would be a significant improvement in working memory. A significant interaction between Condition and Time was found for one mood variable (Positive Affect) and one level of inhibitory control variable (Accuracy Interference). However, no significant interactions were found between Condition and Time for the other mood (Negative Affect) or inhibitory control (MRT Interference) variables; set-shifting (Preservative Errors); or working memory

(2-Back and 3-Back sensitivity). Therefore, hypotheses 1 and 2 were only partially supported, and hypotheses 3 and 4 were not supported.

Based on previous literature (Abramovitch et al., 2013; Fritz & O'Connor, 2016), it was hypothesised that the exercise intervention would result in a significant improvement in mood. This was partially supported by the significant interaction between Condition and Time for Positive Affect, with the Exercise condition leading to a greater increase in Positive Affect between pre-intervention and post-intervention compared to the Control Condition. However, it should be noted that no significant interaction was found for Negative Affect, suggesting that exercise might only increase positive emotions/thoughts, rather than reducing negative ones. Previous research comparing the effects of PA/PE on positive and negative mood/affect/feelings (as two separate variables rather than on a single negative-positive sliding scale) are mixed, with many finding increases in positive mood/affect/feelings and decreases in negative ones (Arent et al., 2000; Garcia et al., 2012; Williamson et al., 2001); a small amount finding no effect on either (Lennox et al., 1990). However overall, studies that have found a difference in the level of effect on positive or negative moods have found the effects to be more pronounced for positive moods than negative ones (Giacobbi et al., 2005) with some finding increases in positive mood/affect/feelings but no significant effect on negative ones (aligning with the findings of this study) (McIntyre et al., 1990; Wichers et al., 2012). One possible explanation behind this could be that (according to the distraction theory) (Bahrke & Morgan, 1978) PE alleviates negatives moods by distracting us from stressful/negative feelings. In this way PE is no more effective at reducing negative moods than equivalent rest or relaxation (D. R. Brown et al., 1993; Glazer & O'Connor, 1993), but actively enhances positive moods through increasing subjective energy (Saklofske et al., 1992), self-esteem (Liu et al., 2015), and endorphin production (Bender et al., 2007).

A further noteworthy point is that simple effect analysis found that the significant interaction found for Positive Affect, was due to a significant decrease between pre-intervention and post-intervention in the control condition, rather than an increase in the Exercise condition (which was non-significant) (see Figure 5). One possible explanation is that the intervention used for the control condition (the MASC) was not entirely neutral, potentially leading to a suppression of positive emotions/thoughts. This may suggest that the MASC task decreased mood, rather than the exercise intervention actively improving it. Alternatively, it is possible that that the MASC was indeed a neutral condition as intended, but that the overall effect of engaging in multiple study sessions (at baseline) contributed to a reduction in positive affect. That is, as each session lasted approximately one hour and participants had to perform multiple different tasks, they could have been perceived as cognitively taxing, tiring, and even tedious. The lack of any significant change in Positive Affect between pre-intervention and post-intervention in the Exercise condition could then represent a mitigation of this negative baseline effect. That is, exercise could have counteracted the decline in mood in the control condition, which in typical circumstances might have ordinarily manifested as an improvement in mood. Additionally, some research suggests that males experience greater levels of positive affect during PE compared to females (Kyral et al., 2019). Given the heavily slanted gender ratio of this study's sample towards females (80.95%) this could explain why a less pronounced positive effect could have been observed compared to other studies with a more balanced sample.

Similarly, the second hypothesis was also partially supported, as there was a significant interaction between Condition and Time on Accuracy Interference/ The exercise intervention led to a greater increase in Accuracy Interference between pre-intervention and post-intervention compared to the Control Condition. This initially suggests that PE led to improvements in some aspects of inhibitory control, aligning to previous research findings

(Kuo et al., 2024; Ludyga et al., 2016; Piepmeier et al., 2015). However, simple effect analysis found that the significant interaction for Positive Affect, was due to a significant difference between the exercise and control conditions at pre-intervention, and while there was a small increase in score post-intervention for the exercise condition, it was not significant. Additionally, no significant interaction was found for MRT Interference, with MRT Interference slightly increasing Affect between pre-intervention and post-intervention in the Exercise Condition, representing a small (non-significant) reduction in inhibitory control related to reaction time. This stands in contrast with evidence that found that a greater beneficial effect was found on response-time than accuracy (Davranche et al., 2009; Tian et al., 2024) (with a detrimental effect on accuracy sometimes found) (McMorris et al., 2011; McMorris & Hale, 2012). These findings possibly highlight the limitation of the current study being underpowered and further research is needed to investigate whether the inversion of the response-time/accuracy effect size is a consistent feature of home-based PE interventions.

The third hypothesis, which proposed a significant improvement in set shifting, was not supported by the current findings as there was no significant interaction between condition and Time on Preservative Errors. Specifically, while there was a decrease in Preservative Errors between pre-intervention and post-intervention in the Exercise condition, an almost identical rate of decrease was found in the control condition, suggesting that any improvement could have been a result of practice effects rather than the exercise intervention itself. This finding contrasts with previous research demonstrating significant improvements in set shifting following PA (Ludyga et al., 2016; Welsch et al., 2021), but supports previous research reporting no significant improvements (Chen et al., 2014; Piepmeier et al., 2015).

Similarly, the findings did not support our fourth hypothesis, that there would be a significant improvement in working memory, as there was no significant interaction between condition and Time on 2back or 3-back sensitivity. This conflicts with previous research that found that found PA to lead to improvements in working memory (Chen et al., 2014; Ludyga et al., 2016; Welsch et al., 2021). The absence of significant results in this study compared to previous literature for working memory (and other EF aspects) could be due to differences in methodology and possible limitations (e.g., lack of sufficient PE intensity, lack of sufficient sample size) discussed further below.

One of these limitations was that the study was underpowered, with the sample size (21-17 depending on dependent variable) being below the level needed to detect a medium effect size ($f= .25$), ($N=34$). Therefore, the findings of this study are more prone to type two errors, as any results would require a medium-large effect size ($f = .32 – .36$) or greater to reach significance, reducing the ability to detect significant and meaningful differences of smaller effect sizes. This is a particular issue as much of the previous research only reported small to medium effect sizes for the effect of PE on EF (Ludyga et al., 2016; McMorris et al., 2011), particularly for younger adults who typically have smaller effect sizes (g =.2) than children (g =.54) or older adults (g =.67). Indeed, although effect sizes were calculated to provide additional context and meaning, sample size remains a limitation. The small sample size was due in part to a high exclusion rate (70.27% of the 74 who started the study and 42.11% of the 38 who completed the study). This high rate likely reflects several factors, such as a lack of in-person monitoring and control (due to its online nature); lengthy experimental conditions (sessions 2 and 3 taking potentially upwards of 1 hour each to complete); and the one-week gap between sessions 2 and 3. Notably, participant retention improved after implementing a more stringent system of email reminders. Thus, implementing such a system from the outset would be a useful addition to future protocols, serving to enhance retention and engagement, and supporting recruitment of larger samples.

Second, the lack of control within the experimental conditions reduces the reliability of study findings. As participants were not monitored during the experimental interventions (exercise or control), there was no assurance that participants fully engaged with the respective interventions. However, in the Control condition, participants had to interact with and answer questions (e.g., the MASC), reducing the risk that participants were not fully engaged or distracted by irrelevant and unrelated activities that may impact on executive abilities. Further, although the use of the BORG scale after the exercise intervention provided a self-reported measure of exertion, participants could have simply not followed the exercise video and misreported their exertion levels. Additionally, while the average reported exertion rate was within the "moderate" range (M = 3.6; Median = 3), seven participants rated their exertion within the "weak" range (2-2.5). As PE intensity moderates the level of effect on various cognitive functions (Best, 2010; McMorris & Hale, 2012; Montalva-Valenzuela et al., 2022; Neudecker et al., 2019; Sun et al., 2022) this could have affected results, particularly as very light intensity PE has been found to have a negative effect on cognitive performance after at least a one minute delay (compared to other intensity levels which had a positive effect) (Chang et al., 2012), and the cognitive tests in this study were performed after at least a 10 minute delay. If participants were performing PE at lower intensities (stationary – light) this could then explain why null effects were found here and contrast with prior research findings (Chen et al., 2014; Kuo et al., 2024; Ludyga et al., 2016; Piepmeier et al., 2015; Welsch et al., 2021) that used moderate-high intensity interventions. To address this methodological limitation, future research could utilise additional verification measures. For instance, one option could be to require participants to submit video recordings of themselves performing the exercises, which would allow researchers to confirm some level of adherence. However, such an approach might present additional challenges, such as concerns about anonymity, confidentiality and privacy, the need for participants to have recording equipment, and their willingness to use it, etc). A potentially better alternative might be to ask participants a series of attentional questions about the contents of the video (e.g., "what colour top was the presenter wearing?"). However, whilst this might index that the participant watched the video, it still does not verify whether they followed and engaged with the exercised contained within, nor provide a more accurate measurement of what intensity was performed. Another alternative could be to use accelerometer-based devices, that could both more accurately confirm PE engagement, and more accurately record physical exertion and PE intensity than self-report measures. However, these would naturally come with increased cost.

Third, as mentioned in the Method despite initial plans, the FTMS variable from the WCST – intended to assess distractibility – could not be analysed due to significant violations of ANOVA assumptions. This likely arose owing to small sample size, which reduced the likelihood of generating a normal distribution. Consequently, the aspect of distractibility, which is particularly relevant for ADHD, could not be effectively measured and analysed in this study. However, as distractibility is linked to inhibitory control, some inferences can still be drawn from the findings relating to inhibitory control variables. Implementing strategies to recruit larger samples, as discussed previously above, would offset the risk of such issues arising in future research.

While the direct effects of the PE condition on EF were measured, changes to barriers to PE were not measured. This is relevant as a key strength of home-based PE interventions highlighted in previous literature is the reduction/removal of barriers to PE (Ransdell et al., 2004; Scott et al., 2020) which could help reduce the greater level of PE barriers experienced by individuals with ADHD (Chapter Four). Any analysis of PE barrier changes likely would have been limited however as the current study only investigated a single PE session over one week (likely not enough time to induce a large enough effect size), compared to the previous research on home-based PE interventions that often took place over around 12 weeks (Ransdell et al., 2004; Scott et al., 2020). Future research could address this by conducting the home-based intervention over a longer period of time and including measures for DE, with particular attention paid to those barriers found to be experienced at a greater level by individuals with ADHD (Chapter Four: Coping Planning; Emotion; Belief in Capability; and Motivation).

Finally, there was also the potential for order effects to influence the findings as the two schedule groups were not evenly numbered, with 11 participants in the C-E group and 10 in the E-C group. Once concern is that there was a possibility that participants in the E-C group, after engaging with the home-based exercise video, may be encouraged to perform more PE in the next week before the third session, possibly affecting the results (due to chronic effects on cognitive skills from the increased PE) (Den Heijer et al., 2017). However, analysis of the basic-exercise measure found no significant differences in scores between the two schedule groups; across the different sessions; and no significant interaction between schedule group and time of measurement. This suggests that order effects likely did not influence the findings of this study.

