CARDIORESPIRATORY FITNESS AND ADULT ADHD

EXPLORING THE ASSOCIATIONS BETWEEN CARDIORESPIRATORY FITNESS, EXECUTIVE FUNCTION, AND MENTAL HEALTH, ALONG WITH UNIQUE BARRIERS AND FACILITATORS TO PHYSICAL ACTIVITY FOR ADULTS WITH ATTENTION DEFICIT HYPERACTIVITY DISORDER

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A Thesis Submitted to the School of Graduate Studies in Partial Fulfilment of the Requirements for the Degree Doctor of Philosophy

DOCTOR OF PHILOSOPHY (Kinesiology)
McMaster University Hamilton, Ontario

TITLE: Exploring the associations between cardiorespiratory fitness, executive function, and mental health, along with unique barriers and facilitators to physical activity for adults with attention deficit hyperactivity disorder

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NUMBER OF PAGES: xv, 145

LAY ABSTRACT

Although attention deficit hyperactivity disorder (ADHD) is commonly considered a childhood condition, many continue to experience poorer cognition and mental health in adulthood. While positive associations between cardiorespiratory fitness—the ability to intake and circulate oxygen throughout the body—and cognitive outcomes have been documented in the general population, these connections have received limited attention for adults with ADHD. This thesis addressed these gaps and found that those with higher fitness had better inhibitory control—an element of cognition that helps us avoid responding to distractions—and less depression, anxiety, and stress. Considering these findings, future work should explore whether increasing fitness through physical activity interventions can provide support. However, during conversations, participants expressed unique ADHD-related barriers and facilitators to physical activity, suggesting the need for tailored approaches. Together, this information can be leveraged by researchers and professionals to help adults with ADHD get active and support symptom management.

ABSTRACT

Higher cardiorespiratory fitness (CRF) is associated with better executive function and mental health in neurotypical populations. However, these associations warrant investigation for adults with attention deficit hyperactivity disorder (ADHD) who experience executive dysfunction and worse mental health. Adults with ADHD also tend to have lower engagement in physical activity, which contributes to CRF, but the reasons for this are unknown. Using mixed methods, the purpose of this dissertation was to explore associations between CRF and executive functions (Study 1), and mental health (Study 2), and to understand barriers and facilitators to physical activity in an adult ADHD sample (Study 3).

Data from Study 1 reveal the association between higher CRF and better inhibitory control; surprisingly, the same associations with CRF were not observed for cognitive flexibility and working memory, suggesting a selective association between CRF and inhibitory control. In Study 2, although adults with ADHD reported significantly higher symptoms of depression, anxiety, and stress than controls, those with higher CRF had better mental health. Together, the findings from Studies 1 and 2 suggest that physical activity interventions aimed at increasing CRF may provide adults with ADHD support for symptom management and mental health. Finally, Study 3 documents the unique barriers and facilitators to getting physically active as described by adults with ADHD. Through semi-structured interviews, the results revealed unique ADHD-related barriers and facilitators to being physically active such that their symptoms could act as both a barrier and facilitator depending on the context. Overall, the results of this dissertation provide valuable information for researchers designing future interventions and professionals recommending physical activity for those with ADHD, with the ultimate goal of creating an inclusive context for movement that is more enjoyable, feasible, and promotes adherence over the long term.

ACKNOWLEDGEMENTS

Firstly, I would like to express my gratitude to my supervisor, Dr. Jennifer Heisz. Your mentorship over my seven years in the NeuroFit lab allowed me to explore my passions and interests, and I am a better researcher, teacher, and person because of it. I would also like to thank the amazing members of my committee, Drs. Steven Bray, Barbara Fenesi, and Matthew Kwan. I am so fortunate to have been supported by such an intelligent, compassionate, and encouraging group of researchers. I am extremely grateful for the entire committee's support and belief in me to wrap up my Ph.D. while starting my dream job. Five years ago, in the acknowledgements of my Master's, I wrote about how I would pursue my passion for teaching and learning for the rest of my life. I am honoured that that is now my reality.

Beyond my committee, I am so fortunate to have an additional network of supportive mentors, including teaching champions who I aspire to be like. This includes my incredible colleagues at McMaster's teaching and learning centre, the MacPherson Institute, who taught me so much about the importance of collaboration and community. Being a part of the EDF program was one of my favourite parts of grad school.

I would like to thank the past and present members of the NeuroFit Lab, particularly the remarkable undergraduate students I have had the privilege of working with. Thank you for your hard work and all the laughs along the way. I would also like to recognize and appreciate the participants who were involved in this program of research for their willingness to engage during a time when energy tanks were running low. Thank you for trusting us with your insights and wisdom.

I say this often (and know I will continue to say it) … but I truly have the best friends and best partner in the entire world. Thank you for always rooting for me. From my biggest achievements to my darkest days, I feel loved and supported day in and day out. Thank you for always believing in me and reminding me to believe in myself. Words cannot fully express how appreciative I am. I couldn't do this life without you.

One of the best gifts that spending another five years at McMaster for my Ph.D. brought me, was being able to see my sister grow throughout her Kinesiology undergraduate degree. Though she may not have always loved her title of "Michelle's little sister," being here for your journey has been a privilege. I am forever and always so proud of you. And to my parents, thank you for always believing in me and pushing me to reach for the top. Your risk taking and sacrifice meant that I could pursue my goals and dreams. I am forever grateful for you both and I love you so much.

I could not have done this without the most incredible community. Though my name might be on this document, the accomplishment is shared with you all.

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LIST OF ABBREVIATIONS

6MWT	Six-Minute Walk Test
ADHD	attention deficit hyperactivity disorder
ASD	autism spectrum disorder
BDNF	brain-derived neurotrophic factor
CAARS	Conners' Adult ADHD Rating Scale
COVID-19	coronavirus disease
CRF	cardiorespiratory fitness
DASS	Depression Anxiety Stress Scales
DSM	Diagnostic and Statistical Manual of Mental Disorders
DV	dependent variable
EF	executive function
ICR	intercoder reliability
IV	independent variable
IQ	intelligence quotient
MAXQDA	qualitative data analysis package
MH	mental health
OSPAN	operation span task
PA	physical activity
PAR-Q	Physical Activity Readiness Questionnaire
RSD	rejection sensitive dysphoria
SPSS	statistical package for the social sciences
TDF	Theoretical Domains Framework
VO_{2max}	maximum rate of oxygen consumption
WCST	Wisconsin Card Sorting Task

PREFACE
DECLARATION OF ACADEMIC ACHIEVEMENT

This thesis is presented as a “sandwich” thesis, as outlined by the School of Graduate Studies’ Guide for the Preparation of Master’s and Doctoral Theses. First, there is a general introduction, followed by three studies led by the author, which are presented in journal article format. It is concluded with a general discussion. The candidate is first author on each of the three studies and all are published.

CONTRIBUTION TO PAPERS WITH MULTIPLE AUTHORSHIP

Chapter 2 (Study 1)

Ogrodnik, M., Karsan, S., Cirone, V., & Heisz, J. (2023). Exploring the relationship between cardiorespiratory fitness and executive functioning in adults with ADHD. *Brain Sciences, 13*(4), 673. https://doi.org/10.3390/brainsci13040673

M. Ogrodnik's role in Study 1:

- Created and developed research question and protocol
- Lead author on obtaining ethics approval from McMaster University
- Obtained permission from MHS to use CAARS tool
- Lead development of research protocol, including measure selection and analysis approach
- Lead author responsible for training research assistants on data collection protocol, analysis, and interpretation
- Primary author of manuscript

Role of co-authors in Study 1:

- SK contributed to data collection
- SK contributed to data analysis and interpretation
- SK served as second author and contributed to manuscript writing
- VC contributed to data collection
- VC provided feedback on the final manuscript
- JH provided feedback about research question and protocol
- JH obtained and provided funding for research
- JH assisted with obtaining ethics approval from McMaster University
- JH provided feedback on the data analysis and interpretation
- JH provided feedback on manuscript drafts and approved the final version published in the Journal of Attention Disorders

Chapter 3 (Study 2)

Ogrodnik, M., Karsan, S., & Heisz, J. (2023) Mental health in adults with ADHD: Examining the relationship with cardiorespiratory fitness. *Journal of Attention Disorders, 27*(7), 698–708. https://doi.org/10.1177/10870547231158383

M. Ogrodnik's role in Study 2:

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- SK served as second author and contributed to manuscript writing
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- JH assisted with obtaining ethics approval from McMaster University
- JH provided feedback on the data analysis and interpretation
- JH provided feedback on manuscript drafts and approved the final version published in the Journal of Attention Disorders

Chapter 4 (Study 3)

Ogrodnik, M., Karsan, S., Malamis, B., Kwan, M., Fenesi, B., & Heisz, J. (2023). Exploring barriers and facilitators to physical activity in adults with ADHD: A qualitative investigation. *Journal of Developmental and Physical Disabilities.* Advanced online publication. https://doi.org/10.1007/s10882-023-09908-6

M. Ogrodnik's role in Study 3:

- Created and developed research question and protocol (including semi-structured interview guide with key questions)
- Lead author on obtaining ethics approval from McMaster University
- Obtained permission from MHS to use CAARS tool
- Lead development of research protocol interview manual Contributed to study design and measure selection
- Conducted all interviews
- Lead author responsible for primary decisions for coding, analysis, and interpretation
- Primary author of manuscript

Role of co-authors in Study 3:

- SK coordinated participant interviews with lead author
- SK coded interviews and contributed to data analysis and interpretation
- SK served as second author and contributed to manuscript writing
- BM provided feedback on project conceptualization and ethics applications
- BM coded interviews and contributed to data analysis and interpretation
- BM provided feedback on final manuscript draft
- MK provided feedback about research question and protocol
- MK provided feedback on interview guide
- MK provided feedback on final manuscript draft

- BF provided feedback about research question and protocol
- BF provided feedback on final manuscript draft
- JH provided feedback about research question and protocol
- JH obtained and provided funding for research
- JH assisted with obtaining ethics approval from McMaster University
- JH provided feedback on the interpretation of the data
- JH provided feedback on manuscript drafts and approved the final version currently submitted to the Journal of Developmental and Physical Disabilities

CHAPTER 1:

INTRODUCTION

AUTHOR NOTE: Language and Perspectives on Disability

ADHD is often described as a neurodivergent profile (i.e., different from the "norm") in comparison to neurotypical peers (i.e., the "norm"). However, it is important to consider that neurodiversity or the idea that there are multiple means of neural expression should be the norm in and of itself—one "normal" neuro-profile may be an incorrect view. Even within the diagnostic label itself, including the word "disorder" in comparison to something such as "neuro-developmental variation" is worth communal reflection. While this thesis incorporates comparisons between those with and without ADHD and often describes those without ADHD as neurotypical as done commonly in the literature at the time of writing, it is important to acknowledge that views and perspectives on neurodiversity are, should, and will continue to shift; simultaneously, so too should language.

In addition, the current thesis describes participants as "those with ADHD" which grammatically structures itself as a person-first approach to describing disability. However, many disability advocates and scholars argue that taking an identity-first approach is more appropriate as it better aligns with their disability identity and experience; one does not separate "the person" from "their disability" as they are intertwined and interconnected self-concepts. Importantly, critiques of identity-first language also note that putting the disability label second suggests that disability is a "bad thing" when, in fact, disability is not a bad thing; rather it is ableist ideologies that create the negative connotation. However, unlike in the autistic community (i.e., a person with autism spectrum disorder (ASD) vs. being autistic) there is less consensus on disability first language for ADHD. Colloquially, some refer to themselves as "ADHDers" while others prefer to say, "I have ADHD," but explain how they do not see themselves as separate from their disability. Critically, when connecting with an ADHDer or someone who has ADHD, using the language that they prefer is important.

While the following thesis will focus on cardiorespiratory fitness and its association with ADHD symptom management (including executive dysfunction and mental health), it is important to acknowledge that support should be positioned as something that the individual may choose to use to help navigate through their day-to-day experiences in current society. However, the purpose of such support is not to "fix" or "cure" those with ADHD as having ADHD is not something to solve. Positioning a disability as something to cure or solve is ableist, connects to themes of eugenics, and is rooted in expectations that are not inclusive of difference. It is best to consider a world where each person, as they are, is recognized and celebrated. To consider designs and spaces where different means of expression and approaches align with a person's goals and needs. At the most rudimentary level, it is important to consider themes from the Social Model of Disability (Oliver, 1983). While an individual may have an impairment (e.g., they may not have as much inhibitory control as someone else) it may be the context (environment, expectations) that disables the person; in one context neurodivergence may be perceived as a "problem" whereas in another context it may be perceived as an incredible asset. Examples of supportive contexts include constructing environments and aligning expectations that focus on the individual's strengths (e.g., valuing the creativity and different perspectives that come from considering different ideas other than the task at hand) or providing the individual with opportunities to do things differently (e.g., flexible schedules and deadlines).

Great disability advocates and scholars have more nuanced, in-depth analyses and critiques of the Social Model of Disability. While their reflections are beyond the scope of this thesis, it is important that when evaluating support strategies researchers prioritize the wants and goals of disabled persons and their community within the bigger societal context. The discussions in this document about the associations and potential impact of cardiorespiratory fitness on cognitive outcomes are meant to explore a possible additional strategy that one can add to their toolbox to navigate ADHD symptom challenges as they see fit; however, this is just one step. Creating and providing support must be done alongside major societal shifts that are more inclusive of neurodivergence.

1.1 Defining Attention Deficit Hyperactivity Disorder (ADHD)

1.1.1 Symptoms, Diagnostic Criteria, Developmental Trajectory, and Prevalence

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by consistent patterns of inattention and/or hyperactivity and impulsivity that negatively impact daily functioning (American Psychiatric Association, 2013). The Diagnostic and Statistical Manual of Mental Disorders: 5^{th} Edition (DSM-5) has criteria for both children and adults (American Psychiatric Association, 2013), which are used by medical doctors or psychologists to diagnose patients. Interestingly, ADHD is the most common neurodevelopmental disorder diagnosed in children with approximately 6% of children and 3-5% of adults diagnosed worldwide (Faraone et al., 2021; Song et al., 2021). As per the DSM-5, for children under 17 years of age symptoms must be present for at least six months and be inappropriate for their developmental stage. When completing assessments, six or more of the nine symptoms listed in the DSM-5 for inattention are typically present. Examples of symptoms include poor attention to detail, challenges with sustaining attention and being easily distracted, difficulties with organization, and limited ability to follow through on tasks (See DSM-5 for the full list of symptoms). Six of the nine symptoms for hyperactivity and impulsivity are also typically met; examples of symptoms include fidgeting, high levels of energy, challenges waiting, and interrupting others. Concerning an adult ADHD diagnosis, similar criteria listed above are used; however, adults must only meet five of the nine symptoms listed rather than six. Importantly, the DSM-5 requires that symptoms must be present in multiple settings, evident over the last six months, and have been present before the age of 12 years old. Symptoms must cause impairment to the person, including in academic, occupational, or social settings. While there are two main categories of symptoms assessed, the DSM-5 lists three subtypes of presentation that can occur: 1) predominantly inattentive, 2) predominantly hyperactive-impulsive, and 3) combined. However, the DSM-5 notes that symptoms can present differently across the lifespan; this, in turn, means that the associated subtype can also vary throughout childhood and into adulthood.