As mentioned above, issues regarding sample size and reliability (particularly around PE intensity) of the current study could have led to the reduced effects compared to more controlled PE interventions (Chen et al., 2014; Kuo et al., 2024; Ludyga et al., 2016; Piepmeier et al., 2015; Welsch et al., 2021) rather than being an inherent trait of home-based exercise. To address this, in addition to implementing suggestions provided above to increase retention, future research could also add a third condition where participants perform a PE intervention outside of their home. This would allow for direct comparison of the effects of home-based exercise on ADHD symptoms, to confirm any differences found were not due to a lack of power or extraneous variables.

5.5.1. Conclusion

In conclusion PE administered through the means of following an online home-based exercise video appears to lead to some specific improvements in ADHD symptoms. However, these improvements seem to apply to a narrower range of symptoms and have a smaller effect size compared to those observed in controlled settings in prior research (Kuo et al., 2024; Ludyga et al., 2016; Piepmeier et al., 2015; Welsch et al., 2021). This suggests that home-based exercises could potentially be a viable interim or supplementary treatment method for ADHD when outside, gym-based, or social-based PE interventions are unavailable or impractical due to various potential obstacles.

Chapter Five: Key Messages

- This study aimed to investigate the effect of a home-based PE intervention on specific ADHD symptoms (EF [inhibitory control; set shifting; working memory] and Mood) compared to a control condition.
- No significant improvements were found for set shifting or working memory variables. Significant interactions were found for elements of Mood (Positive Affect) and inhibitory control (Accuracy Interference). However simple main effect analysis found that these findings were primarily due to Positive Affect decreasing in the control condition (rather than increasing in the Exercise condition); and Accuracy Interference being lower in the Exercise condition than the control condition at pre-intervention.
- These findings suggest that home-based exercise interventions may have limited effects to ADHD symptoms in comparison to previous research on more controlled exercise interventions.
- However, caution should be advised when interpreting these results due to the current study being underpowered and possible reliability limitations around lack of control.
- Future research should address these limitations by employing a larger sample size; utilising further verification methods to improve reliability; and providing direct comparisons with non-home-based exercise.

6. Chapter Six: General Discussion

6.1. Summary of Thesis Aims

The overall aim of this thesis was to investigate the association between PA and ADHD in adults, while exploring underlying and contributing factors. The specific goals were to: 1) Investigate whether PA is associated with ADHD in adults and if so, investigate the nature and extent of the association; 2) Examine how different demographics (e.g., gender; [sub]clinical diagnosis of ADHD; ADHD subtype) may influence associations between PA and ADHD.3) Investigate underlying factors that may influence PA behaviour and associations in relation to ADHD in adults (e.g., motivations; environmental factors); 4) Explore the feasibility of implementing PA as a treatment for ADHD in adults (e.g., practical considerations, potential risks).

6.2. Summary of Key Findings

The key findings of this thesis are summarised in relation to its four core aims:

(1) There is generally a small positive association between PA and ADHD symptoms in adults, with hyperactive symptoms showing a stronger positive association than inattentive symptoms. In contrast, for PE specifically, there tends to be a small negative association with ADHD symptoms in adults, with inattentive symptoms showing a stronger negative association compared to hyperactive symptoms

(2) The associations covered in the previous point are generally more negative in females than males, and in individuals with a subclinical diagnosis of ADHD compared to those without.

(3) Adults with a subclinical diagnosis of ADHD experienced reduced intrinsic PE motivation and face higher levels of barriers to PE participation. These factors

represent significant challenges to PE engagement and highlight specific areas to be targeted to improve PE engagement.

(4) PE interventions for ADHD in adults should focus on overcoming and addressing these barriers and fostering intrinsic PE motivation to optimise both effectiveness and adherence. However, interventions focused around this also need to ensure they do not compromise their impact on ADHD symptoms and are carefully designed and implemented to mitigate against potential risks, such as exacerbating the risk of ED.

Breaking these findings down by specific chapters, Chapter Two initially suggested that while there was a non-significant negative association between overall ADHD symptoms and PA, this central relationship varied depending on symptom subtypes (e.g., inattentive/hyperactive ADHD), subclinical ADHD diagnosis (e.g., Non-ADHD/Sub-ADHD); activity type (e.g., PA/PE), and demographics (e.g., male/female). For instance, inattentive ADHD symptoms had a significant negative correlation with PA, whereas hyperactive ADHD symptoms had a very small non-significant positive correlation. Further, both *inattentive and total* ADHD symptoms were significantly negatively correlated with PE, while hyperactive ADHD symptoms had a very small, non-significant negative correlation. When split by gender, these significant negative correlations were only observed in females and not in males. Similarly, when comparing diagnostic groups, the correlations are much less negative and lost significance in the Non-ADHD subgroup compared to the Sub-ADHD subgroup. The key contribution of this Chapter was highlighting the importance of distinguishing between variable subtypes (e.g., inattentive vs hyperactive ADHD symptoms; PA vs PE) and recognising demographic related variations in the observed associations.

Chapter Three explored underlying motivations related to ADHD and PE, as well as the potential risks associated with implementing PE interventions for individuals with

ADHD. Findings revealed that ADHD symptomatology (total and inattentive) had a negative correlation with autonomous/intrinsic PE motivation; that ADHD symptomatology (total and hyperactive) had a negative correlation with ED; and that autonomous/intrinsic PE motivation had a positive correlation with ED and PE. These findings suggest that limited intrinsic PE motivation might act as a barrier to PE engagement for adults with ADHD. Thus, promoting intrinsic exercise motivation could potentially increase PE engagement within this population. However, any such interventions should be approached cautiously, as intrinsic motivation was also associated with increased ED risk. Given that individuals with ADHD are already at elevated risk of ED, careful implementation is required to avoid exacerbating such risks.

Chapter Four further explored underlying and contributing factors of PE within ADHD, by studying barriers/DE and their links with ADHD, PE, ED and motivation. Results showed that individuals with a subclinical-ADHD diagnosis experience greater levels of certain barriers to exercise, which may need to be overcome or targeted in any potential PE based intervention. However, since some of these barriers were linked with ED risk, caution should be exercised to avoid increasing ED rates further. Initial exploratory research also suggests that intrinsic motivation may act as a mediator between DE and PE engagement for individuals with ADHD.

To investigate potential PE interventions that could account/avoid PE barriers identified in Chapter Four, Chapter Five studied the effects of home-based aerobic PE interventions on specific ADHD symptoms (EF [inhibitory control; set shifting; working memory] and Mood) compared to a control condition. Results were mixed. First, no significant improvements were observed for some EF aspects, such as set shifting, working memory. Second, significant interactions were found for measures of Mood (Positive Affect) and inhibitory control (Accuracy Interference); however, further analysis suggested that these effects were not necessarily due to direct improvements from the PE intervention. Therefore, these findings suggest that home-based aerobic PE might not be as effective as other PE interventions. Further controlled research is necessary before home-based aerobic PE can be recommended as an appropriate intervention for ADHD.

6.3. Theoretical Implications

The findings of this thesis have several potential implications, particularly regarding the development and implementation of possible PE interventions for individuals with ADHD. The finding that ADHD -particularly inattentive ADHD - is associated with reduced intrinsic PE motivation (Chapter Three and Four), suggests that interventions designed to promote intrinsic motivation could effectively increase exercise engagement in this population (Smith & Langberg, 2018). While overall motivation strength was negatively associated with ADHD (Chapter Four), intrinsic motivation deserved particular focus. Extrinsic motivation was not negatively associated with ADHD, suggesting there is less of a deficit that needs to be countered for individuals with ADHD (Chapters Three and Four). Further, extrinsic motivation did not have a significant positive correlation with PE (Chapters Three and Four); intrinsic motivation specifically is associated with improved outcomes (e.g., health, wellbeing, behavioural outcomes, and performance) (Ryan & Deci, 2000; Vansteenkiste et al., 2004), and intrinsic motivation is associated with greater PA adherence (Ryan et al., 1997) whereas extrinsic motivation may hinder the development of self-sustaining behaviour (Smith & Langberg, 2018).

One potential approach for enhancing intrinsic motivation is motivational interviewing, which focusses on increasing personal motivation. This method has previously demonstrated high rates of intervention completion and participant satisfaction among individuals with ADHD (Sibley et al., 2013, 2016). Additionally, motivational coaching strategies, where trainers implement motivational strategies using a motivational coaching guide (Gaesser et al., 2020), have been shown to increase intrinsic motivation in the general population. Such strategies may be particularly relevant for individuals with ADHD for the following reasons. First, coaching related to SDT have shown to be effective for individuals with ADHD (D. R. Parker & Boutelle, 2009). Second, in-person support from personal trainers has been highlighted as a popular approach for ADHD-related PE interventions (Cochrane et al., 2022). Third, athletic trainers have been noted as a critical component for healthcare for individuals with ADHD (Wolfe & Madden, 2016). Finally, motivational coaching also appears to increase perceived competence (Gaesser et al., 2020), which would also help address the barrier of "Beliefs about Capabilities" – a challenge identified as particularly prominent for individuals with ADHD (Chapter Four). Moreover, as noted by Morsink et al., (2022) and supported by exploratory findings in Chapter Four (see section 4.4.5.), intrinsic motivation acts as a mediator between environmental factors and behavioural outcomes. This highlights the importance of addressing specific environmental factors (barriers) to positively influence intrinsic motivation.

Some of these environmental factors could pertain to the barriers identified in Chapter Four, including Motivation; Beliefs about Capabilities; Emotions; Coping Planning. As mentioned previously (see section 4.5.), by applying the Behaviour Change Wheel model (Michie et al., 2011), appropriate intervention functions can be identified to address these barriers. For instance, interventions to address barriers related to Motivation and Beliefs in Capability would benefit from incorporating educational, persuasion, incentivisation and coercion-based functions. Interventions to address barriers related to Emotions should similarly comprise persuasion, incentivisation, and coercion, but also environmental restructuring, modelling and enablement. Then, interventions addressing Coping Planning should focus on education, persuasion, and enablement functions. More specifically, and as mentioned above, utilisation of personal trainers/coaching could be particularly beneficial (Gaesser et al., 2020; Wolfe & Madden, 2016). For example, coaching has been shown to improve motivation and beliefs about capabilities (Gaesser et al., 2020; Wolfe & Madden, 2016) and to foster positive emotional experiences (D. R. Parker & Boutelle, 2009; Wolfe & Madden, 2016), which could also aid in coping planning.

As suggested in Chapter Five, performing home based PE could help avoid or overcome certain barriers experienced by individuals with ADHD, such as lack of community resources and equipment, low self-esteem/confidence, or financial constraints. However, the findings of Chapter Five suggest that the efficacy of such interventions might be limited compared to other interventions. Without further evidence supporting their effectiveness, home-based interventions might best serve as a preliminary stage - building confidence in capabilities and self-efficacy to engage in more social PE interventions. Moving further from the intervention level of the behaviour change wheel, appropriate policy categories could be applied, including guidelines, service provision, and regulation (Michie et al., 2011). Although greater understanding of the effectiveness and practicalities of interventions would need to be reached before making confident recommendations at a policy level.

However, the above interventions should take into consideration relevant risk factors, one of which, as noted in Chapters Three and Four, should be ED/EA. Chapters Three and Four found greater risk of ED to not only be associated with ADHD – particularly hyperactive ADHD – but also with many factors that could be utilised in PE interventions noted above. While the associations identified generally had a small effect size, if a target population with an already existing increased risk rate (albeit small) for ED were assigned interventions that promoted traits that also lead to an increased risk of ED, then the potential risk could be elevated to significant levels. However, as the effect sizes found are quite small (similar to previous research that found higher rates of symptomatic-nondependent ED categorisation but not ED classification itself [Popat et al., 2021; Ramji et al., 2024]); the risk of overestimation with the EDS-R (see section 3.5.); and the uncertain directionality of causality for some factors, this suggests that potential PE interventions do not need to be reduced or restructured to a significant degree. Instead, a proportional response could involve implementing simple, low-cost/effort measures shown to reduce risks of ED. For instance, addressing potential risk factors, such as body dissatisfaction, drive for thinness, and bulimic tendencies, while supporting and enhancing protective factors, such as self-esteem (Gori et al., 2021). Additionally, if personal trainers/coaches are involved in PE interventions, they could try to use similar techniques used by physiotherapists to address ED. These include education to raise awareness of healthy behaviours and body image, prescribing alternative activities to reduce focus on appearance-driven goals, referrals to other psychological and medical professionals where necessary, and psychological strategies to support the formation of healthier attitudes towards both exercise and body image, and enhanced self-esteem (Adams & Kirkby, 1997). Personal trainers can also decrease other relevant risks of PE, such as reducing the risk of sustaining PE related injuries (Lu et al., 2024) which is particularly important as individuals with ADHD are more at risk of sustaining such injuries (Wolfe & Madden, 2016).

Findings from Chapters Two, Three, Four and Five, combined with related research, can also be used to help prioritise and enhance the potential effectiveness of PE based interventions for specific symptoms and populations. The finding that inattentive ADHD is particularly associated with reduced PE (Chapter Two), lower Intrinsic PE motivation (Chapters Three and Four), and greater barriers to exercise (Chapter Four), along with evidence that PA tends to improve inattentive ADHD symptoms (Xie et al., 2021), suggests that interventions designed to address these factors might be especially effective for individuals with inattentive ADHD symptoms/individuals with the inattentive ADHD subtype. Additionally, inattentive ADHD symptoms were found to be less strongly associated with ED risk than hyperactive ADHD symptoms (Chapter Three). This suggests that PE based interventions might pose a lower risk for exacerbating ED in individuals with inattentive ADHD compared to those with hyperactive/combined ADHD, supporting previous research that found that only hyperactive symptoms, not inattentive symptoms, were significant predictors of PE withdrawal (Ramji et al., 2024) .

For similar reasons, interventions specifically focussed on increasing intrinsic PE motivation and reducing PE barriers could be particularly effective and beneficial for females. While existing research has not found significant gender differences in the direct effects of PE on ADHD symptoms (Vysniauske et al., 2020), this may be partly due to a lack of research focussed on females. Findings that females with ADHD have lower PE motivation (see Appendix T) and greater barriers to PE (Appendix U) compared to males (Chapter Four), suggest that interventions based on addressing these deficits/barriers could result in greater overall increase in PE engagement among females. Similar to above, females with ADHD were also found to have lower rates of ED (Appendix U) (Chapter Four), suggesting that it may be less of a significant risk factor for such interventions. These insights do not suggest that PE interventions should be limited to inattentive ADHD or females, as evidence shows that PE still has a positive effect on hyperactive symptoms (Xie et al., 2021) and males with ADHD have also been shown to exhibit reduced PE motivation/greater barriers to PE than the general population (Chapter Four; Appendix T and U). However, the findings suggest that targeting inattentive symptoms and/or females may yield particularly strong outcomes in these groups.

However, it is important not to overstate the significance of these findings or the possible implications discussed above. While it may be tempting to view effectively designed PE based treatments as a cost-effective, widely applicable treatment to ADHD – potentially addressing several limitations of existing treatments, such as side effects, reduced effectiveness over time, non-response rates, and high costs (Banaschewski et al., 2004; Goode et al., 2018; J. Parker et al., 2013; E. Q. Wu et al., 2012) while having additional health benefits - it is important to keep realistic expectations about possible outcomes. Firstly, the high rates of physical disability experienced by those with ADHD (Kim et al., 2011; Vogel et al., 2018) might render PE ineffective or inaccessible (or at least require significant adjustments) for a larger proportion of individuals than might be expected. This limitation extends to psychological comorbidities as well, as while some common comorbidities for ADHD can also be positively affected by PA (Hearing et al., 2016; Jayakody et al., 2014; Sowa & Meulenbroek, 2012) (see section 1.5.6.), many – such as ASD, Anxiety disorders, and Mood disorders (Glowacki et al., 2017; Hillier et al., 2020; Mason et al., 2019) – can introduce additional challenges and barriers. Moreover, comorbidities like eating disorders (Fietz et al., 2014) can elevate risks associated with PE-based interventions.

Additionally, there is mixed evidence on the precise level of effectiveness of PA on ADHD symptoms, with outcomes varying depending on different dimensions of the PA - with the findings from Chapter Five itself suggesting they can be limited. Furthermore, a study by Cochrane et al., (2022) found that while the majority of individuals with ADHD appear to be willing to engage in PE as a treatment, there was a greater preference for PE to be an adjunct treatment (84.6%) compared to a standalone treatment (70.9%). This preference was also even more pronounced among those who were already using medication. Therefore, while further research into the effectiveness and implementation of PE as a treatment for ADHD should be conducted, it should be viewed as a potential supplementary/additional treatment rather than as a substitute or replacement for existing treatments. This aligns with prior research for both ADHD (Gapin et al., 2011; Hoza et al., 2016; LaCount & Hartung, 2018; Welsch et al., 2021) and other psychiatric conditions (Alnawwar et al., 2023; Hearing et al., 2016; Kvam et al., 2016; Y. Wu et al., 2024) which similarly views PE as a complementary intervention to enhance, rather than replace, conventional treatment options.

6.4. Strengths and Limitations

6.4.1. Strengths

A key strength of much of the research presented in this thesis was the use of subclinical measures for ADHD. This approach facilitated the inclusion of undiagnosed individuals from typically underdiagnosed demographics, such as females and adults (Faraone, Biederman, & Mick, 2006; Quinn & Madhoo, 2014). As highlighted previously (see sections 1.5.3.; 1.6.3.), most existing research in this area has predominantly focused on males, potentially overlooking a large proportion of females with ADHD due to underdiagnosis. (Quinn & Madhoo, 2014). Across the studies conducted for this thesis, no significant differences were found in the proportion of Subclinical ADHD diagnosis between males and females (see sections 2.4.1.; 3.4.1.; and 4.4.1.). Specifically, of the 164 males included within the studies of this thesis, 60 (36.59%) reached the subclinical threshold for ADHD, compared to the 614 females, of whom 207 (33.71%) reached the subclinical threshold. A chi-squared on this combined data found this difference was not statistically significant, $\chi 2(1) = 0.47$, $p = .49$ (however it should be noted this analysis relies on data from different data collection methods which may limit its reliability). As such, the results of this thesis support the claim that ADHD may be underdiagnosed in females (Quinn & Madhoo, 2014). The inclusion of females with a subclinical diagnosis of ADHD facilitated analysis of differences between males and females in the thesis (see section 6.3.) that may otherwise have been missed, highlighting the importance of subclinical assessments in capturing ADHD traits across underrepresented groups.

Another strength of this thesis was in distinguishing between ADHD symptomatology presentations, allowing for greater analysis in differences between inattentive and hyperactive ADHD symptoms. This meant certain associations with ADHD symptomatology were noted as being stronger for either inattentive or hyperactive symptoms (or were only significant for one symptom subtype but not the other), for instance with PA/PE (Chapters Two, Three and Four); ED (Chapter Three); intrinsic PE motivation (Chapter Three); and barriers to (Chapter Four, see section 4.4.1.). While previous research has distinguished between inattentive and hyperactive ADHD symptoms in the analysis of the effects of PA (Dastamooz et al., 2023; Xie et al., 2021) and ED (Popat et al., 2021; Ramji et al., 2024), no previous research has done this in relation to PE barriers or PE motivation, from an SDT perspective. The distinction between ADHD subtypes is even more limited in this area of research despite its importance being highlighted (Li et al., 2023; Martín-Rodríguez et al., 2025). The finding from this thesis that multiple key distinctions were found in the nature and level of association of multiple key variables, allows for potential interventions to be better tailored and prioritised for different populations, and highlights the importance for future research to consider distinguishing between inattentive and hyperactive ADHD symptoms (see section 6.3.).

The incorporation of theoretical frameworks (e.g., the SDT and TDF) allowed for findings to be tied to existing frameworks, facilitating comparisons with further literature that use the same theoretical frameworks and for findings to be more effectively linked to further developments of potential interventions (e.g., the behaviour change wheel). Specifically incorporating the SDT and investigating links with other factors, is in line with suggestions from Morsink et al., (2022) regarding ADHD research.

6.4.2. Limitations

It is important to note key limitations of this thesis. Firstly, most of the studies performed were cross-sectional in nature which precludes the inference of causation. As noted in previous sections, the causal directions of any associations remain speculative and could potentially operate in the opposite direction. For example, regarding the negative association found between PE and ADHD (Chapters Two and Four), it is possible that rather than PE leading to reduced ADHD symptoms (as suggested by positive effects found in other experimental research [Dastamooz et al., 2023; Ludyga et al., 2016; Montalva-Valenzuela et al., 2022; Welsch et al., 2021; Xie et al., 2021]) ADHD symptoms might lead to reduced PE level as ADHD symptoms are linked to increased barriers to PE (as suggested in Chapter Four) (Harvey et al., 2014; Ogrodnik et al., 2023). Due to evidence supporting both perspectives, both could be true, creating a negative feedback loop where ADHD symptoms lead to reduced PE engagement, which in turn leads to increased ADHD symptoms.

Regarding the negative association found between intrinsic motivation and inattentive ADHD symptoms (Chapters Three and Four), it is possible that rather than inattentive ADHD symptoms leading to reduced intrinsic PE motivation (as suggested by Morsink et al., [2022]), higher intrinsic motivation could drive greater PE engagement (Ryan et al., 1997), which then subsequently reduces inattentive ADHD symptoms (Dastamooz et al., 2023; Xie et al., 2021). Similarly, for the positive association between barriers to PE and ADHD (Chapter Four), it is plausible that rather than ADHD leading to increased barriers to PE (Harvey et al., 2014; Ogrodnik et al., 2023), reduced barriers to PE could lead to increased PE engagement (Brinthaupt et al., 2010; Pate et al., 2011; Rimmer et al., 2010) which in turn alleviates ADHD symptoms (Dastamooz et al., 2023; Xie et al., 2021). Due to evidence supporting both sides of these correlations (ADHD-I – reduced intrinsic PE motivation; ADHD – increased barriers to PE), both are likely to be occurring to some extent and reinforcing each other (e.g., a bidirectional relationship). However, it is important to note that no environmental factors have been found to be directly causal for ADHD (Faraone & Mick, 2010) and the findings of this thesis do not suggest that lack of PA causes ADHD. Instead, individuals with ADHD likely experience pre-existing ADHD symptoms that may trigger these negative feedback loops, reducing PE engagement and exacerbating existing ADHD symptoms over time.