ADHD has been described as a chronic condition (American Psychiatric Association, 2013; Pozzi et al., 2020). While some children with ADHD experience remission or partial remission (a reduction in their symptoms), many experience symptoms persistently into adulthood (Sibley et al., 2022) with some estimates suggesting that as many as 60%-65% of childhood cases continue into adulthood (Kessler et al., 2005; Owens, Cardoos & Hinshaw, 2015; Wesemann & Van Cleve, 2018). However, not all people with ADHD are diagnosed in childhood. This may be, in part, due to the diagnostic criteria and process for which children are often flagged for assessment. For example, a child who presents as primarily hyperactive-impulsive and who may cause the “greatest disruptions” to classroom spaces or at home, may more readily be flagged by teachers and parents. In contrast, a child who is primarily inattentive but able to maintain classroom norms and academic performance may be more readily missed.

Symptoms of inattention or hyperactivity-impulsivity may present differently in an adult context (American Psychiatric Association, 2013). For example, rather than acting inappropriately impulsive in classroom settings, adults may demonstrate impulsivity in personal spending habits. While inattention in children may look like missing details on homework tasks or forgetting assignments, adult inattention may take the form of forgetting to cancel free trials and ending up having to pay subscription fees for things they no longer want. Consequently, when compared to neurotypical peers, adults with ADHD tend to have higher financial stress and poorer financial well-being alongside lower occupational achievement and impaired work performance (Bangma et al., 2019; Biederman et al., 2006; Brook et al., 2013; Canu et al., 2021; Fletcher, 2014; Goffer et al., 2022; Halleland et al., 2019; Katzman et al., 2017; Kuriyan et al., 2013). Importantly, the impacts of ADHD symptoms can stretch beyond financial troubles. Adults with ADHD also report lower quality of life (Lee et al., 2016; Sjöwall & Thorell, 2022; Stern et al., 2017). Furthermore, work by London & Landes (2016) found an increased risk of mortality for those with ADHD, even after controlling for sociodemographic factors, and noted that accidental death is more common for individuals with ADHD.

Although ADHD is the most common neurodevelopmental disorder, its exact prevalence remains unclear for a few reasons. One major factor is that estimates depend on diagnostic methods, which can differ across geographical and cultural regions. Some suggest that we may be underestimating the prevalence of ADHD particularly for those with inattentive subtypes, including girls and women (London & Landes, 2021; Martin et al., 2018). On the contrary, prevalence rates of ADHD diagnosis in North America have been on the rise since the late 1990s (Gascon et al., 2022), with United States data reporting a more than 4% increase in children and adolescents diagnosed with ADHD between 1997 and 2016 (Xu et al., 2018). Likewise, during a similar period in Canada (1999-2021), researchers have found an increase in ADHD diagnosis in children (age 1-

17 years) and young adults (18-24 years), for both males and females (Vasiliadis et al., 2017). While there has historically been a gender gap in ADHD diagnosis—with boys being more commonly diagnosed than girls given they more frequently present with hyperactive symptoms—recent data from the United States has documented a rise in the number of cases of adult women being diagnosed with ADHD, which is closing that gap (London & Landes, 2021). Critique on whether there is now an over-diagnosis of ADHD has been brought into question citing concerns with the diagnostic criteria, clinical practice, and the overemphasis on "performance" as a central pillar of Western culture (Gascon et al., 2022). More research is needed including studies that span multiple geographic locations, account for different identities (e.g., age, gender, ethnicity), cultures, and access opportunities (e.g., access to health care coverage, socioeconomic status) to have a more fulsome understanding of the true prevalence and incidence rates (Espinet et al., 2022).

1.1.2 Etiology and Brain Differences

ADHD is considered a neurobiological disorder, however, its etiology is unknown and likely diverse (Núñez-Jaramillo et al., 2021). The World Federation of ADHD International Consensus Statement argues that "most cases of ADHD are caused by the combined effects of many genetic and environmental risks" (Farone et al., 2021). Possible genetic factors include genetic mutations resulting in lower levels of brain-derived neurotrophic factor (BDNF) or other neurotrophins (e.g., endothelial growth factor, insulin-like growth factor etc.) and genetic mutations that lead to poor functioning of the dopaminergic system (Núñez-Jaramillo et al., 2021). Differences in dopamine and catecholamine systems are often at the root of etiological investigations and impairments in these systems are tied to cognitive deficits and impaired "reward" system functioning (Chuang et al., 2017; Mehta et al., 2019). Concerning environmental factors, possible factors include premature or traumatic events during birth, severe traumatic brain injuries, maternal diet during pregnancy, and exposure to heavy metals or certain pesticides during development (Farone et al., 2021; Núñez-Jaramillo et al., 2021). Importantly, stress, trauma, and poverty have also been documented as environmental factors (Farone et al., 2021). Finally, researchers have been exploring ADHD etiology from a bio-psycho-social perspective, connecting early and high exposure to stress and trauma with high levels of inflammation in the body, and suggesting that systemically high levels of inflammation may play a role in the etiology of ADHD (Saccaro et al., 2021).

There have been documented structural and functional differences in the brains of those with and without ADHD (Farone et al., 2021). While more research is needed, there are structural differences in areas of the brain responsible for movement and cognition including reductions in the volume of the cerebellum and decreases in the volume and thickness of the anterior cingulate cortex (see Mehta et al., 2019). However, these differences are typically small (Farone et al., 2021). Dysfunctional processing in attentional networks (Cortese et al., 2012) and hypoperfusion—reduced blood flow—to different regions including the amygdala (Tan et al., 2019) have also been observed in individuals with ADHD compared to those without ADHD. Of particular importance are differences in the prefrontal cortex where ADHD is associated with hypoperfusion along with less neural activity and less white and grey matter volume (Mehta et al., 2019; Skalski & Dobrakowski, 2020).

1.1.3 Executive Dysfunction

Given these notable differences in the prefrontal cortex (Mehta et al., 2019), it is not surprising that a core symptom of ADHD manifests as deficits in the cognitive functions that are supported by the prefrontal cortex including higher-order top-down cognitive processes that drive goal-oriented behaviour, aptly named executive functions (Baggetta & Alexander, 2016; Onandia-Hinchado et al., 2021; Silverstein et al., 2020). The core executive functions include working memory, cognitive flexibility, and inhibitory control (Diamond, 2013).

Working memory describes one's ability to keep relevant information in mind while managing other cognitive demands (Baddeley & Hitch, 1974; Cowan, 2014). In practice, using working memory may look like remembering to add something to your to-do list while finishing up your current email, holding a mental map of your navigational route in mind while driving, or remembering a phone number while looking for your phone to dial it. Common lab-based tests to evaluate working memory include the Operation or Reading Span Tasks, the n-back task, or digit span tasks (Conway et al., 2005; McMorris, 2016). Cognitive flexibility represents one's ability to transition between cognitively demanding tasks (Miles et al., 2021). Better cognitive flexibility supports applied scenarios such as transitioning between activities and thinking creatively. Lab-based assessments of cognitive flexibility include the Wisconsin Card Sorting task, the Tower of London Task, and the Trail Making task. Finally, inhibitory control is one's ability to override a prepotent response to a distraction (Friedman & Miyake, 2004; Mirabella, 2021). Applied examples of inhibitory control can include ignoring distractors in a classroom or thinking through how to respond or react to a situation, rather than acting in the "heat of the moment." Lab-based tests that assess inhibitory control include go/no-go tasks, flanker tasks, stop-signal tasks, the Simon task, and the Stroop task. Not surprisingly, inhibitory control supports one's ability to keep attention focused on a given task (Diamond, 2013). For those with ADHD, deficits in inhibitory control have been described as the "hallmark" or primary executive dysfunction (Chmielewski et al., 2019; Wodka et al., 2007).

Previous research on children with ADHD has documented worse performance on many tasks of executive functioning. For example, compared to neurotypical children, children with ADHD have poorer cognitive flexibility, processing speed, reaction time variability, working memory, alertness, and greater distractibility (e.g., Miklós et al., 2019; Sjöwall et al., 2013). Like children, deficits in executive functioning have also been noted in adults with ADHD, though in general, adults with ADHD have been less well-studied (e.g., Alderson et al., 2013; Boonstra et al., 2005; Jarrett, 2016; Marx et al., 2010; Müller et al., 2007). Critically, executive dysfunction can disrupt many different aspects of life including decision-making (Mäntylä et al., 2012), one's ability to manage competing demands (Roshani et al., 2020), and overall sustained focus (Salmi et al, 2018). This, in turn, can have negative impacts on long-term outcomes including lower academic achievement and occupational attainment (e.g., Canu et al., 2021; DuPaul et al., 2009; Goffer et al., 2022; Halleland et al., 2019).

1.1.4 Comorbid Poor Mental Health and Mental Illness

It has been estimated that at some point in their lives, approximately 80% of adults with ADHD will experience psychiatric comorbidities (Jensen & Steinhausen, 2015; Klassen et al., 2010) such as major depressive disorder, anxiety disorders, substance use disorders, and personality disorders (Katzman et al., 2017). That rate is higher in people with ADHD than in the general population (Hesson & Fowler, 2018), and increases with age and ADHD symptom severity (Saccaro et al., 2021). Greater ADHD symptom severity is also associated with greater perceived stress and lower emotional well-being (Miklósi et al., 2016).

Psychiatric comorbidities in ADHD have serious health consequences. For example, research from Sweden found that those with ADHD had a greater risk of premature death, which was associated with psychiatric comorbidities (Sun et al., 2019). In their sample, the time of onset of the psychiatric comorbidity was important when evaluating the relationship with the risk of death. Among those with early-onset ADHD, premature death was primarily associated with natural causes; however, among those with late-onset ADHD, premature death was mainly associated with suicide, unintentional injury, and other unnatural causes. Other research has documented similar grim statistics. Using cross-sectional data, Fuller-Thomson and colleagues (2022) found that “one in seven adults with ADHD have attempted suicide, in comparison to one in 37 adults without ADHD.”

Given that our current society is rooted in both capitalistic views (i.e., the need to consistently work to produce output) and neurotypical expectations (i.e., the consistent reliance on executive functioning to produce these outputs), it is not surprising that those with ADHD can struggle to meet these standards and their well-being suffers because of it. However, psychiatric comorbidities can make diagnosing ADHD challenging. When diagnosing ADHD, the practitioner must ensure that the symptoms described by the patient would “not be better explained by another mental disorder” including mood, anxiety, or personality disorders (American Psychiatric Association, 2013). However, the emotional dysregulation attributed to ADHD symptomology can be misdiagnosed as a mood disorder, for example (Alexander & Harrison, 2013; Katzman et al., 2017). This, in turn, can lead to treating symptoms of the mood disorder, which can be promising, but may not be the driving concern. Even when both an ADHD and comorbid diagnosis are noted, it can be challenging for practitioners to create a treatment plan. Typically, patients are medicated for whatever is presenting with the most severe symptoms (Katzman et al., 2017); however, treating one diagnosis does not always mean improvements in the other. For example, some ADHD medications can exacerbate depressive symptoms (Miklós et al., 2019).

1.1.5 Standard Care for ADHD Symptom Management

The most common approach to symptom management for both children and adults with ADHD is pharmacotherapy (Adler & Nierenberg, 2010; Biederman et al., 2017; Charach & Fernandez, 2013; Meppelink et al., 2016; Stueber & Cuttler, 2022). Stimulant medications that target the central nervous system are most often prescribed as the first line of support, with main ingredients commonly including amphetamines (aka Adderall), methylphenidates (aka Concerta or Ritalin), or lisdexamfetamine (aka Vyvanse; Bolea-

Alamañac et al., 2014; Pozzi et al., 2020). These stimulant medications work to increase neurotransmitters including dopamine and norepinephrine, which in turn can support executive functioning and other symptom management. Stimulants have also been documented to "normalize" hypoperfusion in prefrontal areas and, in turn, improve associated symptoms (Katzman et al., 2017). It has been estimated that approximately 60% of children with ADHD manage their symptoms with medication at some point (Danielson et al., 2018). In adults, approximately seven percent use medication for symptom management (Compton et al., 2018).

However, ADHD medications often come with a host of side effects including stomach aches, poor appetite, headaches, sleep problems, high blood pressure, and mood disturbances (Cascade et al., 2010; Rajeh et al., 2017; Sinha et al., 2016; Stueber & Cuttler, 2022; Pan et al., 2022). These negative side effects have been documented to be the driving factor as to why many people stop taking their medication (Gajria et al., 2014; Toomey et al., 2012). Sometimes, users or parents will even plan "drug holidays" to manage the side effects of medications (Ibrahim & Donyai, 2015). Instances of poor medication adherence have been noted for both children and adults with ADHD (Charach et al., 2004; Safren et al., 2007). Importantly, medication is a day-by-day intervention meaning that if one does not take medication on a given day, their symptoms will re-emerge (Lohr et al., 2021). Even further, some users do not respond to ADHD medications (Geladé et al., 2017). As such, many people with ADHD seek alternative supports to manage their symptoms.

1.2 Movement as a Therapeutic Support for ADHD

Physical movement has been identified as one of the best non-pharmacological approaches to managing ADHD symptoms (Den Heijer et al., 2017; Gapin et al., 2011; Lambez et al., 2020; Ng et al., 2017; Suarez-Manzano et al., 2018) and mental health comorbidities such as depression and anxiety (Kim et al., 2012; Mason & Holt, 2012; Mikkelsen et al., 2017; Stubbs et al., 2018); and may be particularly useful given it is accessible (e.g., lower cost, safe; Christiansen et al., 2019; Ganjeh et al., 2022) with minimal side effects (Vina et al., 2012). The research on movement described below includes *physical activity*, defined as any bodily movement produced by skeletal muscles that results in energy expenditure beyond resting levels, and *exercise*, defined as a planned and structured movement with the intention to maintain or improve an aspect of physical fitness (American College of Sports Medicine, 2018; Caspersen et al., 1985). Importantly, the field often uses both terms interchangeably, favouring language around *acute* and *chronic* exercise to differentiate between a single bout of movement at a single time point versus multiple bouts of movement repeated over time. Chronic exercise increases physical fitness, which is hypothesized to underlie key neurophysiological changes that support cognition and mental health; however, not all protocols used by researchers studying ADHD have outlined the specific intention to maintain or improve physical fitness. As such, physical activity is primarily used instead of exercise as it may be "a more conceptually appropriate descriptor" (Pontifex et al., 2019). Section 1.2.1 describes the research on physical activity, and Section 1.3 focuses more specifically on physical fitness.

1.2.1 Acute and Chronic Physical Activity, Executive Functions, and Mental Health

Aerobic physical activity, defined as activity that increases the use of the cardiorespiratory system, has been the most commonly investigated type of physical activity in research examining cognition and ADHD (Den Heijer et al., 2017. Common forms of aerobic activity include walking, running, cycling, or swimming. While more research is needed, acute and chronic aerobic physical activity interventions benefit both executive functions and mental health in people with ADHD.

In children with ADHD, acute physical activity has been documented to improve the three domains of executive functioning including cognitive flexibility, working memory, and inhibitory control, with small to moderate effects (Benzing et al., 2018; Chan et al., 2022; Chang et al., 2012a; Den Heijer et al., 2017; Gawrilow et al., 2016; Grassmann et al., 2016; Montalva-Valenzuela et al., 2022; Neudeck et al., 2019; Pontifex et al., 2013; Sibbick et al., 2022; Villa-González et al., 2020; Vysniauske et al., 2020; Yu et al., 2020). Although less work has been done in adults with ADHD similar benefits of acute physical activity on executive functions have been noted (Gapin et al., 2015; LaCount et al., 2022; Mehren et al., 2019). Only two studies have evaluated the acute effects of physical activity on mental health for adults with ADHD, observing reduced depressive symptoms following cycling protocols (Fritz & O’Connor, 2016; LaCount et al., 2022). In all cases, moderate or moderate-to-vigorous aerobic activities seem to be most beneficial. However, the acute impacts of physical activity are typically transient, with estimates suggesting benefits for up to only two hours for cognition and 24 hours for mental health (Basso &

Suzuki et al., 2017). As such, chronic physical activity effects are also of interest given the potential for longer-term adaptions.

Among children and adolescents with ADHD, those meeting the 24-hour movement guidelines tend to have fewer cognitive difficulties (Taylor et al., 2023). Moderate to vigorous chronic physical activity interventions improve executive function, with longer interventions yielding greater improvements (Chang et al., 2014; Cerrillo-Urbina et al., 2015; Kamp et al., 2014; Huang et al., 2023; Suarez-Manzano et al., 2018; Vysniauske et al., 2020; Welsch et al., 2021; Xie et al., 2021). Chronic physical activity has been described as a valuable supplementary treatment option for children with ADHD that may be particularly potent in benefitting inhibitory control (Liang et al., 2021; Welsch et al., 2021), while also reducing symptoms of anxiety and depression (Cerrillo-Urbina et al., 2015; Da Silva et al., 2020; Zang, 2019).

Likewise, adults with ADHD who are more physically active suffer from less self-reported behavioural impulsivity (Abramovitch et al., 2013); they also report less worry, fewer intrusive thoughts, and more positive affect (Abramovitch et al., 2013; Koch et al., 2022). However, there have been very few chronic physical activity interventions conducted on adults with ADHD, and most have been completed only recently. For example, one study assessed a six-week yoga intervention for women with ADHD and reported no improvement in executive function (Fritz & O’Connor, 2022). Another study assessed a 24-week Pilates intervention for adults with ADHD; while they found immediate improvements in executive functions, improvements were not all sustained at the six-week follow up (Kouhbanani et al., 2022). With respect to mental health, Fritz and

O'Connor (2022) reported no changes in mood while Kouhbanani and colleagues (2022) did not report on mental health measures. Importantly, unlike yoga and Pilates, many of the chronic interventions conducted in children that report benefits to executive functioning or mental health incorporate more moderate to vigorous aerobic-based activities. As such, more aerobic-based interventions at greater intensities may be needed to impact executive functioning and mental health.

1.3 The Role of Cardiorespiratory Fitness

1.3.1 The Cardiorespiratory Hypothesis

The positive impacts of chronic aerobic physical activity on the brain are largely attributed to the adaptive changes it makes to the cardiorespiratory system and the corresponding increases in cardiorespiratory fitness (CRF), the body's ability to intake and circulate oxygen throughout the body to meet task demands (Caspersen et al., 1985). While CRF is genetically linked, it is also associated with physical activity (Fritz & O'Connor, 2018; Miyamoto-Mikami et al., 2018; Teran-Garcia et al., 2008) with increases from longer engagement at moderate to vigorous intensities (Klevjer et al., 2023; Gormley et al., 2008; Scribbans et al., 2016). At a physiological level, increased CRF coincides with structural and functional adaptations that increase blood volume, cardiac performance, and angiogenesis (Raghuveer et al., 2020). These adaptions occur throughout the body and brain, and importantly a recent systematic review by Salzman and colleagues (2022) found that adults with higher fitness had greater cerebral oxygenation.

The data support a cardiorespiratory hypothesis whereby chronic physical activity improves cognitive functioning because it increases CRF and cerebral oxygenation (Agbangla et al., 2019; Salzman et al., 2022). Stimpson and colleagues (2018) delineate this relationship as it relates to cardiovascular fitness, a subset of cardiorespiratory fitness that focuses on the heart and blood vessels and arteries. First, chronic engagement in physical activity improves cardiovascular fitness, which can improve cerebral angiogenesis (the development of new blood vessels) and circulation. Improved vasculature and circulation promote increases in cerebral blood volume, cerebral oxygenation, and support the upregulation of neurotrophins and neurotransmitters. Finally, it is hypothesized that better circulation and access to necessary resources facilitate improved cognitive function. Stimpson and colleagues also describe the longer-term impacts of improved cerebral vasculature including increased brain plasticity and positive structural changes that elicit cognitive benefits.

1.3.2 CRF, Executive Functions, and Mental Health

While researchers comment that there are likely many different paths that contribute to chronic physical activity-cognitive interactions, improvements in CRF may be an important component. Generally, in neurotypical children and adolescents, higher CRF is associated with better academic performance (Álvarez-Bueno et al, 2020) and executive functioning (Bento-Torres et al., 2019; Chaddock et al., 2012; Dupuy et al., 2015; Kao et al., 2016; Meijer et al., 2021; Van Waelvelde et al., 2020), and the two are likely related (Visier-Alfonso et al., 2021; Yangüez et al., 2021). Higher CRF is also associated with better mental health (Gianfredi et al., 2021; Kandola et al., 2019; Schuch et al., 2016), especially for those experiencing high stress (Gerber et al., 2013). But, again, this has only been demonstrated in neurotypical populations. Therefore, given that adults with ADHD experience executive dysfunction (Alderson et al., 2013; Jarrett, 2016; Marx et al., 2009; Mohamed et al., 2021) and greater incidents of mental illness (Hesson & Fowler, 2018), the relationship between CRF and executive function, and mental health is of particular interest in this population. However, limited research has been done to examine the connection between CRF and executive functioning in adults with ADHD. At the time of this dissertation, only two studies have been conducted. One study by Jeoung (2014) noted positive associations between self-reported symptoms of executive dysfunction and fitness in adult men with ADHD. The other study by Mehren and colleagues (2019) found positive associations between CRF and inhibitory control performance (as measured by the Flanker Task). However, these studies are not without limitations. Jeoung (2014) did not objectively assess executive function and while Mehren and colleagues (2019) did, they only examined inhibitory control and did not examine the other two executive functions, working memory and mental flexibility. As such, more research was needed to understand the association between CRF and executive functioning in adults with ADHD. Furthermore, to the best of the author's knowledge, the association between CRF and mental health had yet to be investigated for adults with ADHD. The first and second aims of this thesis were to help fill those two gaps.

Given the potential benefits of CRF on executive function and mental health, it is important to consider how to best implement a program of chronic physical activity that has the potential to increase CRF in adults with ADHD. Unfortunately, in both children and adults, the presence of ADHD and greater ADHD symptom severity coincides with lower CRF (Fritz & O'Connor, 2018; Jeoung, 2014; Jeyanthi et al., 2019; Muntaner-Mas et al., 2020) and less participation in physical activity (Fritz & O'Connor, 2018; Mercurio et al., 2021). Therefore, understanding why people with ADHD are less physically active is important, especially the unique barriers and facilitators they face because of their ADHD symptoms. However, no study had explored this in adults with ADHD.

1.4 Objectives and Hypothesis

1.4.1 General Purpose of Dissertation

The purpose of this dissertation was to first explore the associations of CRF with executive functions and mental health in an adult ADHD population, and then understand the unique barriers and facilitators adults with ADHD face when trying to be more physically active as a promising interventional support strategy for increasing CRF.

1.4.2 Specific Objectives and Hypotheses

The specific objectives and hypotheses for each study included in this dissertation were to:

Study 1 – The objective of Study 1 was to examine the cross-sectional differences and associations between CRF and executive functioning outcomes (working memory, cognitive flexibility, and inhibitory control) in adults with ADHD and controls. It was hypothesized that those with ADHD would have poorer performance on all three measures of executive functioning compared to controls. It was also hypothesized that higher CRF would be associated with better performance on all executive functions and that these associations would be stronger for adults with ADHD than controls.

Study 2 – The objective of Study 2 was to examine the cross-sectional differences and associations between CRF and mental health outcomes (depression, anxiety, and perceived stress) in adults with ADHD and controls. It was hypothesized that those with ADHD would have worse mental health than controls and that higher CRF would be associated with better mental health and that these associations may be stronger for adults with ADHD than controls.

Study 3 – The objective of Study 3 was to document the barriers to and facilitators to physical activity as identified by adults with ADHD via semi-structured interviews. It was hypothesized that adults with ADHD would have unique barriers associated with their ADHD symptoms.

1.5 Context of the Dissertation: COVID-19

It is important to note that the data collected for each study of this dissertation occurred during the COVID-19 pandemic. To conduct research during this time, research protocols were developed to be adaptable to the ever-changing public health measures, including lockdown measures that restricted in-person contact with anyone outside of one's household. Consequently, these unprecedented conditions constrained the research methods that were used. For example, the gold-standard way to measure CRF is using a VO_{2max} test (Fletcher et al., 2001); however, such tests require substantial in-person contact and would have been incompatible with public health measures. As such, an estimated CRF protocol was used because the participant could complete it independently. COVID-19 health and safety measures also impacted responses to measures of physical activity. Based on pre-pandemic research, the 7-Day Physical Activity Recall interview provides useful estimates of habitual physical activity (Blair et al., 1985; Steinhardt & Dishman, 1989); however, during data collection, the participants assessed here voiced unique constraints concerning self-isolation and safe access to public spaces. Therefore, although the 7-Day Physical Activity Recall interview was collected the analyses for Studies 1 and 2 rely exclusively on CRF. Further discussion of the impact of COVID-19 on the program of research is described in Section 5.2 of the General Discussion.

1.6 Summary

Three different research projects were completed to better understand the associations between CRF and executive functioning (Study 1) and mental health (Study 2) in adults with ADHD. Given that those with ADHD tend to be less fit and less physically active than the general population (Fritz & O'Connor, 2018), potential barriers and facilitators to getting physically active were identified via semi-structured interviews with adults with ADHD (Study 3). Each study is presented in detail via their published manuscripts in the following three chapters and followed by a general discussion. The general discussion synthesizes key findings and highlights the importance of this work for researchers and physical activity professionals working in the fields of health and exercise psychology and ADHD. Future research directions and broader societal considerations are also discussed.

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CHAPTER 2:

Exploring the relationship between cardiorespiratory fitness and executive functioning in adults with ADHD

Preamble

Exploring the relationship between cardiorespiratory fitness and executive functioning in adults with ADHD serves as the first study in this dissertation. This study examined cross-sectional associations between cardiorespiratory fitness and executive function, for those with and without ADHD.

The chapter is included in manuscript form, which has been published in *Brain Science*. The manuscript is formatted in alignment with the author guidelines for *Brain Science* and is included as accepted for publication. The published version of this manuscript can be found at: https://doi.org/10.3390/brainsci13040673

Contributions of Study 1 to the overall dissertation

Executive dysfunction is a common challenge for adults with ADHD. However, current research suggests that physical activity may be a useful support to help boost executive functioning. While some research has documented the benefit of acute and chronic physical activity on executive functioning in an adult ADHD sample, there is limited research that has investigated the relationship between aerobic adaptations that accompany chronic physical activity engagement—known as cardiorespiratory fitness—and executive functioning in this population. To the authors' knowledge, Study 1 is the first study to examine the relationship between estimated cardiorespiratory fitness and three domains of executive functioning as measured via lab-based assessments for adults with and without ADHD. While mean performance on measures of executive function did not differ by group, data support an association between higher estimated cardiorespiratory fitness and incongruent trial accuracy on the Stroop task, a measure of inhibitory control.

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Exploring the Relationship between Cardiorespiratory Fitness and Executive Functioning in Adults with ADHD

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Abstract: Objective: Associations between measures of executive functioning (EF) and cardiorespiratory fitness (CRF) were examined for adults with and without ADHD. Method: Measures of executive functioning including the Stroop task, Wisconsin Card Sorting task, and Operation Span Task were completed virtually (n = 36 ADHD; n = 36 Control). Participants completed the Six-Minute Walk Test to estimate CRF. Results: Mean performance measures of executive function did not differ by group. However, higher estimated CRF was associated with better Stroop task performance, and the association was strongest for individuals with ADHD. Conclusion: In adults with ADHD, higher estimated CRF was associated with better inhibitory control, but not with other measures of executive functioning.