Some of the correlations found in this thesis (outlined previously) could also be explained by both factors being influenced by a third variable. The high comorbidity rates of conditions such as mood disorders and learning disabilities with ADHD (Kooij et al., 2012; Reale et al., 2017) suggest that these conditions could have potentially acted as confounding factors, particularly given evidence that these conditions can affect certain DE (Firth et al., 2016), PE motivation (Glowacki et al., 2017; Hillier et al., 2020; Mason et al., 2019), PE engagement (Hearing et al., 2016; Hillier et al., 2020), and incidence of overuse injuries (Ramji et al., 2024). Across Chapters Two through Five, Sub-ADHD groups generally had higher rates of comorbidities compared to Non-ADHD groups. However, chi squared-tests revealed that most differences in frequency were non-significant, with the exception of ADHD diagnosis itself (as expected); learning disabilities in Chapter Four ($\chi2[1] = 8.11$, $p = .004$); and mood disorders ($\chi2[1] = 5.2$, $p = .023$), sleep disorders ($\chi2[1] = 4.55$, $p = .033$) and anxiety disorders ($\chi2[1] = 5.76$, $p = .016$) in Chapter Two. These findings suggest that comorbid conditions, such as mood and anxiety disorders, were unlikely to have significantly influenced the results. What is difficult to determine though, is whether the higher rates of physical disability associated with ADHD (Kim et al., 2011; Vogel et al., 2018) could have acted as a confounding variable. The comorbidity questionnaire used across all thesis studies, as well as the DPAQ in Chapter Four, did not directly measure physical disability. While the DPAQ partially captured related aspects under the domain “Belief about Capabilities”, this limitation meant that no analysis of could be conducted to explore how physical disability might have influenced other variables. This is relevant as the higher prevalence of physical disability in individuals with ADHD could make PE-based interventions inaccessible or unsuitable for a large proportion of the target population – or require significant adjustments and adaptations. Future research should incorporate direct measures of physical disability to better assess its potential role as a confounding variable and possible implications for PE-based interventions.

There was also a notable sample bias throughout much of the research in this thesis, being skewed towards females, students and young adults. Across the four studies within Chapters Two through Five, 803 participants took part, of whom 614 (76.46%) were female, 503 (62.64%) were full time students, and the mean age was 24.74 years (SD = 8.42). While this provided valuable insights into typically underdiagnosed populations (see section 6.3.) it potentially limits the generalisability of the findings to the broader population. For example, as students are generally found to have higher rates of ADHD (Gray et al., 2014), the prevalence of adult ADHD symptoms in this study may not accurately represent those of the general population. Indeed, across all four studies, 284 (35.37%) participants met the subclinical diagnostic threshold for ADHD, a rate notably higher than general populations estimates of 2.8% (Fayyad et al., 2017) to 5% (Willcutt, 2012). While a higher rate might be expected due to the inclusion of undiagnosed individuals (see section 6.3.), this is still likely to be larger than the general population rate. Further, while females typically reported higher rates of inattentive ADHD (Biederman et al., 2004; Willcutt, 2012), no significant differences in ADHD symptomatology were found between males and females in Chapters Two through Five. This suggests that the data might not have been skewed for ADHD symptomatology but might have been skewed for the gender differences highlighted previously (see section 6.3.) for PE motivation, ED and barriers to exercise (see Appendix S and T).

Due to limited numbers of participants marking themselves as “other” for gender - with only 19 (2.37%) out of the 803 total participants selecting it – further analysis of gender variance was not able to be performed due to insufficient power. This is particularly relevant because as mentioned previously (see section 1.3.3.) gender variance has also been linked with elevated symptoms of ADHD (Strang et al., 2014) but is underrepresented in research. The findings from Chapters Two through Five appear to support this as 63.16% of participants who answered “other” met the subclinical threshold for ADHD in this thesis (compared to 33.71% of females and 36.59% of males). Future research could address this by prioritising recruitment around these populations and/or incorporating existing recommendations for the measurement of sex/gender (Bates et al., 2022).

The use of self-report and subclinical measures throughout much of this thesis could also be considered a limitation. Specifically, the use of self-report measures for PA and PE also introduces potential biases. PE diaries tend to overestimate the amount of PE performed (Nicolson et al., 2018), and a systematic review of PA self-report measures found that they can both overestimate and underestimate PA levels compared to direct measurement of PA (Prince et al., 2008). As such, it is difficult to determine whether the research in this thesis may have either overestimated or underestimated participants level of PA. Nonetheless, the self-report measures used in this thesis adhered to conditions known to optimise reliability (Kuh, 2001), such as requesting information readily known to individuals, using clear and unambiguous language, referring to recent and specific activities, encouraging thoughtful responses, and avoiding questions that might threaten or violate participants’ privacy.

While the use of subclinical measures for ADHD diagnosis adhered to established practices (Döpfner et al., 2006; Kessler et al., 2005; Mattingly et al., 2012; Ustun et al., 2017) and facilitated the inclusion of undiagnosed individuals (see section 6.4.1.), limitations remain. The scale used to identify individuals above symptomatic thresholds for Chapters Three and Four (ADHD-RS-IV) was based on DSM-IV rather than DSM-5 criteria. While both editions assess the same 18 symptoms, DSM-5 lowered the symptom count threshold for adults to five per domain, compared to six in DSM-IV. As the DSM-IV symptom count was used in Chapters Three and Four (see section 3.3.5.) this could have led to an underdiagnosis of subclinical ADHD. Secondly, participants were not independently evaluated by professionals, which may have affected the reliability of findings. Self-report measures, while valuable for large scale studies, lack the robustness of a formal diagnosis, especially when assessing nuanced conditions like ADHD.

A lack of standardisation in some of the measures used in this thesis is a further limitation. As noted above different methods were employed to determine subclinical ADHD diagnosis across chapters. The ADHD-RS-IV was used in Chapters Three and Four, whereas the ASRS-6 was used in Chapters Three and Four (due to improved sensitivity). This raises questions about the comparability of the findings across chapters owing to differences in measurement approach. To address this issue though, the ADHD-RS-IV method was retrospectively applied to the data from Chapter Two to assess whether core outcomes would differ. The central significant findings remained consistent, supporting the reliability of the findings and ability to compare findings across the chapters despite differences in diagnostic method.

Additionally, the inclusion of individuals/groups with certain characteristics could have been inhibited due to certain study design conditions/exclusion criteria. For instance, the exclusion of participants who failed attention checks in Chapters Three and Four could have introduced bias by potentially excluding individuals with attentional difficulties, such as those with ADHD. However, this risk was outweighed by the benefit of removing a larger number of potentially non-genuine responses, thereby enhancing the overall quality of the data. Notably, a high proportion of participants who failed the attentional checks exhibited very short completion times and/or provided repetitive answers on certain questionnaires, supporting the decision to exclude participants who failed basic attentional checks. Furthermore, in Chapter Five, the requirement for participants to adhere to a study with a specific time schedule naturally could have led to the exclusion of individuals with ADHD who have organisational difficulties, even with reminder efforts to support adherence (see section 5.3.5.). Additionally, Chapter Five excluded individuals with physical or health restrictions that would prevent them from performing moderate exercise. This exclusion criteria could have led to the exclusion of some individuals with ADHD, as ADHD is associated with higher rates of obesity (Kim et al., 2011) and physical disability (Vogel et al., 2018). This is possibly supported by only one individual from the final sample of 21 in Chapter Five meeting the subclinical threshold for ADHD (4.76%), substantially lower than previous chapters.

Finally, there remains an issue regarding the inconsistency of some findings across Chapters Two, Three and Four. Notably, the relationship between ADHD symptomatology and PE level was mainly negative in Chapter Two and Chapter Four, but positive in Chapter Three. Similarly, the relationship between ADHD symptomatology and PA level was mainly negative in Chapter Two, but positive in Chapter Three and Four. Naturally this can lead to concerns about how reliable the findings are if they are inconsistent across similar studies. Potential explanations for some of these differences have been discussed in previous sections of the thesis, including differences in sample demographics and COVID-19 lockdown conditions (see sections 3.5. and 4.5. respectively). Despite these inconsistencies, some general trends can be observed across the three chapters:

1) PA/PE more negatively/less positively associated with Inattentive ADHD than Hyperactive ADHD.
2) ADHD more negatively/less positively associated with PE than PA.
3) Females generally have a more negative/less positive association between ADHD and PA/PE than males.
4) Subclinical ADHD individuals generally have more negative/less positive associations between ADHD and PA/PE than Non-ADHD individuals.
5) Fulltime workers generally have a more negative/less positive association between ADHD and PA/PE than Full time students.

Chapter Three stands out as the most divergent, being the only one to contradict trend two with a positive correlation between PE and ADHD symptomatology and being the least aligned to previous research (Abramovitch et al., 2013). As highlighted previously, Chapter Three had the highest proportion of full-time students (70.39%) and lowest proportion of full-time workers (7.89%), compared to Chapters Two and Four, which could have partially contributed to the difference in findings (see sections 3.5. and 4.5.). Related to this, the main data collection period for Chapter Three was April to June, a period where students would be more likely to be having exams. Adults with ADHD are more likely to use maladaptive coping strategies, such as avoidance, in response to stress than neurotypical adults (Barra et al., 2021; Torrente et al., 2014). Further, PE has been linked to avoidance coping (Loumidis & Wells, 2001). This suggests that students with ADHD could use PE as an avoidance coping strategy in response to stress, leading to increased PE engagement around exam periods, possibly explaining the positive correlation found between ADHD and PE level in Chapter Three. However, this possibility remains speculative, underscoring the need for future research to further explore and replicate findings. Such research should endeavour to account for contextual factors, such as external stressors, to further elucidate variability in the relationships between ADHD, PA, and PE.

6.5. Future Directions and Recommendations

One of the most natural directions for future research would be to address limitations of this thesis listed above (see section 6.4.2.) and to see if findings can be replicated. As stated previously, the nature of causation for many of the relationships analysed in this thesis could be investigated via longitudinal research. This would not be without challenges, as individuals with ADHD have been found to have lower data retention rates in longitudinal research compared to individuals without ADHD (Barkley & Fischer, 2016; DuPaul et al., 2021; Molina et al., 2017). To account for this, future longitudinal studies could gather larger sample sizes at the start of the research and utilise strategies that have been found to boost longitudinal research retention rates (e.g., tailoring strategies to participants, emphasising study benefits, using study reminders, reducing barriers/burden to participation (Abshire et al., 2017; Teague et al., 2018).

Further research is particularly needed to explore the relationships between PA/PE and ADHD symptomatology (total, inattentive and hyperactive), which showed inconsistent findings across studies in this thesis. Future studies should carefully consider and measure the variables noted previously in this thesis (see sections 3.5., 4.5. and 6.4.2.) that could have led to the discrepancies in findings. These include factors such as gender, employment/student status, (sub)clinical ADHD diagnosis, and lockdown conditions. By more systematically accounting for these factors, future research could provide additional insight and help clarify potentially complex relationships between ADHD symptomatology and PE/PA.