Keywords: ADHD; adults; executive function; cardiorespiratory fitness

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Citation: Ogrodnik, M.; Karsan, S.; Cirone, V.; Heisz, J.J. Exploring the Relationship between Cardiorespiratory Fitness and Executive Functioning in Adults with ADHD. *Brain Sci.* **2023**, *13*, 673. https://doi.org/10.3390/brainsci13040673

Academic Editors: Joseph Sadek and Fengyu Zhang

Received: 6 March 2023
Revised: 4 April 2023
Accepted: 13 April 2023
Published: 17 April 2023

1. Introduction

Attention deficit hyperactivity disorder (ADHD) is one of the most common neurodevelopmental disorders affecting approximately six percent of children and three percent of adults worldwide [1]. A core symptom of ADHD is executive dysfunction [2], which disrupts decision-making [3], sustained focus [4], and the ability to manage multiple competing demands [5]. Unfortunately, societal norms are built on the premise that everyone's executive functioning is always operating optimally, and consequently, those with ADHD often experience real-world problems. For example, children with ADHD participate less in class, have a lower retention capacity for learning, and struggle to perform well on tests compared to their neurotypical peers [6]. These challenges in childhood can persist into adulthood, limiting future academic achievement and occupational attainment [7–9], and can negatively impact their quality of life [10,11]. Alongside societal shifts towards inclusivity, it is critical to consider immediate and accessible supports that can help people with ADHD manage their executive dysfunction. Most research on ADHD has focused on children and adolescents, even though the recent criteria for ADHD describe it as a chronic condition that often persists into adulthood [12,13]. Therefore, it is important to understand how to best support executive dysfunction in adults with ADHD, which was the aim of the present study.

Executive dysfunction associated with ADHD can arise from an impairment in one of three executive functions: inhibitory control, cognitive flexibility, or working memory. Inhibitory control refers to one's ability to override an automatic or prepotent response to a stimulus [14], and has been described as the hallmark of executive dysfunction for those with ADHD [15]. Cognitive flexibility refers to one's ability to transition accurately and efficiently between cognitively demanding tasks [16]. Working memory refers to one's capacity to keep relevant information in mind when completing a cognitive task [17]. When compared to neurotypical children, those with ADHD perform worse on a range of tasks that depend on executive functions including having greater variability in reaction times on tasks of alertness, making more errors on tasks of distractibility, and having poorer overall cognitive flexibility [18]. Research on adults with ADHD parallel that of children, with some evidence indicating that executive dysfunction is a part of the chronic symptomology [19–21]. For example, adults with ADHD self-reported difficulty with cognitive flexibility and performed poorly on the Iowa Gambling Task [5], during which they struggled to select the optimal solution to a problem when multiple competing options were available and made more impulsive decisions (i.e., had faster reaction times) on questions that assessed risk-taking behaviour.

The most common intervention for ADHD symptoms is pharmacotherapy [22]. Approximately 60% of children diagnosed with ADHD take medication at some point to manage their symptoms [23]. The most prescribed ADHD medications are stimulants that increase dopamine levels in the brain, which the prefrontal cortex needs to optimally perform its suite of executive functions [12,24]. Pharmacotherapy is also the front-line treatment for adults with ADHD and it can improve many domains of executive function [25]; however, there are also multiple points of concern. Across the board, children and adults with ADHD have poor adherence to their prescribed medication. Over 60% of children failed to adhere to their prescribed medication schedule over five years [26] and approximately 18% of adults failed to adhere to their prescribed medication schedule over two weeks [27]. Unfortunately, when individuals do not take their medication, symptoms of executive dysfunction can return [28]. ADHD medication can also give rise to negative side effects including appetite suppression, insomnia, irritability, and increased blood pressure [29,30], and this is the main reason why most people discontinue medication use [31]. Finally, there are concerns regarding the long-term use of ADHD medication, including safety and efficacy [32]. Taken together, it is not surprising that only approximately seven percent of adults with ADHD take medication [33]. As such, there is a critical need for alternative strategies to help adults with ADHD manage their symptoms.

Physical activity has been identified as one of the best non-pharmacological interventions for managing ADHD symptoms [34,35]. Physical activity can increase levels of dopamine and improve prefrontal functioning [36,37], thus having a similar intended pharmacotherapeutic effect as ADHD medications [38]. An acute bout (~30 min) of physical activity can improve executive functioning in children [39–41] and adults with ADHD [42–44] as well as in neurotypical children and adults [45,46]; however, most of the research on physical activity for ADHD has been conducted in children.

The beneficial effects of an acute bout of physical activity for executive dysfunction in children are noteworthy. An acute bout of physical activity in children with ADHD has been documented to elicit significant improvements in inhibitory control, cognitive flexibility, and working memory [40,47–49], with some research reporting positive effects on inhibitory control after just five minutes of physical activity [50]. Although more research is needed in adults with ADHD [39], there is some evidence demonstrating that acute physical activity benefits executive functions [42,43]. College-aged students with ADHD were tested and found that a 30-min acute bout of jogging improved all three domains of executive function but elicited the greatest benefit for inhibitory control [42]. More recently, adults with ADHD completed a high-intensity interval cycling protocol for a total of 16 min. Following their protocol, adults with ADHD showed improvements in processing speed and decreased reaction time variability as measured by the AX-Continuous Performance Test, which assesses goal maintenance abilities and working memory [43].

With respect to the chronic effects of regular engagement in physical activity on executive functions, even less is known about the effects in adults with ADHD. Engaging in chronic physical activity can improve cardiorespiratory fitness (CRF), defined as the circulatory and respiratory systems' ability to supply oxygen to the skeletal muscles for energy production [51]. Previous research has noted that neurotypical children and adults with higher CRF have better inhibitory control, cognitive flexibility, and working memory [52–54]. The same is true for children with ADHD [49,55–57]. In children with ADHD, 8 weeks of aerobic training resulted in better inhibitory control [58] and 12 weeks of aerobic training resulted in better inhibitory control, cognitive flexibility, and working memory [59]. In children and adolescents with ADHD, a 2023 meta-analysis highlighted that chronic exercise interventions have small-to-moderate effects on inhibitory control, working memory, and cognitive flexibility, with the greatest improvements for inhibitory control [57]. While these papers did not measure changes in fitness directly, improved CRF is a result of chronic physical activity, and prior research in neurotypical individuals points to CRF as a component of the mechanism through which physical activity improves executive functions [60,61].

In adults with ADHD, we are only aware of two prior studies that have examined the relationship between CRF and executive functions specifically. In one study, Jeoung (2014) explored the association between CRF and measures of self-reported executive dysfunction including inattention/memory, hyperactivity/restlessness, and impulsivity/emotional lability in men with ADHD. They found that those with higher CRF had fewer self-reported symptoms of executive dysfunction. However, this research is limited because it did not include women with ADHD, nor did it include objective assessments of executive functioning [62]. In the other study, Mehren and colleagues (2019) explored the association between CRF and inhibitory control performance on the Flanker Task in men and women with ADHD and found that those with higher CRF had better inhibitory control performance; however, this paper did not assess other two domains of executive function, namely, cognitive flexibility or working memory [44].

The present study was designed to fill these gaps by investigating the relationship between CRF and three domains of executive functioning in adults with ADHD. We examined cross-sectional differences between adults with and without ADHD on performance measures of inhibitory control, cognitive flexibility, and working memory. We used an objective estimate of CRF and assessed whether it predicted performance on each measure of executive function. We also explored whether the association between CRF and executive functions differed by group (ADHD vs. Control). It was hypothesized that adults with ADHD would have poorer performance across all three domains of executive functioning. It was also expected that participants with higher CRF would have better executive functioning across all three domains, but the associations would be stronger for adults with ADHD. Previous research reveals stronger relationships between fitness and cognition in individuals with greater executive dysfunction (i.e., older adults) compared to those with less executive dysfunction (i.e., neurotypical younger adults) [63]. Therefore, we hypothesized that adults with ADHD may have a stronger relationship between fitness and cognition because of their executive dysfunction. Since executive dysfunction has significant negative impacts on daily living [8] and adults with ADHD are understudied [39], the present work provides important baseline data for understanding an accessible way to potentially help manage ADHD symptoms.

2. Methods

2.1. Participants

Previous research using this data set, including an overview of the participants, is provided in Ogrodnik et al. (2023) [64]. This project was approved by the McMaster Research Ethics Board (Project ID 5111). Adults between 18 and 35 years old were recruited to complete this study (May 2020–February 2022) and they received monetary compensation. Participants needed to be able to read, write, and speak English. As the experimental protocol included the Stroop task (described below), participants were deemed ineligible if they had a known diagnosis affecting colour vision. Participants also could not have any other neurodevelopmental diagnoses beyond ADHD. Prior to the completion of the protocol, all participants were screened using the Physical Activity Readiness questionnaire to ensure safety for the six-minute walk test [65]. A self-reported formal diagnosis of ADHD was required for those in the ADHD group. However, all participants also completed the Connors Adult ADHD Rating Scale (CAARS) to ensure they met the appropriate cut-offs for their respective groups; participants in the ADHD group needed to score $\geq$ 65 while those in the neurotypical group needed to score < 65. Those taking ADHD-related medication needed to consent to refrain from taking their medication for 24 h prior to their virtual visit, to participate. As part of a broader study, a pre-established sample size of 71 participants was calculated (fixed model, R^2 deviation from zero, Cohen's f = 0.23, β = 0.95 and α = 0.05) using G*Power version 3.1.9.2 [66]. Eighty-five participants completed the study; however, due to missing data (n = 1; the participant was unable to complete the cognitive task portion of the experiment due to technical difficulties), no formal ADHD diagnosis (n = 1), or not meeting CAARS score cut-offs (control = 7; ADHD = 4), 72 participants were included in data analyses for this project (36 ADHD, 36 non-ADHD) [64].

2.2. Materials

2.2.1. Conner's Adult ADHD Rating Scale (CAARS)

The CAARS is a reliable and validated 30-item self-report questionnaire, which was used to evaluate ADHD symptoms in all participants [67,68]. Items were ranked using a 0–3 scale of "not at all, never" = 0, "just a little", "once in a while" = 1, "pretty much, often" = 2, and "very much, very frequently" = 3. Responses were combined using guidelines from Multi-Health Systems, where (1) a clinical cut-off of 65 indicated the presence of ADHD and (2) a higher score reflected greater symptom severity.

2.2.2. Estimated Cardiorespiratory Fitness (CRF)

The six-minute walk test (6MWT) is a tool used to measure the distance an individual can walk on a straight path in six-minutes [69,70]. The 6MWT was administered virtually using the '6WT' mobile application [71] where participants walked outdoors, on their own, and the application automatically recorded their distance. Prior to completing the 6MWT, participants also measured their heart rate using the 'Instant Heart Rate' mobile application by Azumio, which has been validated against gold standard heart rate measures [72]. Taken together, the distance from the 6MWT, resting heart rate, and a participant's sex, age, and body weight were used to calculate their VO_2 max, which reflects an estimated maximum rate of oxygen consumption [73]. Estimated VO_2 max was calculated through Equation (1) as this has been shown to be a valid and reliable measure "and accounts for approximately 72% of the variance associated with the gold-standard measure for cardiorespiratory fitness" [64,74,75].

$$\begin{gathered}\text{Estimated } VO_2 \text{ max } (\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) = 70.161 + (0.023 \times \text{6MWT [m]}) - \\ (0.276 \times \text{weight [kg]}) - (6.79 \times \text{sex, where m} = 0, \text{f} = 1) - (0.193 \times \text{resting HR} \\ \text{[beats per minute]}) - (0.191 \times \text{age [y]})\end{gathered} \tag{1}$$

2.3. Cognitive Tasks

All cognitive tasks were administered virtually using Inquisit Web (Version 6.3.5). Participants were provided the web-license link by a research assistant and completed all tasks on their personal computer. All tasks used were from the Millisecond library [76].

2.4. Stroop

The Stroop task, version "Colour Word Stroop with Keyboard Responding" [77], was used to assess inhibitory control. Stimuli presented on the screen were either words identifying one of four colours ("red", "green", "blue", "black") or solid, coloured rectangles. The solid rectangles were used in control trials where participants were instructed to identify the colour of the rectangle. Colour words were used for congruent and incongruent trials. Congruent trials were when the ink colour matched the word (i.e., the word "red" presented in the colour red) while incongruent trials had mismatched ink colour (i.e., the word "red" presented in the colour black). Trials were randomly sampled, and participants were instructed to identify the colour of all trials as accurately and quickly as possible using the assigned keyboard responses. Stimuli remained on the screen until the participant responded. Following a response, a 200-millisecond interval was applied between all trials. In total participants completed 84 trials. Overall accuracy and accuracy on congruent and incongruent trials were recorded. Interference scores were calculated by taking the difference between incongruent and congruent performance for both accuracy and reaction time (RT).

2.5. Wisconsin Card Sorting Task (WCST)

The Wisconsin Card Sorting Task [78] was used to measure cognitive flexibility. Participants were instructed to sort a deck of cards into separate categories without being provided explicit instructions on the rules of categorization. Potential categories were based on shape, colour, or number of items on the face of the card. The cards remained on the screen until they were categorized. Participants reached the end of the task by completing the maximum number of trials, which included 2 decks of 64 cards, for a total of 128 cards, or by successfully completing 6 blocks of 10 correct trials for colour, shape, or number. The percent of correct trials and percent perseverative errors—i.e., using the previous categorization strategy despite a change in the rule—were calculated.

2.6. Operation Span (OSPAN) Task

The Operation Span Task [79] was used to measure working memory. For each trial, participants were presented with a sequence of three to seven letters on a computer screen for one second each and were instructed to remember them in order. Then, for up to five seconds, participants were required to review simple math equations with a provided answer and identify whether the provided answer was “true” or “false”. Finally, participants were presented with a three by four matrix of letters and had to select the letters in sequence as they had appeared prior to the math task. The matrix remained on the screen until the participant submitted a recall sequence. Participants completed four practice trials where the letter sequencing and math problem were carried out separately, and three practice trials where the letter sequencing and math problem were carried out together, as described above. Participants then began the recorded OSPAN test with a total of 15 trials. Performance on the OSPAN task was calculated for participants who scored higher than 85% on the math trials, by summing the total number of letter sequences that were perfectly recalled, where a higher score indicates superior working memory capacity.

2.7. Covariates

Factors of sex, sleep, and mental health were characterized and included as covariates because they are known to impact both CRF [80–82] and cognition [83–85]. Ad hoc questions were used to determine sex and sleep. Specifically, participants were asked “What sex were you assigned at birth?” with options of male, female, intersex or “prefer not to say”, and “How many hours of sleep did you get last night?”.

Mental health was characterized using the Depression, Anxiety, and Stress Scale 42 [86]. The DASS is a validated questionnaire that measures constructs including depression, anxiety, and stress, all graded on a 0–3 scale (“did not apply to me at all” = 0, “applied to me to some degree” = 1, “applied to me to a considerable degree” = 2, and “applied to me very much” = 3) with a higher score indicating more severe symptoms. As recommended in the DASS manual, an overall index of mental health for each participant was computed by averaging the average z-scores for each subscale [86].

2.8. Procedure

This study was completed via a virtual visit on Zoom (Version 5.11.10) that lasted approximately 2.5 h. Participants completed the DASS and CAARS questionnaires along with a demographic questionnaire that included questions about biological sex and sleep the night before. Then, participants completed the cognitive tasks via Inquisit Web, in the following order: (1) Stroop, (2) WCST, and (3) OSPAN. The researcher provided instructions prior to each task and remained on the Zoom call while participants completed each task independently. Finally, participants completed the estimated CRF protocol. As the first step, each participant rested for five minutes and took three measurements of their resting heart rate monitored by the researcher. Then, the researcher provided instructions on how to complete the 6MWT, including how to use the 6WT mobile application. Participants temporarily left the Zoom call to complete the 6WT outside, unsupervised. After finding an appropriate location to complete the test (i.e., flat path, limited tall buildings that may disrupt GPS signal), participants started the application, which automatically timed the six minutes and recorded the distance walked. The session ended after participants returned to the Zoom call to report their 6MWT distance and debriefed with the researcher.

2.9. Statistical Analysis

IBM SPSS (V28) was used for all data analyses, with an alpha level set to less than 0.05. Descriptive statistics were calculated, and normality was assessed for all measures outlined above. Normality was assessed using visual inspection alongside values of skewness and kurtosis, and the Shapiro–Wilk test. Outliers were considered if a data point exceeded three standard deviations beyond the mean [87]. Only one participant was removed from the ADHD group for all Stroop analyses because their average reaction time on incongruent trials was more than five standard deviations away from the mean.

Three domains of executive functioning (inhibitory control, cognitive flexibility, and working memory) were evaluated. Inhibitory control was evaluated using the Stroop task performance scores of overall accuracy, accuracy on incongruent trials, and interference scores. Cognitive flexibility was evaluated using the WCST percent perseverative errors and percent of correct trials. Working memory was evaluated using the OSPAN score.

Continuous variables (domains of executive functioning and estimated CRF) were compared between groups using independent samples *t*-tests. Exploratory moderation analyses were carried out using Model 1 in Hayes PROCESS Macro, Version 4.1 SPSS plug-in, to test the associations between CRF (IV) and measures of executive function (DVs), and to explore whether the associations were moderated by group. Covariates in all models included sex, sleep, and mental health.

3. Results

3.1. Descriptive Statistics

Most participants were white (49%) and female (75%) and had an average age of 21 years old (SD = 3.0) (see Table 1).

As expected, CAARS scores were significantly higher for the ADHD group (M = 79.86, SD = 7.00) than the controls (M = 49.14, SD = 8.29; $p < 0.001$). Mental health, as measured by the DASS, was significantly worse for the ADHD group (Mean Z score = 0.41, SD = 0.98) than for controls (Mean Z score = −0.41, SD = 0.60; $p < 0.001$) (see Ogrodnik et al., 2023, for more details on mental health outcomes) [64]. The groups did not differ in estimated CRF ($p = 0.43$) or in their performance on any task of executive functioning (all $p \geq 0.17$) (Table 2).

3.2. Fitness x Executive Function

Higher estimated CRF was associated with greater accuracy on *all* trials of the Stroop task ($p < 0.05$), and this relationship was observed for those with and without ADHD ($b = 0.01$, $SE\ b = 0.003$, 95% CI = 0.00 to 0.01). Furthermore, there was an association between higher estimated CRF and greater accuracy on *incongruent* trials of the Stroop task, but this was moderated by group (Table 3), and only observed for adults with ADHD ($b = -0.01$, $SE\ b = 0.01$, 95% CI = −0.02 to −0.001) (Figure 1A,B). No other associations were observed between estimated CRF and executive functioning (Table 3).

Table 1. Demographic Characteristics.

Characteristic	ADHD	Control
	N (%)	N (%)
Sex		
Female	26 (72)	28 (78)
Male	10 (28)	8 (22)
Intersex	-	-
Gender		
Woman	23 (64)	27 (75)
Man	11 (30)	8 (22)
Non-binary	2 (6)	1 (3)
Two-spirit	-	-
Race		
Caucasian	19 (53)	16 (44)
East/Southeast Asian	5 (14)	8 (22)
South Asian	4 (11)	7 (19)
Multiracial	4 (11)	3 (10)
Middle Eastern	2 (5)	2 (5)
Black	1 (3)	-
Latino	1 (3)	-
Indigenous	-	-
Highest level of education		
Less than secondary	-	1 (3)
Secondary	21 (58)	26 (72)
More than secondary	15 (42)	9 (25)

Table 2. Cognitive Outcomes and CRF Outcomes.

Outcomes	ADHD Mean (±SD)	Control Mean (±SD)	*p*-Value
CAARS Scores	79.86 (7.00)	49.14 (8.29)	<0.001 ***
DASS Z Score	0.41 (0.98)	−0.41 (0.60)	<0.001 ***
Estimated CRF	41.55 (5.23)	42.35 (2.97)	0.43
Stroop Task			
Overall Accuracy	0.95 (0.04)	0.96 (.03)	0.47
Incongruent Accuracy	0.92 (0.08)	0.93 (0.07)	0.82
Accuracy Interference	−0.05 (0.08)	−0.06 (0.07)	0.68
Reaction Time Interference	223.2 (155.17)	284.63 (209.20)	0.17
WCST			
Percent Perseverative Errors	31.82 (18.34)	35.71 (21.63)	0.41
Percent Correct	71.96 (11.25)	71.26 (11.28)	0.79
OSPAN	37.81 (18.54)	39.89 (21.13)	0.66

Notes: CRF = Cardiorespiratory Fitness, WCST = Wisconsin Card Sorting Task, OSPAN = Operation Span task, *** $p < 0.001$. All analyses included N = 36 for the ADHD group and N = 36 for the Control group except Stroop task analyses which included N = 35 for ADHD and N = 36 for the Control group.

Higher estimated CRF was associated with greater accuracy on *all* trials of the Stroop task ($p < 0.05$), and this relationship was observed for those with and without ADHD (b = 0.01, $SE\ b$ = 0.003, 95% CI = 0.00 to 0.01). Furthermore, there was an association between higher estimated CRF and greater accuracy on *incongruent* trials of the Stroop task, but this was moderated by group (Table 3), and only observed for adults with ADHD (b = −0.01, $SE\ b$ = 0.01, 95% CI = −0.02 to −0.001) (Figure 1A,B). No other associations were observed between estimated CRF and executive functioning (Table 3).

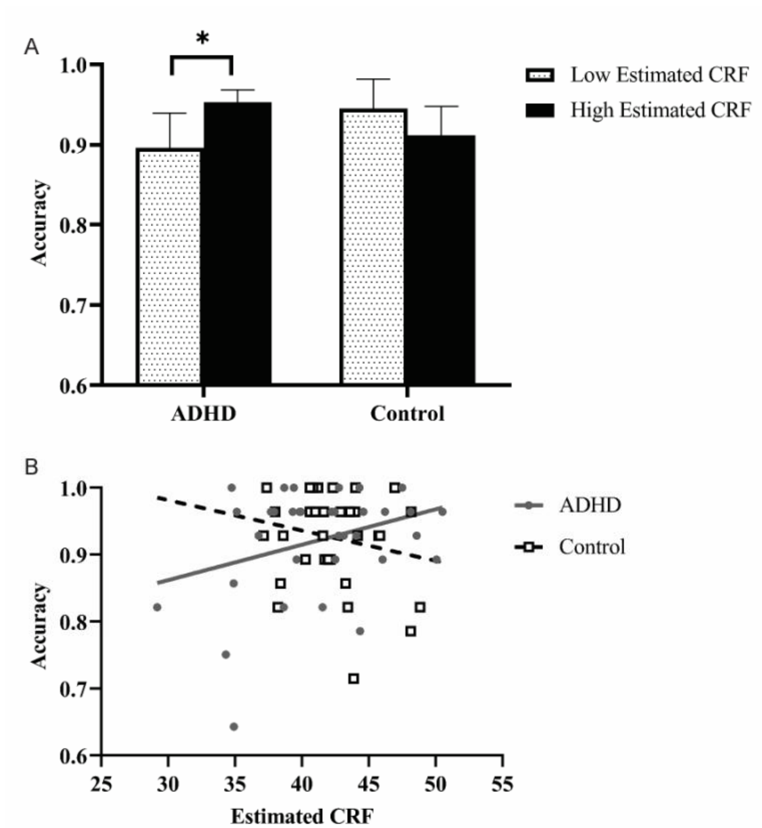

Figure 1. (**A**) The moderating effect of group (ADHD vs. Control) on the relationship between estimated CRF and Stroop incongruent accuracy. Bars reflect standard error. * $p < 0.05$ (**B**) Scatterplot of raw data included in the mediation analysis. Regression lines reflect the mediation output (solid grey line = ADHD; dashed black line = Control).

Figure 1. (**A**) The moderating effect of group (ADHD vs. Control) on the relationship between estimated CRF and Stroop incongruent accuracy. Bars reflect standard error. * $p < 0.05$ (**B**) Scatterplot of raw data included in the mediation analysis. Regression lines reflect the mediation output (solid grey line = ADHD; dashed black line = Control).

Table 3. Regression coefficients of the moderating effect of group (ADHD vs. Control) on estimated CRF and cognitive outcomes.

DV		R^2	b	SE b	95% Cis	*p*
Stroop						
Overall Accuracy		0.16				0.07
	Estimated CRF		0.01	0.003	(0.00, 0.01)	<0.05 *
	Group		0.13	0.10	(−0.08, 0.33)	0.21
	Interaction		−0.003	0.002	(−0.01, 0.001)	0.22
Incongruent Accuracy		0.11				0.26
	Estimated CRF		0.02	0.01	(0.004, 0.03)	0.01 *
	Group		0.47	0.21	(0.05, 0.89)	0.03 *
	Interaction		−0.01	0.01	(−0.02, −0.001)	0.03 *
Accuracy Interference		0.07				0.57
	Estimated CRF		0.01	0.01	(−0.001, 0.03)	0.06
	Group		0.38	0.22	(−0.05, 0.82)	0.08
	Interaction		−0.01	0.01	(−0.02, 0.001)	0.07
RT Interference		0.10				0.34
	Estimated CRF		8.08	17.30	(−26.47, 42.64)	0.64

Table 3. *Cont.*

DV		R^2	b	SE b	95% Cis	*p*
	Group		36.11	526.41	(−1015.52, 1087.74)	0.95
	Interaction		0.14	12.46	(−24.76, 25.04)	0.99
WCST						
		0.04				0.82
Percent Perseverative Error	Estimated CRF		0.02	1.83	(−3.64, 3.67)	0.99
	Group		11.25	57.21	(−103.01, 125.52)	0.84
	Interaction		−0.21	1.35	(−2.91, 2.49)	0.88
		0.08				0.46
Percent Correct	Estimated CRF		0.01	0.01	(−0.01, 0.03)	0.58
	Group		0.17	0.31	(−0.45, 0.80)	0.58
	Interaction		−0.005	0.01	(−0.02, 0.01)	0.52
OSPAN						
		0.03				0.94
OSPAN	Estimated CRF		−0.50	1.82	(−4.14, 3.14)	0.79
	Group		−5.73	57.03	(−119.63, 108.17)	0.92
	Interaction		0.23	1.35	(−2.46, 2.92)	0.87

Notes: CRF = Cardiorespiratory Fitness, WCST = Wisconsin Card Sorting Task, OSPAN = Operation Span task, * $p < 0.05$. All analyses included N = 36 for the ADHD group and N = 36 for the Control group except Stroop task analyses which included N = 35 for ADHD and N = 36 for the Control group.

4. Discussion

The current project examined the association between estimated CRF and executive functioning in adults with ADHD compared to neurotypical controls. To our knowledge, this was the first study to examine this association in an adult group across all three domains of executive functioning. Surprisingly, both groups were well-matched in terms of their estimated CRF and executive functioning. Importantly, higher estimated CRF was associated with better inhibitory control for adults with ADHD.

A strength of our study is that we used three validated computerized tests of executive functions that are commonly used to assess deficits in inhibitory control [88], cognitive flexibility [89], and working memory [90,91]; namely, the Stroop task measured inhibition, the Wisconsin Card Sorting task measured cognitive flexibility, and the OSPAN task measured working memory. Yet, in our adult sample, we did not observe group differences between adults with and without ADHD in performance on any of these objective measures. This contrasts some prior research showing that children and adults with ADHD perform worse on these tasks compared to their neurotypical peers with small-to-moderate effects [18–21]. That said, the effect sizes tend to be larger in children than in adults [92] The more subtle impairments in executive task performance for adults with ADHD may explain why not all research, including ours, observe significant group differences. For example, in line with our observations, Barkley and Murphy (2011) [93] found no significant group differences in the proportion of adults with and without ADHD who showed clinical impairments on the Stroop task of inhibition, the Wisconsin Card Sorting Task of cognitive flexibility, and the Digit Span task of working memory [93].

Individual differences among adults with ADHD may further minimize group-wise differences. A key difference between our study and prior studies is that our participants were highly educated. Most of our participants were in pursuit of or held a university degree and may have already developed effective strategies for managing their executive dysfunction [13,94,95]. Indeed, previous research that used the same cognitive tasks found that adults with ADHD and a higher IQ had less pronounced differences in inhibitory control and working memory performance—these differences were still evident in adults with ADHD and a standard IQ [96]. Furthermore, in adults with ADHD, those with a standard IQ tend to have lower academic grades, educational attainment, and occupational attainment than those with a higher IQ [97]. Therefore, the lack of a group-wide ADHD deficit in the executive function tasks observed here may be a consequence of our highly educated, adult sample.

That said, individual differences in inhibitory control performance were observed among adults with ADHD when CRF was accounted for. This observation further supports the importance of acknowledging the heterogeneity in executive dysfunction among adults with ADHD. In the present study, we found that CRF was associated with accuracy on incongruent trials in adults with ADHD. Importantly, this was not observed for neurotypical participants, though higher CRF was associated with better overall accuracy on the Stroop task for all participants. Our results align with previous research which suggests that fitness-related benefits may be most useful for those with executive dysfunction, whereas healthy controls may not show notable benefits given the ceiling effects [44,55,98]. Furthermore, the association between higher CRF and better performance for those with ADHD was not observed for the other tasks of executive functions. This aligns with previous research in children and adolescents with ADHD, which has found that fitness has the strongest impact on inhibitory control compared to other executive functions, including working memory [55,99]. Our research suggests the same is true in adults with ADHD. While it is unclear why inhibitory control may have a stronger connection with CRF in comparison to other executive functions, there seems to be a selective association between inhibitory control and other health outcomes. For example, prior studies have documented a selective link between tasks of inhibitory control and adiposity that was not observed for other cognitive tasks [100,101]. From a physiological perspective, this could be because cardiometabolic health is associated with enhanced cerebral vasculature and neurotrophic pathways along with increased cerebral blood flow [36,37,102,103]. Thus, the brain would be more adequately supplied with the resources it needs to perform the metabolically demanding tasks of inhibitory control. This may be particularly important for people with ADHD who display hypoperfusion of the prefrontal cortex [104]. From a behavioural perspective, this could be because inhibitory control is "flexed" every time one engages in a healthy behaviour that requires self-control. In fact, previous research has noted that inhibitory control training can positively impact health behaviours [105]. Although our cross-sectional study is unable to test these hypotheses, they should be evaluated by future research.