Going beyond addressing methodological limitations of this thesis, future research should also investigate the practical implementation of interventions suggested previously (see section 6.3.). For instance, many of the proposed interventions aimed at increasing intrinsic PE motivation for ADHD individuals were either interventions to increase intrinsic motivation for individuals with ADHD, which could then be extended to intrinsic PE motivation (e.g., motivational interviewing); or interventions to increase intrinsic PE motivation, which could then be extended to individuals with ADHD (e.g., motivational coaching strategies). However, the effectiveness of these different techniques could vary depending on the circumstances in which they are implemented. For example, the motivational interviewing techniques demonstrated by Sibley et al., (Sibley et al., 2013, 2016) to increase intrinsic motivation were performed with adolescents with ADHD and in collaboration with family members. Adults with ADHD, by contrast, might be more likely to live independently from family and may lack consistent family support. While Motivational Interviewing has shown to be effective in individual interviews (Rubak et al., 2005), future research should explore its specific effectiveness in adults with ADHD and consider adaptations to account for different social and living arrangements.

Another practical consideration for implementing potential PE interventions for ADHD is ensuring sufficient adherence, as highlighted previously (see section 1.5.6.). While there is relatively scarce evidence regarding adherence rates for non-pharmacological treatments for ADHD (Australasian ADHD Professionals Association, 2022), the poor adherence for other treatments (Gajria et al., 2014) and the well documented challenges individuals with ADHD experience in maintaining routines (Wender, 1998; Wolf & Wasserstein, 2001), suggest that adherence to PE interventions could potentially be a significant challenge for adults with ADHD. Research also indicates that the barriers to maintaining PE can differ from those associated with initially starting PE (André &

Agbangla, 2020; Tulloch et al., 2013). This suggests that the findings of Chapter Four regarding barriers to PE in ADHD may depend on whether an individual is initiating or sustaining PE engagement. Therefore, future research should investigate adherence rates and strategies to improve adherence. These strategies could draw from interventions shown to enhance adherence to PE (Sunesson et al., 2021; Woodard & Berry, 2001) or from approaches shown to improve adherence to other ADHD treatments (Parkin et al., 2022). Such strategies could also leverage intrinsic motivation, which, as noted previously, is linked with increased PE adherence (Almagro et al., 2020; Ryan et al., 1997). For those with ADHD, fostering intrinsic motivation through tailored interventions might increase the likelihood of achieving sustained and meaningful participation in PE programs.

A related concern involves the accessibility of PE based treatments for individuals with ADHD (see sections 6.3. and 6.4.2.), particularly given higher rates of physical disability (Vogel et al., 2018). While the survey from Cochrane et al., (2022) found that individuals with ADHD reported high levels of willingness and feasibility to engage in PE based interventions, findings may overestimate actual engagement rates owing to several reasons. For instance, the sample was skewed towards younger individuals, with a higher than average proportion of the sample classified as physically fit (70%) and active (75.2%), compared to typical ADHD populations (Björk et al., 2018; Vogel et al., 2018). The use of self-report measures may also result in participants overestimating their free time, willingness, or capacity to engage in PE. Therefore, further research should also investigate how accessible PE would be for individuals with ADHD, with a larger and more generalisable sample, with specific consideration of physical disability. Another accessibility concern is that many of the potential intervention strategies suggested previously (see section 6.3.) are often delivered by trained coaches or personal trainers, and their success may depend on the availability of such professionals and the affordability of these services for adults with ADHD. As individuals with ADHD are more likely to come from families from a more disadvantaged socioeconomic status (Russell et al., 2016) and experience increased financial burdens (Pitts et al., 2015) future research should investigate the feasibility and scalability of these interventions, particularly for underserved or low-income populations.

Finally, specific methodological recommendations for future research can be made based on the findings of this thesis. As highlighted in Chapters Two and Four, there can be some significant differences in the scores of certain variables and strength of certain associations between females and males. This highlights the importance of investigating potential gender differences in future studies. As mentioned previously (see section 1.5.3.) females are often underrepresented in the research area due to studies lacking sufficient power to control for gender differences in study designs (Abramovitch et al., 2013; Fritz & O'Connor, 2016). As shown by the research conducted in this thesis, this could be addressed by utilising subclinical measures and diagnostic classification to counter potential underdiagnosis of females with ADHD. However, this may come at the cost of reduced reliability compared to formal diagnoses (see section 6.4.2.).

Additionally, as highlighted in Chapters Two, Three and Four, multiple factors - PA; PE; ED; RAI; and DE - have varying levels and strength of association with hyperactive and inattentive ADHD symptoms. Combined with further evidence suggesting that PA has different levels of effect on hyperactive and inattentive ADHD symptoms (Xie et al., 2021), and suggestions that PA interventions may have different levels of effectiveness between ADHD subtypes (Li et al., 2023; Martín-Rodríguez et al., 2025), this suggests that further related research should measure and distinguish between hyperactive and inattentive subtypes to capture these potentially nuanced relationships. Despite this, and as mentioned previously (see section 6.4.1.), little research in the area has distinguished between inattentive/hyperactive ADHD symptoms, with even fewer distinguishing between ADHD subtypes. To address this, future research based on self-report methods could utilise the methodology utilised in this thesis (see section 3.3.5.) and previous research (Döpfner et al., 2006; Mattingly et al., 2012) to distinguish ADHD subtypes. Furthermore, future research could recruit participants with formal diagnoses or use trained clinical interviews, to address limitations with self-report methods noted previously (see section 6.4.2.). This could be particularly relevant for research into specific areas highlighted in this thesis where differences between subtypes could be particularly salient (e.g., monitoring risks of ED; investigating the need/effectiveness of motivation-based interventions) (see section 6.3.). Future research that intends to do this and possibly perform comparisons on ADHD subtypes should also be mindful of unequal subgroup sizes in order to ensure that there are sufficient numbers of each subtype recruited for any such analysis. The sub-type that would have the greatest difficulty to recruit sufficient numbers for would likely be predominantly-hyperactive, making only 15.79% and 15.57% of the sample classified as subclinical ADHD in Chapter 3 and Chapter 4 respectively (or 5.92% and 5.25% of the total samples), and 7% of diagnosed adult ADHD cases (Wilens et al., 2009), with some previous research having to exclude them from analyse due to low prevalence (Volk et al., 2009).

6.6. Thesis Conclusion

In conclusion, this thesis investigated key factors related and contributing to the association between PA and ADHD in adults. The key findings presented in this thesis suggest that ADHD is associated with reduced PE; reduced intrinsic PE motivation; increased risk of ED; and increased barriers to PE. Utilising the understanding of the links between these factors in the development of potential PE based interventions as a treatment for ADHD, could lead to improved efficacy and safety. This could be done by increasing PE engagement (by promoting intrinsic PE motivation and reducing barriers to PE), reducing possible risks (such as ED), and considering individual factors that could influence possible benefits or risks (e.g., ADHD presentation and gender). Future research should further establish causality between factors highlighted in this thesis, as well as investigating practical considerations of any PE based interventions, such as maximising adherence and accessibility. The findings of this thesis contribute to a growing body of research investigating the effects and associations of PA on ADHD and provide further insight regarding the implementation and methodology of potential PE based treatments for ADHD.

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Appendices

Appendix A

Demographic Questionnaire

What is your age in years?

▼ 18 ... 100 +

What is your gender?

◯ Male

◯ Female

◯ Other

◯ Prefer not to say

What is your ethnicity?

◯ Welsh/English/Scottish/Northern Irish/British

◯ Irish

◯ Gypsy or Irish Traveller

◯ Any other White background

◯ White and Black Caribbean

◯ White and Black African

◯ White and Asian

◯ Any other Mixed / Multiple ethnic background

◯ Indian

- ◯ Pakistani
- ◯ Bangladeshi
- ◯ Chinese
- ◯ Any other Asian background
- ◯ African
- ◯ Caribbean
- ◯ Any other Black / African / Caribbean background
- ◯ Arab
- ◯ Other (Please enter) ____

In which country do you currently reside?

▼ United Kingdom ... Zimbabwe

What is your highest level of education?

- ◯ No formal education
- ◯ Secondary/Highschool (e.g. GCSE's) or equivalent
- ◯ College/Sixth form (e.g. BTEC, A-Levels) or equivalent
- ◯ University undergraduate (e.g. BSc, BA, Degree)
- ◯ Masters (e.g. MSC, MA)
- ◯ PhD/Doctorate
- ◯ Other (Please specify) ____

What is your employment status?

- ◯ Full-time employment
- ◯ Part-time employment
- ◯ Unemployed as unable to work
- ◯ Currently unemployed but looking for work
- ◯ Retired
- ◯ Unpaid family work/Homemaker/Carer
- ◯ Full-time student
- ◯ Part-time student
- ◯ Unpaid voluntary work
- ◯ Other (Please specify) ____

Appendix B

Comorbidities Questionnaire

Have you ever been diagnosed with any of the following conditions/disorders? Select any that apply

- [ ] ⊗None
- [ ] A mood disorder (e.g Depression)
- [ ] Learning disabilities
- [ ] Substance use disorders
- [ ] ADHD (Attention Deficit Hyperactivity Disorder)
- [ ] Sleep disorders
- [ ] Anxiety disorders
- [ ] Conduct disorders
- [ ] Eating disorders
- [ ] Other (please specify)

____

If so, do you take any prescribed medication?

○ Yes (Please specify the disorder[s] you take it for)

____

○ No

○ N/A (I do not have any of the above conditions/disorders)

Appendix C

Fitness Questionnaire

In the last 7 days which forms of exercise listed here have you done? (select all that apply)

- [ ] None
- [ ] Archery
- [ ] Basketball family (e.g. Basketball, Netball, etc)
- [ ] Bat sports (e.g. Cricket, Rounders, Baseball, etc)
- [ ] Bracket sports (e.g. Tennis, Badminton, etc)
- [ ] Climbing
- [ ] CrossFit
- [ ] Cycling
- [ ] Dancing
- [ ] Dodgeball
- [ ] Fencing
- [ ] Field events (Jumping) (e.g. Long jump, High jump, etc)
- [ ] Field events (Throwing) (e.g. shot put, Javelin, Frisbee, etc)
- [ ] Football
- [ ] Golf
- [ ] Gymnastics

- ☐ Hiking
- ☐ Hockey
- ☐ Horse riding
- ☐ Kayaking
- ☐ Martial Arts/Combat Sports (e.g. Karate, Wrestling, MMA, etc)
- ☐ Parkour/Free running
- ☐ Rowing
- ☐ Rugby
- ☐ Running
- ☐ Sailing
- ☐ Skating
- ☐ Skiing
- ☐ Snowboarding
- ☐ Surfing
- ☐ Swimming
- ☐ Trampolining
- ☐ Volleyball
- ☐ Walking

☐ Weight training

☐ Yoga

☐ Other (please specify)

____

Please rank the forms of exercise you selected in order of which you have done the most in the last 7 days(e.g. 1- did this form of exercise the most in the last 7 days, 2 - did this form of exercise the second most in the last 7 days, etc). Do this by dragging the options up and down (with rank 1 at the top)

⊗ _______ None
_______ Archery
_______ Basketball family (e.g. Basketball, Netball, etc)
_______ Bat sports (e.g. Cricket, Rounders, Baseball, etc)
_______ Bracket sports (e.g. Tennis, Badminton, etc)
_______ Climbing
_______ CrossFit
_______ Cycling
_______ Dancing
_______ Dodgeball
_______ Fencing
_______ Field events (Jumping) (e.g. Long jump, High jump, etc)
_______ Field events (Throwing) (e.g. shot put, Javelin, Frisbee, etc)
_______ Football
_______ Golf
_______ Gymnastics
_______ Hiking
_______ Hockey
_______ Horse riding
_______ Kayaking
_______ Martial Arts/Combat Sports (e.g. Karate, Wrestling, MMA, etc)
_______ Parkour/Free running
_______ Rowing
_______ Rugby
_______ Running
_______ Sailing
_______ Skating
_______ Skiing
_______ Snowboarding
_______ Surfing
_______ Swimming
_______ Trampolining

_______ Volleyball
_______ Walking
_______ Weight training
_______ Yoga
_______ Other (please specify)

Do you use any fitness tracking tools (Fitbit, smartphone apps, etc)

- ◯ Yes (Please specify) ____
- ◯ No

What is your main reason / motivation for exercising? (if you do)

- ◯ Fitness and health
- ◯ To lose weight
- ◯ For social reasons
- ◯ Self defence
- ◯ For my appearance
- ◯ Don't exercise
- ◯ Other (Please specify) ____

Appendix D

ASRS-6

Check the box that best describes how you have felt and conducted yourself over the past 6 months.