While not seen in our data, adults with ADHD tend to be less physically active than their neurotypical peers [106,107], and therefore, may especially benefit from an exercise intervention that increases fitness. Given that inhibitory control is the hallmark of executive dysfunction associated with ADHD [108] and may be especially sensitive to chronic exercise adaptations [109], exercise programs that increase CRF in adults with ADHD may be supportive of their inhibitory control functioning and should be explored in future research. This may also benefit beyond inhibitory control; associations between ADHD and physical conditions have been documented including type II diabetes, metabolic syndrome, and obesity [110,111], many of which have symptoms that can be managed with exercise [112].

In contrast to the objective measures of executive dysfunction, we observed the expected significant group differences in *subjective* ratings of ADHD symptoms, as indicated by higher CAARS scores for the ADHD group than controls. This demonstrates a divergence between subjective and objective assessments of cognition, which further complicates the assessment of executive dysfunction in adults with ADHD. Although some studies in children with ADHD have found that subjective and objective measures of executive function are moderately correlated [113–115], there are also documented inconsistencies between subjective and objective measures for children with ADHD [114,116]. Our work extends these inconsistencies into an adult population and highlights the need for multiple forms of assessments to fully capture executive dysfunction in adults with ADHD [117,118].

The lack of concordance between subjective and objective measures of executive dysfunction may reflect differences in the nature of the dysfunction being captured by the assessments. Self-reported assessments ask participants to reflect on their daily life, which tends to be more ambiguous and complex than performance-based measures using highly controlled tasks with a unitary predefined goal. Like our results, a prior study found that adults with ADHD self-report worse executive dysfunction than their performance on objective measures would indicate [119]. Similar findings are observed in children with autism spectrum disorder, another neurodevelopmental disorder that causes difficulty with executive functioning; specifically, the findings suggest that executive functioning deficits in autism are worse when assessing their "day-to-day executive function-related behaviour" than their in-lab test performance [120]. In adults with ADHD, Barkley and Murphy (2010; 2011) [93,121] suggest that perceptions of executive dysfunction, rather than tasks of executive function, are more closely related to real-life impairments, including academic and occupational outcomes [93,121]. As such, future research should consider a particular emphasis on using assessments that simulate daily tasks (i.e., poor self-organization and sustained effort in everyday settings) to capture the more subtle struggles of executive dysfunction that adults with ADHD grapple with daily [122].

Limitations and Future Directions

The current data provide insight on executive dysfunction in adult ADHD and its association with CRF. While this study fills an important gap in the literature, it is not without limitations. Most importantly, our data are cross-sectional, and therefore, causality cannot be determined. While previous research in children with ADHD has established that higher fitness is associated with better executive functioning [55] and that chronic exercise interventions can improve executive functioning [58,123], future randomized controlled trials are needed to confirm the direction of this relationship in adults with ADHD. It is also important for future research to consider other factors that may exacerbate executive dysfunction in ADHD including chronic stressors associated with lower socioeconomic status [124–127].

All data were collected during the COVID-19 pandemic and, therefore, it is important to acknowledge the potential for measurement errors within our virtual protocol. For example, CRF was estimated using the Six-Minute Walk Test. Although this standardized test shows good validity [74], it was carried out unsupervised. Likewise, participants completed all cognitive tasks in their own environments. The lack of consistency (e.g., environmental distractors, different device sizes, internet lags, etc.) may have added noise to these measurements. While the virtual nature may have introduced additional variance, it is interesting that participants across both groups performed well on all tasks. Given that there were no group-level differences in executive functioning, the executive dysfunction associated with ADHD may vary across the lifespan and depend on factors such as education level. Therefore, more work specifically in adults is needed.

5. Conclusions

Taken together, our results provide important insights into the executive dysfunction of adults with ADHD and its association with CRF. Although at the group level adults with ADHD performed similarly to the controls on the tasks of executive function, we observed interesting individual differences, such that higher fitness in adults with ADHD was associated with better inhibitory control. The same individual differences were not observed for cognitive flexibility or working memory. Given that inhibitory control is the hallmark of executive dysfunction for ADHD [15], using physical activity to improve fitness in adults with ADHD may be an effective strategy to support symptom management. However, it should be acknowledged that adhering to a program of physical activity requires executive functioning to schedule and initiate [128], and therefore, future research is needed to identify the unique ADHD-related barriers that individuals may face so that the necessary support can be provided.

Author Contributions: Conceptualization, M.O. and J.J.H.; methodology, M.O. and J.J.H.; formal analysis, M.O., S.K. and J.J.H.; data collection, M.O., S.K. and V.C.; writing—original draft preparation, M.O. and S.K.; writing—review and editing, M.O., S.K., V.C. and J.J.H.; project administration, M.O.; funding acquisition, J.J.H. All authors have read and agreed to the published version of the manuscript.

Funding: The funding for this project was provided by Tier 2 Canada Research Chair in Brain Health and Aging [950-232967].

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the McMaster Research Ethics Board (Project ID 5111).

Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available as participants did not consent to this.

Conflicts of Interest: The authors have no potential conflict of interest to report.

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CHAPTER 3:

Mental health in adults with ADHD: Examining the relationship with cardiorespiratory fitness

Preamble

Mental health in adults with ADHD: Examining the relationship with cardiorespiratory fitness serves as the second study in this dissertation. This study examined cross-sectional associations between cardiorespiratory fitness and mental health, for those with and without ADHD.

The chapter is a finalized paper, which has been published in the *Journal of Attention Disorders*. The manuscript is formatted in alignment with the author guidelines for the *Journal of Attention Disorders* and is included as accepted for publication. The published version of the manuscript can be found at: https://doi.org/10.1177/10870547231158383

Contributions of Study 2 to the overall dissertation

Study 2 is the first study to examine the relationship between CRF and mental health in adults with ADHD. While executive dysfunction is a hallmark of ADHD, adults with ADHD also experience poor mental health. Study 2 documents the significantly higher prevalence of poor mental health in adults with ADHD than controls as revealed by higher self-reported depression, anxiety, and stress symptoms. Across both groups, lower CRF was significantly associated with worse depression, anxiety, and stress. However, higher estimated CRF was associated with lower stress for those with ADHD. Among those with less severe ADHD symptoms, higher perceived CRF was associated with lower depressive symptoms. Taken together, data highlight the mental health issues faced by adults with ADHD and reveal an association between higher CRF and better self-reported mental health.

Article

Journal of Attention Disorders
2023, Vol. 27(7) 698–708

DOI: 10.1177/10870547231158383
journals.sagepub.com/home/jad
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Mental Health in Adults With ADHD: Examining the Relationship With Cardiorespiratory Fitness

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Abstract

Objective: The mental health of adults with ADHD was compared to neurotypical controls, and associations between cardiorespiratory fitness (CRF) and mental health were examined.
Method: Seventy-two participants ($n = 36$ with ADHD) completed demographic questions assessing ADHD and mental health symptoms. CRF was estimated using the 6-Minute Walk Test and a self-perception question.
Results: Those with ADHD had significantly poorer mental health outcomes than controls ($p < .001$), with 50% of adults with ADHD reporting moderate to extremely severe symptoms of depression, anxiety, and stress. Critically, lower CRF was associated with worse depression, anxiety, and stress (all $p \leq .03$) across both groups. Within the ADHD group, those with higher estimated CRF had significantly lower stress. Among participants with less severe ADHD symptoms, those with higher perceived CRF had significantly lower depressive symptoms.
Conclusion: In our cross-sectional study, participants with ADHD had poorer mental health than neurotypical controls, and higher fitness was associated with better mental health. *(J. of Att. Dis. 2023; 27(7) 698-708)*

Keywords
ADHD, depression, anxiety, stress, cardiorespiratory fitness

Introduction

ADHD is a common neurodevelopmental disorder that affects approximately 5% of adults globally (Song et al., 2021). In addition to the traditional symptoms of inattention and impulsivity (Felt et al., 2014), many people with ADHD also suffer from mental illness (Katzman et al., 2017; Riglin et al., 2021; Sciberras et al., 2009). Approximately 80% of adults diagnosed with ADHD also present with a psychiatric comorbidity at least once in their lifetime (Klassen et al., 2010). Common comorbidities include major depressive disorder, anxiety disorders, substance use disorders, and personality disorders (Katzman et al., 2017). Unfortunately, when ADHD is comorbid with a mental illness it can be difficult to diagnose and devise a treatment plan to manage the constellation of symptoms (Katzman et al., 2017).

The first approach for managing both ADHD and mental illness typically involves pharmacotherapy (Meppelink et al., 2016); however, prescribing mood stabilizers for conditions such as depression and anxiety on top of stimulant medications for ADHD is not typically recommended given the negative side effects of the drug-to-drug interactions (Brown et al., 2018; Y. Kim et al., 2021; Miklós et al., 2019). Consequently, patients may only be medicated for the most severe symptoms (Katzman et al., 2017). Unfortunately, treating one disorder does not always lead to improvements in the other and in some cases, ADHD medications can exacerbate symptoms of depression (Miklós et al., 2019).

In contrast, treatment approaches that incorporate physical activity can have a potent impact on both symptoms of ADHD (Den Heijer et al., 2017; Y. S. Kim et al., 2012; Ng et al., 2017) and mental illness (Hosker et al., 2019; Oddie et al., 2014) with minimal side effects (Vina et al., 2012). Physical activity is effective at reducing depression and anxiety in neurotypical populations (Kandola, Ashdown-Franks, Stubbs, Osborn, & Hayes, 2019; McDowell et al., 2019; Rebar et al., 2015) and emerging evidence suggests the same may be true for people with ADHD (Da Silva et al., 2020; Den Heijer et al., 2017; K. M. Fritz & O'Connor, 2016).

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A key adaptation afforded by long-term engagement in physical activity is improved physical fitness (Boulé et al., 2003; Lin et al., 2015) including better aerobic or cardiorespiratory fitness (CRF). Higher CRF, which reflects our ability to intake and circulate oxygen throughout the body to meet task demands (Caspersen et al., 1985), has been associated with better mental health and fewer incidents of mental illness in neurotypical populations (Kandola, Ashdown-Franks, Hendrikse, et al., 2019; Schuch et al., 2016) and individuals with stress-related exhaustion disorder (Lindegård et al., 2019). Importantly, there is some evidence to suggest that those with ADHD may have lower CRF (K. Fritz & O'Connor, 2018; Jeoung, 2014) and higher incidences of mental illness (C. M. Jensen & Steinhausen, 2015). However, the relationship between CRF and mental health in adults with ADHD has yet to be explored.

The present study aimed to document the relationship between CRF and mental health outcomes. First, we examined the cross-sectional differences in mental health outcomes (depression, anxiety, and perceived stress) between those with ADHD compared to their neurotypical peers. Then, we investigated whether higher CRF was associated with better mental health and explored whether an ADHD diagnosis or ADHD symptom severity moderated that association. We hypothesized that those with an ADHD diagnosis and worse ADHD symptoms would have poorer mental health, but that higher CRF would be associated with a more positive mental health profile across both groups, and perhaps more so for ADHD participants. Given that those with more severe ADHD tend to have worse mental health (Daviss, 2008), and prior research has failed to adequately control for comorbid mental illnesses (Carr et al., 2006; Fisher et al., 2011; Maoz et al., 2018), this research represents an important step in evaluating the effectiveness of alternative approaches for symptom management for adults with ADHD.

Methods

Participants

Eighty-five Canadian young adults between 18 and 35 years old completed this study (May 2020–February 2022). Eligible participants completed the Physical Activity Readiness Questionnaire (PAR-Q) to confirm they could safely complete the physical activity protocol. In addition, eligible participants needed to be fluent in English (read, write, and speak), and have access to a computer and the internet. Finally, they could not have a disorder affecting color vision, for a separate study not included in this manuscript. While those with comorbid mental illnesses were eligible to participate, participants with additional neurodevelopmental diagnoses (e.g., autism spectrum disorder) were deemed ineligible. Those in the ADHD group required a self-reported formal diagnosis from a healthcare professional. In addition, all participants completed the Connors Adult ADHD Rating Scale (CAARS) to assess ADHD symptoms. In the final analysis, all participants in the ADHD group scored above the CAARS 65-point threshold, which is the criteria used to screen for ADHD, while those in the control group needed to score below 65. In total, 13 participants were excluded after completing the protocol (control = 7; ADHD = 6) due to missing data ($n = 1$), no formal ADHD diagnosis ($n = 1$), or not meeting CAARS score cut-offs (control = 7; ADHD = 4). As part of a broader study exploring CRF on cognition, a sample size calculation was conducted using G*Power version 3.1.9.2 (Faul et al., 2009), for linear multiple regression (fixed model, R^2 deviation from zero) with Cohen's f set to = 0.23 (Newson & Kemps, 2008), a conservative $\beta = .95$ and $\alpha = .05$. Results indicated that 71 participants were sufficient. The final analysis consisted of 72 participants (36 ADHD, 36 non-ADHD). All participants provided informed consent before study participation and were provided with monetary compensation. The study was approved by the McMaster Research Ethics Board (MREB) of McMaster University (Project ID 5111).

Materials

Conner's Adult ADHD Rating Scale (CAARS). The CAARS was used to assess ADHD symptoms (Conners et al., 1999). The CAARS is a 30-item self-report questionnaire and is a commonly used validated tool to "screen for the presence and severity of ADHD symptoms in adults aged 18 and older" (MHS Assessments, 2021). Each item was ranked by participants on a scale from 0 to 3 in increasing severity ("not at all, never" = 0, "just a little," "once in a while" = 1, "pretty much, often" = 2, and "very much, very frequently" = 3). Overall scores were calculated manually using guidelines outlined by Multi-Health Systems, with a score of 65 or higher indicating the presence of ADHD and higher scores indicating greater ADHD symptom severity. The CAARS assessment has been used frequently in research examining adults with ADHD and has demonstrated good reliability and validity with an overall efficiency rate of 85% (Adler et al., 2008; Conners et al., 1999).