	Never	Rarely	Sometimes	Often	Very often
How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?	○	○	○	○	○
How often do you have difficulty getting things in order when you have to do a task that requires organization?	○	○	○	○	○
How often do you have problems remembering appointments or obligations?	○	○	○	○	○
When you have a task that requires a lot of thought, how often do you avoid or delay getting started?	○	○	○	○	○
How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?	○	○	○	○	○
How often do you feel overly active and compelled to do things, like you were driven by a motor?	○	○	○	○	○

Appendix E

ADHD-RS-IV With Adult Prompts

This questionnaire consists of 18 main items. Please read each main item (1-18) carefully and indicate the degree that each items affects you on the corresponding scale (None, Mild, Moderate, Severe).

Each main item (1-18) contains a number of prompts and questions, and you should select the highest applicable response on the scale (None, Mild, Moderate, or Severe) for each main item.

For example, if one prompt in Item 1 is scored "Moderate" and all the other prompts are "Mild", you should select “Moderate" as your overall response for Item 1.

	None	Mild	Moderate	Severe
1. Do you make a lot of mistakes (in school or work)? Is this because you’re careless? Do you rush through work or activities? Do you have trouble with detailed work? Do you not check your work? Do people complain that you’re careless? Are you messy or sloppy? Is your desk or workspace so messy that you have difficulty finding things?	○	○	○	○
2. Do you have trouble paying attention when watching movies, reading, or attending	○	○	○	○

lectures? Or on fun activities such as sports or board games? Is it hard for you to keep your mind on school or work? Do you have unusual trouble staying focused on boring or repetitive tasks? Does it take a lot longer than it should to complete tasks because you can't keep your mind on the task? Is it even harder for you than some others you know? Do you have trouble remembering what you read and do you need to re-read the same passage several times?				
3. Do people (spouse, boss, colleagues, friends) complain that you don't seem to listen or respond (or daydream) when spoken to or when asked to do tasks? A lot? Do people have to repeat directions? Do	○	○	○	○

you find that you miss the key parts of conversations because of drifting off in your own thoughts? Does it cause problems?				
4. Do you have trouble finishing things (such as work or chores)? Do you often leave things half done and start another project? Do you need consequences (such as deadlines) to finish? Do you have trouble following instructions (especially complex, multistep instructions that have to be done in a certain order with different steps)? Do you need to write down instructions, otherwise you will forget them?	○	○	○	○
5. Do you have trouble organizing tasks into ordered steps? Is it hard prioritizing work and chores? Do	○	○	○	○

you need others to plan for you? Do you have trouble with time management? Does it cause problems? Does difficulty in planning lead to procrastination and putting off tasks until the last moment possible?				
6. Do you avoid tasks (work, chores, reading, board games) that are challenging or lengthy because it's hard to stay focused on these things for a long time? Do you have to force yourself to do these tasks? How hard is it? Do you procrastinate and put off tasks until the last moment possible?	○	○	○	○
7. Do you lose things (eg, important work papers, keys, wallet, coats, etc)? A lot? More than others? Are you constantly looking for important items?	○	○	○	○

Do you get into trouble for this (at work or at home)? Do you need to put items (eg, glasses, wallet, keys) in the same place each time, otherwise you will lose them?				
8. Are you ever very easily distracted by events around you such as noise (conversation, TV, radio), movement, or clutter? Do you need relative isolation to get work done? Can almost anything get your mind off of what you are doing, such as work, chores, or if you're talking to someone? Is it hard to get back to a task once you stop?	○	○	○	○
9. Do you forget a lot of things in your daily routine? Like what? Chores? Work? Appointments or obligations? Do you forget to bring things to	○	○	○	○

work, such as work materials or assignments due that day? Do you need to write regular reminders to yourself to do most activities or tasks, otherwise you will forget?				
10. Can you sit still or are you always moving your hands or feet, or fidgeting in your chair? Do you tap your pencil or your feet? A lot? Do people notice? Do you regularly play with your hair or clothing? Do you consciously resist fidgeting or squirming?	○	○	○	○
11. Do you have trouble staying in your seat? At work? In class? At home (eg, watching TV, eating dinner)? In church or temple? Do you choose to walk around rather than sit? Do you have to force yourself to remain seated? Is it difficult for you to sit	○	○	○	○

through a long meeting or lecture? Do you try to avoid going to functions that require you to sit still for long periods of time?				
12. Are you physically restless? Do you feel restless inside? A lot? Do you feel more agitated when you cannot exercise on an almost daily basis?	○	○	○	○
13. Do you have a hard time playing/working quietly? During leisure activity (nonstructured times or on your own such as reading a book, listening to music, playing a board game), are you agitated or dysphoric? Do you always need to be busy after work or while on vacation?	○	○	○	○
14. Is it hard for you to slow down? Do you feel like you (often) have a lot of energy and that you always	○	○	○	○

have to be moving, are always “on the go”? Do you feel like you’re driven by a motor? Do you feel unable to relax?				
15. Do you talk a lot? All the time? More than other people? Do people complain about your talking? Is it a problem? Are you often louder than the people you are talking to?	○	○	○	○
16. Do you give answers to questions before someone finishes asking? Do you say things before it is your turn? Do you say things that don’t fit into the conversation? Do you do things without thinking? A lot?	○	○	○	○
17. Is it hard for you to wait your turn (in conversation, in lines, while driving)? Are you frequently frustrated with delays? Does it cause problems?	○	○	○	○

Do you put a great deal of effort into planning to not be in situations where you might have to wait?				
18. Do you talk when others are talking, without waiting until you are acknowledged? Do you butt into others' conversations before being invited? Do you interrupt others' activities? Is it hard for you to wait to get your point across in conversations or at meetings?	○	○	○	○

Appendix F

IPAQ-L

You will now be presented with a sequence of questions for you to answer. Please note, depending on your answers to some questions, new questions might appear. Additionally, do not worry if the questions do not appear sequentially, simply answer the questions as they are presented to you.

PART 1. 1) Do you currently have a job or do any unpaid work outside your home?

○ Yes

○ No

1.2) During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, heavy construction, or climbing up stairs as part of your work? Think about only those physical activities that you did for at least 10 minutes at a time.

▼ 0 ... 7

1.2.2) How much time did you usually spend on one of those days doing vigorous physical activities as part of your work? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

1.3) Again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate

physical activities like carrying light loads as part of your work? Please do not include walking.

▼ 0 ... 7

1.3.2) How much time did you usually spend on one of those days doing moderate physical activities as part of your work? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

1.4) During the last 7 days, on how many days did you walk for at least 10 minutes at a time as part of your work? Please do not count any walking you did to travel to or from work.

▼ 0 ... 7

1.4.2) How much time did you usually spend on one of those days walking as part of your work? (so if you usually spend 2 and a half hours doing this, put "02" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

PART 2.1) During the last 7 days, on how many days did you travel in a motor vehicle like a train, bus, car, or tram?

▼ 0 ... 7

2.1.2) How much time did you usually spend on one of those days traveling in a train, bus, car, tram, or other kind of motor vehicle? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

2.2) During the last 7 days, on how many days did you bicycle for at least 10 minutes at a time to go from place to place?

▼ 0 ... 7

2.2.2) How much time did you usually spend on one of those days to bicycle from place to place? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

2.3) During the last 7 days, on how many days did you walk for at least 10 minutes at a time to go from place to place?

▼ 0 ... 7

2.3.2) How much time did you usually spend on one of those days walking from place to place? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

PART 3.1) Think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, chopping wood, shoveling snow, or digging in the garden or yard?

▼ 0 ... 7

3.1.2) How much time did you usually spend on one of those days doing vigorous physical activities in the garden or yard? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

3.2) Again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate activities like carrying light loads, sweeping, washing windows, and raking in the garden or yard?

▼ 0 ... 7

3.2.2) How much time did you usually spend on one of those days doing moderate physical activities in the garden or yard? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

3.3) Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate activities like carrying light loads, washing windows, scrubbing floors and sweeping inside your home?

▼ 0 ... 7

3.3.2) How much time did you usually spend on one of those days doing moderate physical
activities inside your home?
(so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second)
Hours:

▼ 0 ... 23

Minutes:

▼ 0 ... 59

PART 4.1) Not counting any walking you have already mentioned, during the last 7 days, on how many days did you walk for at least 10 minutes at a time in your leisure time?

▼ 0 ... 7

4.1.2) How much time did you usually spend on one of those days walking in your leisure time? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

4.2) Think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do vigorous physical activities like aerobics, running, fast bicycling, or fast swimming in your leisure time?

▼ 0 ... 7

4.2.2) How much time did you usually spend on one of those days doing vigorous physical activities in your leisure time? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

4.3) Again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate

physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis in your leisure time?

▼ 0 ... 7

4.3.2) How much time did you usually spend on one of those days doing moderate physical activities in your leisure time? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

PART 5.1) During the last 7 days, how much time did you usually spend sitting on a weekday? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

5.2) During the last 7 days, how much time did you usually spend sitting on a weekend day? (so if you usually spend 2 and a half hours doing this, put "2" in the first box and "30" in the second) **Hours:**

▼ 0 ... 23

Minutes:

▼ 0 ... 59

Appendix G

Chapter Two Study Ethical Approval Letter

17 December 2020

Dear RORY LUKE TUCKER, , , Dr CLAIRE Williams, PHIL Reed,

Re: 5003 , Attention, memory, and hyperactivity in adults: Links with physical exercise

Your application - https://swansea.forms.ethicalreviewmanager.com/ProjectView/Index/5003 - has been reviewed and approved by the Department of Psychology Ethics Committee.

The list of additional students (if any) are included in the table below:

Other student applicant - first name	Other student applicant - Surname	Other student applicant - email

additional researcher or student - first name	additional researcher or student - surname	additional researcher or student - email

The conditions of this approval are as follows:

1. To conduct your study strictly in accordance with the proposal that has been approved by the committee, including any approved amendments
2. To advise the ethics committee chair of any complaints or other issues that may warrant ethical review of the project
3. To submit for approval any changes to the approved protocol before implementing any such changes
4. To keep any information obtained from your participants absolutely confidential

Please note that failure to comply with these conditions of approval may result in the withdrawal of approval for the project.

To advertise your study on the departmental Participant Pool: You will need to send send a request for your study to be made visible, via the link on the Experiment Management System website (see Researcher Documentation for details). Please ensure that you attach this letter to your request. (If you are unable to attach the Ethics approval, send it in a separate email to Dr. Phil Tucker[redacted]).

For students: Please ensure that the signed copy of this Ethical Approval, together with any other paperwork associated with your research, is included in your final write up.

Yours Sincerely,

Dr John Towler (Reviewer of Application)

Dr Gabriela Jiga-Boy (Committee Chair)

Appendix H

English Language Proficiency Questionnaire

Is English your first language?

- ◯ Yes
- ◯ No

If English is not your first language, how would you describe your English Language Skills (e.g., reading, writing, speaking)?

- ◯ Very weak
- ◯ Weak
- ◯ Intermediate
- ◯ Strong
- ◯ Excellent

Appendix I

BREQ-3

Using the scale below, please indicate to what extent each of the following items is true for you. Please note that there are no right or wrong answers and no trick questions. We simply want to know how you personally feel about exercise. Your responses will be held in confidence and only used for our research purposes. Please rate your answers from 0 (not true for me) to 4 (very true for me).

	0 - Not true for me	1	2 - Sometimes true for me	3	4 - Very true for me
1. It's important to me to exercise regularly	○	○	○	○	○
2. I don't see why I should have to exercise	○	○	○	○	○
3. I exercise because it's fun	○	○	○	○	○
4. I feel guilty when I don't exercise	○	○	○	○	○
5. I exercise because it is consistent with my life goals	○	○	○	○	○
6. I exercise because other people say I should	○	○	○	○	○
7. I value the benefits of exercise	○	○	○	○	○
8. I can't see why I should bother exercising	○	○	○	○	○
9. I enjoy my exercise sessions	○	○	○	○	○
10. I feel ashamed when I miss an exercise session	○	○	○	○	○

11. I consider exercise part of my identity	○	○	○	○	○
12. I take part in exercise because my friends/family/partner say I should	○	○	○	○	○
13. I think it is important to make the effort to exercise regularly	○	○	○	○	○
14. Please select option "2-Sometimes true for me"	○	○	○	○	○
15. I don’t see the point in exercising	○	○	○	○	○
16. I find exercise a pleasurable activity	○	○	○	○	○
17. I feel like a failure when I haven’t exercised in a while	○	○	○	○	○
18. I consider exercise a fundamental part of who I am	○	○	○	○	○
19. I exercise because others will not be pleased with me if I don't	○	○	○	○	○
20. I get restless if I don’t exercise regularly	○	○	○	○	○
21. I think exercising is a waste of time	○	○	○	○	○
22. I get pleasure and satisfaction from participating in exercise	○	○	○	○	○

23. I would feel bad about myself if I was not making time to exercise	○	○	○	○	○
24. I consider exercise consistent with my values	○	○	○	○	○
25. I feel under pressure from my friends/family to exercise	○	○	○	○	○

Appendix J

EDS-R

Using the scale provided below, please complete the following questions as honestly as possible. The questions refer to current exercise beliefs and behaviours that have occurred in the past 3 months. Please rate your answers from 1 (never) to 6 (always).

	1 - Never	2	3	4	5	6 - Always
1. I exercise to avoid feeling irritable:	○	○	○	○	○	○
2. I exercise despite recurring physical problems:	○	○	○	○	○	○
3. I continually increase my exercise intensity to achieve the desired effects/benefits:	○	○	○	○	○	○
4. I am unable to reduce how long I exercise:	○	○	○	○	○	○
5. I would rather exercise than spend time with family/friends:	○	○	○	○	○	○
6. I spend a lot of time exercising:	○	○	○	○	○	○
7. I exercise longer than I intend:	○	○	○	○	○	○
8. I exercise to avoid feeling anxious:	○	○	○	○	○	○

9. I exercise when injured:	○	○	○	○	○	○
10. I continually increase my exercise frequency to achieve the desired effects/benefits:	○	○	○	○	○	○
11. I am unable to reduce how often I exercise:	○	○	○	○	○	○
12. I think about exercise when I should be concentrating on school/work:	○	○	○	○	○	○
13. I spend most of my free time exercising:	○	○	○	○	○	○
14. I exercise longer than I expect:	○	○	○	○	○	○
15. I exercise to avoid feeling tense.:	○	○	○	○	○	○
16. Please select option "4"	○	○	○	○	○	○
17. I exercise despite persistent physical problems:	○	○	○	○	○	○
18. I continually	○	○	○	○	○	○

increase my exercise duration to achieve the desired effects/benefits:						
19. I am unable to reduce how intense I exercise:	○	○	○	○	○	○
20. I choose to exercise so that I can get out of spending time with family/friends:	○	○	○	○	○	○
21. A great deal of my time is spent exercising:	○	○	○	○	○	○
22. I exercise longer than I plan:	○	○	○	○	○	○

Appendix K

ASRS-5

Check the box that best describes how you have felt and conducted yourself over the past 6 months.

	Never	Rarely	Sometimes	Often	Very often
How often do you have difficulty concentrating on what people are saying to you even when they are speaking to you directly?	○	○	○	○	○
Please select "often"	○	○	○	○	○
How often do you leave your seat in meetings or other situations in which you are expected to remain seated?	○	○	○	○	○
How often do you have difficulty unwinding and relaxing when you have time to yourself?	○	○	○	○	○
When you're in a conversation, how often do you find yourself	○	○	○	○	○

finishing the sentences of the people you are talking to before they can finish them themselves?					
How often do you put things off until the last minute?	○	○	○	○	○
How often do you depend on others to keep your life in order and attend to details?	○	○	○	○	○

Appendix L

Chapter Three Study Ethical Approval Letter

Swansea University
Prifysgol Abertawe

Approval Date: 27/03/2023

Research Ethics Approval Number: 1 2023 6008 5223

Thank you for completing a research ethics application for ethical approval and submitting the required documentation via the online platform.

Project Title	Physical activity, motivation and behaviour in adults
Applicant name	MR RORY TUCKER
Submitted by	MR RORY TUCKER / PROF PHIL REED
Full application form link	https://swansea.forms.ethicalreviewmanager.com/Project/Index/7664

The Psychology ethics committee has approved the ethics application, subject to the conditions outlined below:

Approval conditions

1. The approval is based on the information given within the application and the work will be conducted in line with this. It is the responsibility of the applicant to ensure all relevant external and internal regulations, policies and legislations are met.
2. This project may be subject to periodic review by the committee. The approval may be suspended or revoked at any time if there has been a breach of conditions.
3. Any substantial amendments to the approved proposal will be submitted to the ethics committee prior to implementing any such changes.

Specific conditions in respect of this application:

The application has been classified as Low risk to the University.

No additional conditions.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees. It complies with the guidelines of UKRI and the concordat to support Research Integrity.

Psychology Research and Ethics Chair

Swansea University.

If you have any query regarding this notification, then please contact your research ethics administrator for the faculty.

- For Science and Engineering contact FSE-Ethics@swansea.ac.uk
- For Medicine, Health and Life Science contact FMHLS-Ethics@swansea.ac.uk
- For Humanities and Social Sciences contact FHSS-Ethics@swansea.ac.uk

Appendix M

Table 24

*Correlation Coefficients (Spearman's rho) between PE level and Motivation subscales (*N*=152)*

Variable	PE Level
RAI	.34***
Amotivation	-.18*
External Regulation	.15
Introjected Regulation	.32***
Identified Regulation	.41***
Integrated Regulation	.43***
Intrinsic Regulation	.37***

Note. Statistical significance: **p* < .05; ****p* < .001.

RAI = Relative Autonomy Indec; PE = Physical Exercise

Appendix N

Modified DPAQ

Using the scale below, please indicate to what extent you agree with each of the following statements. Please note that there are no right or wrong answers and no trick questions. Please rate your answers from 1 (Strongly disagree) to 7 (Strongly agree). Note: "PA" refers to Physical Activity

	1 - Strongly Disagree	2 - Disagree	3 - Somewhat Disagree	4 - Neither agree nor disagree	5 - Somewhat Agree	6 - Agree	7 - Strongly Agree
1. I know what the recommended levels of physical activity are	○	○	○	○	○	○	○
2. I DO NOT know the reasons why I should be meeting the nationally recommended PA guidelines	○	○	○	○	○	○	○
3. I have NOT previously read information about the current nationally recommended PA guidelines	○	○	○	○	○	○	○
4. Facilities are available to help me to do physical activity	○	○	○	○	○	○	○
5. There is NO WHERE to do physical activity near me	○	○	○	○	○	○	○
6. My local area is NOT very attractive and this puts me off doing physical activity	○	○	○	○	○	○	○

7. I want to do physical activity	○	○	○	○	○	○	○
8. I CANNOT be bothered to do physical activity	○	○	○	○	○	○	○
9. I feel motivated to do physical activity	○	○	○	○	○	○	○
10. I DO NOT feel confident when doing physical activity	○	○	○	○	○	○	○
11. Doing physical activity makes me feel embarrassed	○	○	○	○	○	○	○
12.I FIND IT HARD to do physical activity when I see others doing well at physical activity (e.g. watching others run for a long time on the treadmill)	○	○	○	○	○	○	○
13. I can do physical activity to a good enough standard	○	○	○	○	○	○	○
14. I've NEVER really had sports skills so I DON'T do physical activity	○	○	○	○	○	○	○
15. I don't seem to have the skills to keep going in physical activity sessions	○	○	○	○	○	○	○
16. Daily life is too stressful for physical activity	○	○	○	○	○	○	○

17. I have too many negative emotions which prevent me from doing physical activity	○	○	○	○	○	○	○
18. When I think about doing physical activity, I start to worry	○	○	○	○	○	○	○
19. My friends DON'T support or encourage my physical activity	○	○	○	○	○	○	○
20. The people I spend my free time with don't do physical activity	○	○	○	○	○	○	○
21. I DON'T have anyone to do physical activity with	○	○	○	○	○	○	○
22. If I do PA, it will benefit me in the short term (e.g. burn calories, sleep better etc.)	○	○	○	○	○	○	○
23. If I do PA it will benefit me in the long term (e.g. live longer, lose weight etc.)	○	○	○	○	○	○	○
24. I think physical activity will change my life for the better	○	○	○	○	○	○	○
25. I tend to plan where my PA will happen (e.g. at the park, leisure centre etc.)	○	○	○	○	○	○	○

26. I do not tend to plan when my PA will happen (e.g. Monday at 6pm etc.)	○	○	○	○	○	○	○
27. I tend to plan how my PA will happen (e.g. how to get there, kit needed etc.)	○	○	○	○	○	○	○
28. I do not tend to plan what type of PA I will do (e.g. aerobics class, walking to work, session at the gym etc.)	○	○	○	○	○	○	○
29. I know what to do in difficult situations in order to make sure I do the physical activity I have planned	○	○	○	○	○	○	○
30. I get easily distracted from the physical activity I have planned	○	○	○	○	○	○	○
31. I always work around obstacles to physical activity; nothing really stops me	○	○	○	○	○	○	○
32. I WOULD NOT be prepared to give up work ambitions to do physical activity	○	○	○	○	○	○	○
33. I would be prepared to give up things I usually do in my leisure time for physical activity	○	○	○	○	○	○	○

34. I WOULD NOT be prepared to give up spending time with my friends for physical activity	○	○	○	○	○	○	○
35. I feel like I need to be perfect from the outset when it comes to PA and don't want to start it if I can't be perfect.	○	○	○	○	○	○	○
36. I often feel hyperactive and PA is a way I use to quench that hyperactivity.	○	○	○	○	○	○	○
37. Having high energy and engaging in PA is part of my identity.	○	○	○	○	○	○	○
38. There are days where I forget to do PA (even if intended to) or forget PA equipment.	○	○	○	○	○	○	○
39. I am sometimes hyper-fixated (i.e., being particularly concentrated on one thing) on doing PA.	○	○	○	○	○	○	○
40. I often have difficulties with time management (e.g., being unaware how much time has passed; taking longer to do other tasks) when it comes to PA.	○	○	○	○	○	○	○

41. I find it hard to stick to plans I have made regarding PA.	○	○	○	○	○	○	○
42. Actually getting started is a big obstacle for doing PA for me.	○	○	○	○	○	○	○
43. I prepare in advance for PA (e.g., pack a gym bag the night before; make sure you have all the equipment/clothes you need ready ahead of time).	○	○	○	○	○	○	○
44. I had routines/habits for doing PA at an early age.	○	○	○	○	○	○	○
45. I have had the urge to be physically active from an early age.	○	○	○	○	○	○	○
46. I know how to build routines/habits for PA because of routines/habits I had at an early age.	○	○	○	○	○	○	○

Appendix O

PVQ-II

Please read carefully through the value description below and consider it when answering the questions below

Personal value: Engaging in Physical Activity/Exercise.