Depression Anxiety and Stress Scale (DASS). The DASS was used to assess mental health and well-being. The DASS consists of 42 items that evaluate the severity of depression, anxiety, and perceived stress symptoms (Imam, 2008). Items specific to each disorder include a list of four statements graded on a scale from 0 to 3 in increasing severity ("did not apply to me at all" = 0, "applied to me to some degree" = 1, "applied to me to a considerable degree" = 2, and "applied to me very much" = 3). The total score within each category was then summed, with a higher score indicating greater symptom severity for each category.

Cut-offs have been established to determine normal, moderate, severe, or extremely severe symptoms of depression, anxiety, and stress (see Lovibond & Lovibond, 1995 for cut-off details). The DASS is a valid and reliable measure when used in both clinical and non-clinical populations (Pooravari et al., 2017; Vignola & Tucci, 2014).

Estimated Cardiorespiratory Fitness. Distance reported from the six-minute walk test (6MWT) was combined with the participant's self-reported body weight, sex, age, and resting heart rate (which was the average of three measurements) to estimate one's maximal oxygen consumption or VO_2 max, an indicator of CRF (Burr et al., 2011). The "6WT" mobile application was used to record the distance of the 6MWT, which is used to estimate CRF (Stienen et al., 2019). This application has been validated and used in previous research (Marashi et al., 2021; Stienen et al., 2019). Participants completed the test outside and were required to walk as fast as they could in a straight line for 6 min, without running or jogging. Additionally, participants were advised to find a flat path and avoid walking in areas with tall buildings where possible, to eliminate disruptions to the GPS signal used to calculate the distance walked. At the end of the 6 min, the application provided a total distance which participants reported once they returned from their walk. Heart rate measurements were completed using the "Instant Heart Rate" mobile application by Azumio. The application uses photoplethysmography, changes in blood volume during circulation, to measure heart rate (Castaneda et al., 2018). Participants held their finger over their smartphone camera for 30 s while the flashlight was on and using an advanced algorithm, the application calculated their heart rate by monitoring color changes each time there was a heartbeat. The application has shown concurrent validity with other more accurate heart rate measures such as the "FT7 Polar" and has acceptable test-retest reliability (Mitchell et al., 2016). Equation 1 was used to calculate CRF (Burr et al., 2011), as it is a valid and reliable measure that accounts for approximately 72% of the variance associated with the gold-standard measure for cardiorespiratory fitness (Burr et al., 2011; Marashi et al., 2021).

$$\begin{aligned}\text{Estimated } VO_2\text{max } &\left(\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}\right) \\ &= 70.161 + \left(0.023 \times \text{6MWT } [\text{m}]\right) \\ &- \left(0.276 \times \text{weight } [\text{kg}]\right) \\ &- \left(6.79 \times \text{sex, where m} = 0, \text{ f} = 1\right) \\ &- \left(0.193 \times \text{resting HR } [\text{beats per minute}]\right) \\ &- \left(0.191 \times \text{age } [\text{y}]\right)\end{aligned} \tag{1}$$

Perceived Cardiorespiratory Fitness. Participants reported perceived CRF by responding to the question: "In general, I would say that my current aerobic fitness (ability to walk/run distances) is: Excellent (4), Very Good (3), Good (2), Fair (1), Poor (0)." Given the virtual nature of our estimated-CRF measure (which was necessary due to COVID-19 pandemic restrictions), perceived CRF was included as a secondary estimate of fitness. Previous literature reports positive correlations between estimated CRF and perceived fitness in neurotypical populations (K. G. Jensen et al., 2018; Monroe et al., 2010).

Procedure. As part of a larger project, participants completed a 2.5-hr virtual visit via Zoom (Version 5.11.10) during which the primary measures were assessed. Participants completed a series of questionnaires including a demographic questionnaire, the CAARS, the DASS, and the question on perceived CRF. Then, participants took a 5-min quiet rest (monitored by the researcher) before taking three samples of their resting heart rate using the Instant Heart Rate application. Participants then left the Zoom call to independently complete the 6MWT, which was used to estimate CRF. Once completed, participants returned to the Zoom call to report their results and debrief with the researcher.

Statistical Analysis. Data were analyzed using IBM SPSS (Version 28). Descriptive statistics were computed for all variables, and normality was assessed via the Shapiro-Wilk statistic, skewness and kurtosis, and visual inspection. Perceived fitness was treated as an ordinal variable, which was originally measured on a 5-point scale (i.e., Excellent, Very Good, Good, Fair, Poor); however, to meet the assumptions of a chi-squared test, the categories were collapsed into (1) Excellent/Very Good, (2) Good, and (3) Fair/Poor. This three-category perceived fitness variable was then used for subsequent analyses. Estimated CRF was treated as a continuous variable. A two-tailed Spearman's correlation was used to test whether estimated and perceived CRF were related to one another. Independent samples *t*-tests were computed to determine whether mental health outcomes and estimated CRF differed by group (ADHD vs. Control). A chi-squared test was used to investigate whether perceived CRF was different between groups. Regression analyses were used to test whether estimated CRF and perceived CRF predicted mental health outcomes. Hayes PROCESS Macro, Version 4.1 SPSS plug-in (Model 1) was used to conduct exploratory moderation analyses to determine whether the relationship between CRF (IV) and mental health (DV) differed by group (ADHD vs. Control) or CAARS score within the ADHD group (moderator). All analyses were set to an alpha level of less than 0.05. Biological sex was used as a covariate in all regression and moderation analyses as sex differences have been noted in ADHD symptoms (Fedele et al., 2012), CRF (Al-Mallah et al., 2016; Dimech et al., 2019), and mental health (Altemus et al., 2014). ADHD medication was used as a covariate in analyses for the ADHD group to determine whether the association between CRF and mental health remained

Table 1. Demographic Characteristics.

Characteristic	ADHD *N* (%)	Control *N* (%)
Sex		
Female	26 (72)	28 (78)
Male	10 (28)	8 (22)
Intersex	-	-
Gender		
Woman	23 (64)	27 (75)
Man	11 (30)	8 (22)
Non-binary	2 (6)	1 (3)
Two-spirit	-	-
Race		
Caucasian	19 (53)	16 (44)
East/Southeast Asian	5 (14)	8 (22)
South Asian	4 (11)	7 (19)
Multiracial	4 (11)	3 (10)
Middle Eastern	2 (5)	2 (5)
Black	1 (3)	-
Latino	1 (3)	-
Indigenous	-	-
Highest level of education		
Less than secondary	-	1 (3)
Secondary	21 (58)	26 (72)
More than secondary	15 (42)	9 (25)
Employment status		
Student	29 (80)	24 (66)
Employed for wages	6 (17)	9 (25)
Self-employed	-	1 (3)
Not employed for wages	1 (3)	2 (6)
Medication use		
ADHD medication	24 (67)	-
Mental health medication	1 (3)	-
Perceived fitness level		
Poor	3 (8)	1 (3)
Fair	5 (14)	3 (8)
Good	16 (44)	11 (31)
Very good	10 (28)	15 (42)
Excellent	2 (6)	6 (17)

after controlling for ADHD medication use.

Results

Descriptive Statistics

Descriptive statistics are presented in Table 1. Participants on average were 21.0 years old (±3.0) and were predominately female (75%). Most participants were white university students. Sixty-seven percent of participants with ADHD were currently taking medication for their ADHD symptoms, and 81% had been prescribed ADHD medication at some point. All participants with ADHD had a CAARS score of 65 or higher (79.9 ± 7.0) whereas all controls had a CAARS score below 65 (49.1 ± 8.3) (See Table 2).

Mental Health

Individuals in the ADHD group had significantly greater depression ($t(70)=3.83$, $p<.001$), anxiety ($t(70)=3.41$, $p=.001$), and perceived stress ($t(70)=4.09$, $p<.001$), indicating worse mental health compared to controls (See Table 2). Sixty-seven percent of participants with ADHD reported moderate to extremely severe symptoms in at least one subscale of depression, anxiety, or perceived stress, while the same was only observed for approximately 36% of controls (Table 3; Figure 1).

Fitness

Estimated CRF and perceived CRF were positively correlated ($r(70)=.34$, $p<.01$). Neither estimated CRF ($p=.43$) nor perceived fitness ($p=.10$) were significantly lower in the ADHD group compared to controls.

Fitness × Mental Health

Higher estimated CRF was associated with lower perceived stress scores [$\Delta R^2=.07$, $F(2, 69)=3.35$, $p=.03$], accounting for 7% of the variance (Table 4). This relationship was not moderated by the group (Table 5), but it was moderated by ADHD symptom severity for participants with ADHD ($b=0.10$, *SE* b=0.05, 95% CI [.004, .19]) (Figure 2). Specifically, the relationship between higher estimated CRF and less perceived stress was statistically significant for the individuals with less severe ADHD symptoms but not for those with more severe symptoms (Figure 2; Table 6).

Higher perceived fitness was associated with less depression [$\Delta R^2=.12$, $F(2, 69)=5.40$, $p<.01$], anxiety [$\Delta R^2=.08$, $F(2, 69)=4.44$, $p=.02$], and perceived stress [$\Delta R^2=.17$, $F(2, 69)=8.20$, $p<.001$], accounting for 12%, 8%, and 17% of the variance, respectively (Table 4). However, only the relationship between perceived CRF and depression was moderated by the presence of ADHD ($b=7.39$, *SE* b=2.71, 95% CI [1.98, 12.80]) (Figure 3). Specifically, the relationship between higher perceived CRF and less depression was stronger in people with ADHD than in those without (Figure 3; Table 7). Symptom severity within the ADHD group did not moderate the relationship between perceived CRF and mental health outcomes (Table 8).

Discussion

The present study examined the incidence of poor mental health among individuals with ADHD compared to their neurotypical peers, while also exploring the association between mental health and cardiorespiratory fitness (CRF). Compared to neurotypical participants, those with ADHD

Table 2. Mental Health and CRF Outcomes.

Outcomes	ADHD Mean (±SD) n = 36	Control Mean (±SD) n = 36	p-value
CAARS Scores	79.86 (7.00)	49.14 (8.29)	<.001***
Depression	13.69 (10.38)	5.69 (7.02)	<.001***
Anxiety	12.19 (9.47)	6.08 (5.08)	.001**
Stress	17.94 (10.01)	9.75 (6.66)	<.001***
Estimated CRF	41.55 (5.23)	42.35 (2.97)	.43
Perceived CRF	2.08 (1.00)	2.61 (.96)	.10

Note. CRF = Cardiorespiratory Fitness. All outcomes were compared using a *t*-test except perceived CRF; given the categorical nature of the data, this was compared using a chi squared test.
$^*p<.05$. $^{**}p<.01$. $^{***}p<.001$.

Table 3. Mental Health Symptom Severity.

Mental Health outcome	Symptom Severity	ADHD N (%)	Control N (%)
Depression	Normal (0–9)	14 (39)	31 (86)
	Mild (10–13)	4 (11)	1 (3)
	Moderate (14–20)	8 (22)	2 (5.5)
	Severe (21–27)	5 (14)	-
	Extremely Severe (28+)	5 (14)	2 (5.5)
Anxiety	Normal (0–7)	13 (36)	26 (72)
	Mild (8–9)	4 (11)	1 (3)
	Moderate (10–14)	5 (14)	7 (19)
	Severe (15–19)	10 (28)	1 (3)
	Extremely Severe (20+)	4 (11)	1 (3)
Perceived Stress	Normal (0–14)	17 (47)	29 (81)
	Mild (15–18)	1 (3)	3 (8)
	Moderate (19–25)	7 (19)	4 (11)
	Severe (26–33)	10 (28)	-
	Extremely Severe (34+)	1 (3)	-

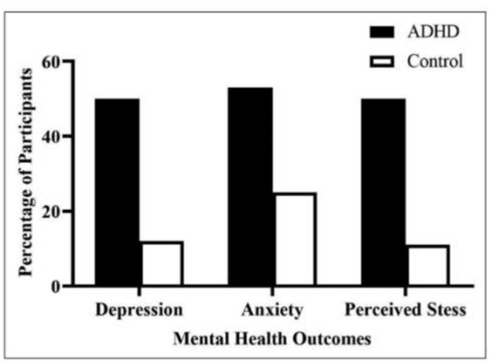

Figure 1. Percentage of participants experiencing moderate to severe depression, anxiety, and perceived stress symptoms, as measured by the DASS.

had poorer mental health. Critically, higher CRF was associated with less depression, anxiety, and perceived stress, especially for those with ADHD.

The comorbidity between ADHD and mental illness is challenging for many reasons including the issue of treating both conditions simultaneously given the negative interactions between their respective pharmacotherapies (Brown et al., 2018). Alarmingly, 50% of ADHD participants reported severe or extremely severe symptoms of depression, anxiety, or perceived stress and those with more severe ADHD symptoms were more mentally distressed. Critically, this degree of mental health symptom severity was not reported by the control group, highlighting the unique vulnerability to mental health issues faced by adults with ADHD. Notably, over 80% of our participants in the ADHD group reported taking medication for their ADHD symptoms (either currently or at some point since their diagnosis) and those currently taking ADHD medication (67%)

Table 4. Linear Regression Table for Estimated and Perceived CRF Predicting Mental Health Outcomes.

	Estimated CRF					Perceived CRF				
Outcomes	ΔR^2	*B*	*SE b*	β	*p*	ΔR^2	*B*	*SE b*	β	*p*
Depression	.02	−0.37	0.28	−.16	.19	.12	−4.57	1.48	−.35	<.01**
Anxiety	.001	−0.06	0.24	−.03	.79	.08	−3.05	1.26	−.28	.02*
Stress	.07	−0.60	0.27	−.27	.03*	.17	−5.27	1.38	−.42	<.001***

Note. Sex was used as a covariate. CRF = Cardiorespiratory Fitness.
*p < .05. **p < .01. ***p < .001.

Table 5. Regression Coefficients of the Moderating Effect of Group (ADHD vs. Control) on Estimated CRF and Mental Health Outcomes.

DV		R^2	*b*	*SE b*	95% CIs	*p*
		.21				<.01**
Depression	Estimated CRF		−0.26	0.77	[−1.80, 1.29]	.74
	Group		−7.96	24.57	[−57.01, 41.08]	.75
	Sex		2.55	2.54	[−2.53, 7.63]	.32
	Estimated CRF × Group		<0.001	0.58	[−1.16, 1.16]	1.00
		.19				<.01**
Anxiety	Estimated CRF		−0.04	0.66	[−1.35, 1.27]	.95
	Group		−8.78	20.89	[−50.48, 32.92]	.68
	Sex		4.22	2.16	[−0.10, 8.54]	.06
	Estimated CRF × Group		0.06	0.49	[−0.93, 1.04]	.91
		.27				<.001***
Stress	Estimated CRF		−0.60	0.72	[−2.03, 0.84]	.41
	Group		−11.90	22.93	[−57.68, 33.87]	.61
	Sex		2.38	2.38	[−2.36, 7.12]	.32
	Estimated CRF × Group		0.09	0.54	[−0.99, 1.18]	.86

Note. Sex was used as a covariate. CRF = Cardiorespiratory Fitness.
*p < .05. **p < .01. ***p < .001.