Think of exercising regularly; being active; engaging in sports, and/or keeping physically healthy. Please answer the following questions by selecting the responce that is true for you:

1. How important is this value to you?

◯ 1 - Not at all important

◯ 2 - A little bit important

◯ 3 - Moderately important

◯ 4 - Quite important

◯ 5 - Extremely important

2. How committed are you to living this value?

◯ 1 - Not at all committed

◯ 2 - Slightly Committed

◯ 3 - Moderately committed

◯ 4 - Quite committed

◯ 5 - Extremely committed

3. Right now, would you like to improve your progress on this value?

◯ 1 - Not at all

◯ 2 - A little bit

○ 3 - Moderately so

○ 4 - Quite a bit

○ 5 - Extremely so

4. In the last 10 weeks, I have been this successful in living this value:

○ 1 - 0-20% Successful

○ 2 - 21-40% Successful

○ 3 - 41-60% Successful

○ 4 - 61-80% Successful

○ 5 - 81-100% Successful

5. I value this because:

	1 - Strongly Disagree	2 - Moderately Disagree	3 - Neither Disagree nor Agree	4 - Moderately Agree	5- Strongly Agree
a. Other people would be upset with me if these values were not important to me.	○	○	○	○	○
b. I would feel guilty or ashamed if these values were not important to me.	○	○	○	○	○
c. These values are important to me, whether	○	○	○	○	○

or not others agree					
d. Living consistently with these values makes my life more meaningful	○	○	○	○	○
e. I experience fun and enjoyment when I live consistently with these values.	○	○	○	○	○

Appendix P

Chapter Four Study Ethical Approval Letter

Swansea University
Prifysgol Abertawe

Approval Date: 02/10/2023

Research Ethics Approval Number: 1 2023 7799 6755

Thank you for completing a research ethics application for ethical approval and submitting the required documentation via the online platform.

Project Title	Physical activity in adults: Barriers and Facilitators
Applicant name	MR RORY TUCKER
Submitted by	MR RORY TUCKER /
Full application form link	https://swansea.forms.ethicalreviewmanager.com/Project/Index/9705

The Psychology ethics committee has approved the ethics application, subject to the conditions outlined below:

Approval conditions

1. The approval is based on the information given within the application and the work will be conducted in line with this. It is the responsibility of the applicant to ensure all relevant external and internal regulations, policies, and legislations are met.
2. This project may be subject to periodic review by the committee. The approval may be suspended or revoked at any time if there has been a breach of conditions.
3. Any substantial amendments to the approved proposal will be submitted to the ethics committee prior to implementing any such changes.

Specific conditions in respect of this application:

The application has been classified as Low Risk to the University.

No additional conditions.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees. It complies with the guidelines of UKRI and the concordat to support Research Integrity.

Psychology Research and Ethics Chair

Swansea University.

If you have any queries regarding this notification, then please contact your research ethics administrator for the faculty.

- For Science and Engineering contact FSE-Ethics@swansea.ac.uk
- For Medicine, Health and Life Science contact FMHLS-Ethics@swansea.ac.uk
- For Humanities and Social Sciences contact FHSS-Ethics@swansea.ac.uk

Appendix Q

The Borg CR scale (R) (CR10) ((C) Gunnar Borg, 1982, 1998, 2004)

(Scale printed with permission. The scale and full instruction can be obtained through BorgPerception www.borgperception.se)

Instruction. Use this rating scale to report how strong your perception is. It can be exertion, pain or something else. First look at the words on the scale, and then the numbers. Of these ten (10) or "Extremely strong", "Maximal" is a very important intensity level. This is the most intense perception or feeling you have ever had.

If your experience or feeling is "Very weak", you should select "1", if it is "Moderate", select "3". Note that "Moderate" is "3" and thus weaker than "Medium", "Mean" or "Middle". If the experience is "Strong" or "Heavy" (it feels "Difficult") select "5". Note that "Strong" is about half of "Maximal". If your feeling is "Very strong", select a number from 6 to 8. If your perception or feeling is stronger than "10", - "Extremely strong", "Maximal" – you can use a larger number, e.g. 12 or still higher (that's why "Absolute maximum" is marked with a dot "•").

It's very important that you report what you actually experience or feel, not what you think you should report. Be as spontaneous and honest as possible and try to avoid under- or overestimating. Look at the words and then select a number.

When rating exertion give a number that corresponds to how hard and strenuous you perceive the work to be. The perception of exertion is mainly felt as strain and fatigue in your muscles and as breathlessness or any aches.

0 "Nothing at all", means that you don't feel any exertion whatsoever, no muscle fatigue, no breathlessness or difficulties breathing.

1 "Very weak" means a very light exertion. As taking a shorter walk at your own pace.

3 "Moderate" is somewhat but not especially hard. It feels good and not difficult to go on.

5 "Strong". The work is hard and tiring, but continuing isn't terribly difficult. The effort and exertion is about half as intense as "Maximal".

7 "Very strong" is really very strenuous. You can still go on, but you really have to push yourself and you are very tired.

10 "Extremely strong – Maximal" is an extremely strenuous level. For most people this is the most strenuous exertion they have ever experienced previously in their lives.

● Is "Absolute maximum" for example "12" or even somewhat more.

Any questions?

0	Nothing at all	
0.3		
0.5	Extremely weak	Just noticeable
0.7		
1	Very weak	
1.5		
2	Weak	Light
2.5		
3	Moderate	
4		
5	Strong	Heavy
6		
7	Very strong	
8		
9		
10	Extremely strong	"Maximal"
11		
●	Absolute maximum	Highest possible

Appendix R

PANAS

This scale consists of a number of words that describe different feelings and emotions. Read each item and then mark the appropriate answer in the space next to that word.

Indicate to what extent you feel right now.

Use the following scale to record your answers.

Interested

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Distressed

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Excited

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Upset

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Strong

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Guilty

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Scared

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Hostile

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Enthusiastic

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Proud

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Irritable

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Alert

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Ashamed

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Inspired

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Nervous

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Determined

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Attentive

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Jittery

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Active

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Afraid

1) Very slightly or not at all	2) A little	3) Moderately	4) Quite a bit	5) Extremely

Appendix S

Chapter Five Study Ethical Approval Letter

15 March 2022

Dear RORY LUKE TUCKER, , , Dr Claire Williams, Phil Reed,

Re: 5414 , Effect of changing conditions on executive function

Your application - https://swansea.forms.ethicalreviewmanager.com/ProjectView/Index/5414 - has been reviewed and approved by the Department of Psychology Ethics Committee.

The list of additional students (if any) are included in the table below:

Other student applicant - first name	Other student applicant - Surname	Other student applicant - email

additional researcher or student - first name	additional researcher or student - surname	additional researcher or student - email

The conditions of this approval are as follows:

1. To conduct your study strictly in accordance with the proposal that has been approved by the committee, including any approved amendments
2. To advise the ethics committee chair of any complaints or other issues that may warrant ethical review of the project
3. To submit for approval any changes to the approved protocol before implementing any such changes
4. To keep any information obtained from your participants absolutely confidential

Please note that failure to comply with these conditions of approval may result in the withdrawal of approval for the project.

To advertise your study on the departmental Participant Pool: You will need to send send a request for your study to be made visible, via the link on the Experiment Management System website (see Researcher Documentation for details). Please ensure that you attach this letter to your request. (If you are unable to attach the Ethics approval, send it in a separate email to Dr. Phil Tucker [redacted]).

For students: Please ensure that the signed copy of this Ethical Approval, together with any other paperwork associated with your research, is included in your final write up.

Yours Sincerely,

Dr Menna Price (Reviewer of Application)

Dr Menna Price (Committee Chair)

Appendix T

Table 25

T-Tests of Differences in Parametric Variable Scores Between Males and Females With Subclinical ADHD in Chapter Four

Variable	Females (*n*=87)		Males (*n*=28)		*t* value	*p*	Cohen's *d*
	M	SD	M	SD			
EDS-T	6.88	1.4	7.69	1.11	2.8	.006	.61
RAI	5.53	5.83	8.18	5.77	2.1	.038	.46
PVQ-S	12.58	2.76	13.93	2.45	2.32	.022	.5
PVQ-T	1.22	1.57	1.57	1.08	1.39	.167	.3

Note. EDS-T = Exercise Dependence Score-Total; RAI = Relative Autonomy Index; PVQ-S = Motivation Strength; PVQ-T = Motivation Type.

Appendix U

Table 26

Mann-Whitney U tests of Differences in Non-Parametric Variable Scores Between Males and Females With Subclinical ADHD in Chapter Four

Variable	Females (n=87)		Males (n=28)		U	p	r_{rb}
	Median	IQR	Median	IQR			
PE Level	396	1074	973.24	2163.75	1429.5	.165	.17
Knowledge	4.67	2.17	4.5	1.25	1273.5	.719	.05
E Context	6	2	5.83	2.17	1184.5	.829	.03
Motivation	4.67	1.33	5	1.08	1539.5	.036	.26
BCap	3	1.67	5.17	2.75	1738.5	<.001	.43
Skills	5	2	5.5	1.58	1612.5	.01	.32
Emotion	4	2.5	4.5	1.67	1343	.416	.1
Social Influences	4.67	2.17	5	2	1323	.494	.09
BCon	6	1.33	6.33	1	1353	.37	.11
Action Planning	5	2	5	1.75	1133	.581	.07
Coping Planning	3	1.67	3.17	1.08	1562.5	.024	.28
Goal Conflict	3.33	1.67	3.67	1	1402.5	.229	.15

Note. PE = Physical Exercise; E Context = Environmental Context; BCap = Beliefs about Capabilities; BCon = Belief in Consequences.