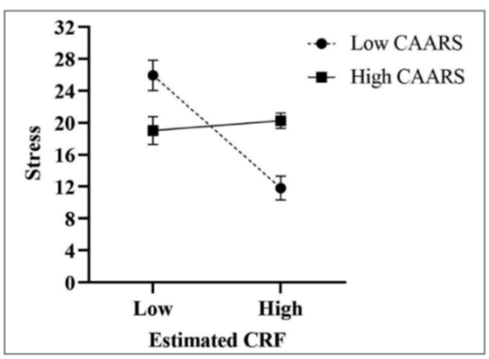

Figure 2. The moderating effect of ADHD symptom severity (CAARS) within the ADHD group on the relationship between estimated CRF and stress. Error bars represent standard error. "Low CAARS" represents one standard deviation below the mean CAARS score (65.0–72.9) and "High CAARS" represents one standard deviation above the mean CAARS score (86.9–90.0), within the ADHD group.

reported greater anxiety and stress symptoms than those who were not. In contrast, only one participant formally disclosed taking medication for their mental health, suggesting there may be an important treatment-gap for mental health in adults with ADHD.

The bidirectional relationship between ADHD and mental health means that the two can exacerbate each other (Austerman, 2015). Mental illnesses like depression and anxiety can impair concentration and augment the cognitive and behavioral symptoms of ADHD (Pan & Yeh, 2017). Although it is true that mood and emotional problems can be a side effect of ADHD medications (Tobaiqy et al., 2011), many people with ADHD report experiencing anxiety and depression from the sheer act of navigating in a world that is constrained by neurotypical societal expectations (e.g., the expectation that one must sustain focus for long periods of time at work or school) (Björk et al., 2018). Poorer academic achievement, poorer occupational attainment, and lower socioeconomic status are some of the negative fallouts of such a mismatch (Arnold et al., 2020; Goffer et al., 2022), which in turn, can exacerbate their psychological burden. Therefore, in

Table 6. Regression Coefficients of the Moderating Effect of ADHD Symptom Severity (CAARS Score) on Estimated CRF and Mental Health Outcomes.

DV		R^2	b	SE b	95% CIs	p
		.12				.55
Depression	Estimated CRF		−6.71	4.51	[−15.92, 2.50]	.15
	CAARS		−3.30	2.32	[−8.05, 1.44]	.17
	Sex		0.98	4.42	[−8.04, 10.01]	.83
	Medication		2.33	4.07	[−5.98, 10.63]	.57
	Estimated CRF × CAARS		0.08	0.06	[- 0.03, 0.20]	.16
		.27				.08
Anxiety	Estimated CRF		−5.45	3.74	[−13.09, 2.19]	.16
	CAARS		−3.12	1.93	[−7.06, 0.81]	.12
	Sex		4.10	3.67	[−3.39, 11.59]	.27
	Medication		8.15	3.38	[1.26, 15.04]	.02*
	Estimated CRF× CAARS		0.07	0.05	[−0.03, 0.16]	.14
		.35				.02*
Stress	Estimated CRF		−8.31	3.72	[−15.92, −0.71]	.03*
	CAARS		−4.10	1.92	[−8.02, −0.18]	.04*
	Sex		−1.31	3.65	[−8.76, 6.14]	.72
	Medication		7.68	3.36	[0.83, 14.54]	.03*
	Estimated CRF × CAARS		0.10	0.05	[0.004, 0.19]	.04*

Note. Sex and medication use were covariates. CRF = Cardiorespiratory Fitness.
$*p < .05$. $**p < .01$. $***p < .001$.

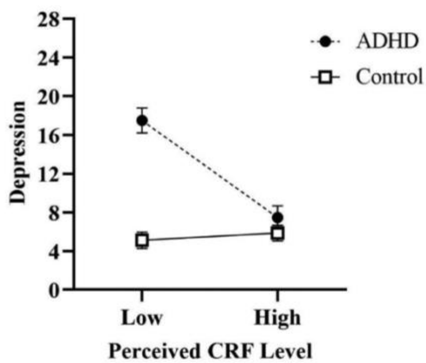

Figure 3. The moderating effect of group (ADHD vs. Control) on the relationship between perceived CRF and depression. Error bars represent standard error.

addition to advocating for societal shifts to promote the inclusivity of neurodivergence, there is an immediate need for mental health support for individuals with ADHD.

While acknowledging the cross-sectional nature of our data, our results suggest that increasing physical fitness may be a promising mental health strategy for adults with ADHD. Across both groups, higher CRF was associated with less depression, anxiety, and perceived stress symptoms. Among participants with ADHD, those with higher perceived CRF had fewer depressive symptoms and those with higher estimated CRF had lower perceived stress levels. Notably, these fitness-related differences for ADHD participants were associated with categorical differences in mental health symptom severity. Specifically, higher fit individuals were classified as "normal" for depression and perceived stress, whereas lower fit individuals were classified as "moderate" for depression and "severe" for perceived stress. When compared to their neurotypical peers, the average estimated CRF for participants with ADHD was not statistically different. Prior research has reported lower CRF in men with ADHD (K. Fritz & O'Connor, 2018; Jeoung, 2014), whereas our sample was predominantly women (ADHD = 64%; control = 75%), suggesting there may be gender or sex differences to explore. It is also important to note that the association between fitness and perceived stress was only observed for individuals with mild ADHD symptoms. Those with more severe ADHD symptoms did not see a similar pattern, suggesting that this subset may require additional support to protect against poor mental health.

Strengths and Limitations

Although the virtual nature of the protocol provided engagement opportunities for those who may not have been able to participate in a laboratory-based setting, it created limitations too. Gold-standard measures for estimating CRF were unavailable (i.e., VO_2 max tests); instead, participants self-completed HR measurements and a 6MWT which was

Table 7. Regression Coefficients of the Moderating Effect of Group (ADHD vs. Control) on Perceived CRF and Mental Health Outcomes.

DV		R^2	b	SE b	95% CIs	p
		.33				<.001***
Depression	Perceived CRF		−14.15	4.18	[−22.50, −5.80]	<.01**
	Group		−16.61	4.07	[−24.73, −8.49]	<.001***
	Sex		2.97	2.25	[−1.52, 7.46]	.19
	Perceived CRF × Group		7.39	2.71	[1.98, 12.80]	.01*
		.24				.001**
Anxiety	Perceived CRF		−6.10	3.76	[−13.60, 1.40]	.11
	Group		−9.18	3.66	[−16.47, −1.88]	.01*
	Sex		3.82	2.02	[−0.22, 7.85]	.06
	Perceived CRF × Group		2.76	2.44	[−2.10, 7.62]	.26
		.35				<.001***
Stress	Perceived CRF		−10.47	4.01	[−18.48, −2.46]	.01*
	Group		−12.63	3.90	[−20.43, −4.84]	<.01**
	Sex		3.14	2.16	[−1.16, 7.45]	.15
	Perceived CRF × Group		4.39	2.60	[−0.80, 9.58]	.10

Note. Sex was used as a covariate. CRF = Cardiorespiratory Fitness.
*$p < .05$. **$p < .01$. ***$p < .001$.

Table 8. Regression Coefficients of the Moderating Effect of ADHD Symptom Severity (CAARS) on Perceived CRF and Mental Health Outcomes.

DV		R^2	b	SE b	95% CIs	p
		.27				.07
Depression	Perceived CRF		2.37	28.39	[−55.60, 60.35]	.93
	CAARS		−0.07	0.49	[−1.07, 0.92]	.88
	Sex		2.15	3.62	[−5.25, 9.56]	.56
	Medication		1.69	3.64	[−5.74, 9.12]	.65
	Perceived CRF × CAARS		−.12	0.35	[−0.84, 0.60]	.73
		.30				.05
Anxiety	Perceived CRF		18.95	25.48	[−33.09, 71.00]	.46
	CAARS		−.11	0.44	[−1.00, 0.79]	.81
	Sex		4.43	3.25	[−2.22, 11.07]	.18
	Medication		7.84	3.26	[1.18, 14.51]	.02*
	Perceived CRF × CAARS		−.28	0.32	[−0.93, 0.36]	.38
		.38				.01*
Stress	Perceived CRF		22.47	25.38	[−29.37, 74.30]	.38
	CAARS		0.24	0.44	[−0.65, 1.13]	.59
	Sex		1.77	3.24	[−4.84, 8.39]	.59
	Medication		8.40	3.25	[1.76, 15.05]	.01*
	Perceived CRF × CAARS		−.35	0.32	[−0.99, 0.30]	.28

Note. Sex and medication use were covariates. CRF = Cardiorespiratory Fitness.
*$p < .05$. **$p < .01$. ***$p < .001$.

unsupervised and completed on an unstandardized path. Although both measures were correlated ($r = .34$, $p < .01$), the self-reported measure of CRF was more sensitive to individual variations in mental health. Specifically, higher *perceived* CRF was associated with lower depression, anxiety, and perceived stress, whereas higher *estimated* CRF was only associated with lower perceived stress. These minor differences in associations with the CRF measurements may reflect the risk of measurement error due to the virtual nature of the study design and point to the need for further lab-based studies that include standardized questionnaires to assess perceived CRF (e.g., Monroe et al., 2010) and gold standard approaches for estimated CRF (e.g., VO2 max). Virtual protocols also introduce selection biases; participants needed a computer, smartphone, and internet access to participate. Furthermore, given the cross-sectional study design, we are unable to speak about the causality of the observed relationships between CRF and mental health in adults with ADHD; it is possible that those with poor mental health are less likely to maintain a regular exercise regime needed to increase fitness. Through randomized controlled trials, both causality and mechanisms can be explored to determine whether CRF is a modifiable and protective factor for this population and, therefore, such an approach would be advisable for future research.

Conclusions

In our sample, participants with ADHD had poorer mental health than neurotypical controls. However, having higher fitness was associated with better mental health. Specifically, among those with less severe ADHD symptoms, higher CRF was associated with less depression, anxiety, and perceived stress. Future research is needed to examine the causal relationship between fitness and mental health in adults with ADHD, while also accounting for individual differences in the severity of both ADHD and mental health symptoms.

Acknowledgments

The authors would like to thank Victoria Cirone for her support on the project and members of the NeuroFit Lab.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Funding for this project was provided by Tier 2 Canada Research Chair in Brain Health and Aging [20013825].

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CHAPTER 4:

Exploring barriers and facilitators to physical activity in adults with ADHD: A qualitative investigation

Preamble

Exploring barriers and facilitators to physical activity in adults with ADHD: A qualitative investigation serves as the third and final study in this dissertation. Through semi-structured interviews, key barriers and facilitators to being physically active for adults with ADHD were identified and organized thematically using the Theoretical Domains Framework.

The chapter is included in manuscript form, which has been accepted in the *Journal of Developmental and Physical Disabilities.* The manuscript is formatted in alignment with the author guidelines for the *Journal of Developmental and Physical Disabilities* and is included as accepted for publication. The published version of this manuscript can be found at: https://doi.org/10.1007/s10882-023-09908-6.

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Contributions of Study 3 to the overall dissertation
Physical activity is an important precursor to improving CRF; however, adults with ADHD tend to engage in less physical activity than their neurotypical peers. Study 3 is the first to identify the unique barriers and facilitators to physical activity from the perspective of adults with ADHD. Data from 30 semi-structured interviews were thematically analyzed and organized using the Theory Domains Framework. Unique ADHD-related barriers (e.g., feeling over/under-stimulated or executive dysfunction) made goal-oriented, planned behaviour challenging to follow through. However, unique facilitators (e.g., "quenching" hyperactivity or managing ADHD without medication) were related to improved physical activity engagement. Results from this study can be used to inform the development of physical activity resources designed to meet with unique needs of those with ADHD.

Journal of Developmental and Physical Disabilities
https://doi.org/10.1007/s10882-023-09908-6

ORIGINAL ARTICLE

Exploring Barriers and Facilitators to Physical Activity in Adults with ADHD: A Qualitative Investigation

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Accepted: 27 March 2023

Abstract
Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by executive dysfunction. Physical activity (PA) may improve executive dysfunction; however, specific barriers and facilitators to PA participation for adults with ADHD have not been formally documented, which was the aim of the present study. Thirty adults with ADHD completed virtual semi-structured interviews, which were analyzed thematically and guided by the Theoretical Domains Framework. Expressions of both barriers and facilitators to PA were identified. Themes such as executive dysfunction (described as forgetfulness, difficulty with sustained focus, and time management), poor self-esteem, and lack of motivation were seen as barriers to PA. Key facilitators were tied to the benefits of being physically active including improvements in executive functioning, mood, and mental health during and after activity, as well as the enjoyment of being active with others. To better support adults with ADHD in initiating physical activity, it is crucial to develop unique resources that are tailored to their specific needs. These resources should be designed to minimize barriers and maximize facilitators, while also supporting the awareness and acceptance of neurodiverse experiences.

Keywords ADHD · Physical activity · Qualitive · Barrier · Facilitator

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Published online: 04 May 2023

Introduction

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by persistent patterns of inattention and/or hyperactivity-impulsivity that is rooted in deficiencies of executive functioning including inhibition, working memory, and task switching (Felt et al., 2014). Because executive functions are needed for effective decision making (Cristofori et al., 2019), individuals with ADHD often struggle to complete routine tasks, resulting in a sense of underachievement that negatively impacts their daily life (Matheson et al., 2013). While ADHD is commonly diagnosed during childhood, estimates suggest that 65% of childhood ADHD cases persist into adulthood (Wesemann & Van Cleve, 2018) affecting approximately 5% of adults globally (Song et al., 2021). Yet, research on adults with ADHD is lacking (Schneider et al., 2019). In fact, there is a misconception that ADHD is restricted to childhood and, therefore, adults with ADHD are left under-supported by social services and insurance coverage (Singh & Tuomainen, 2015). Furthermore, the first line of treatment for managing symptoms of ADHD is psychostimulant medication (Meppelink et al., 2016); however, research on children suggests that 30% of users do not respond to medication (Geladé et al., 2017). For those who do respond, they can experience an array of unpleasant side effects coupled with the uncertainty concerning the long-term efficacy of using the medication into adulthood.

Physical activity (PA) interventions may be a viable supplementary approach for both children and adults with ADHD. When children with ADHD engage in acute (< 30 min/short-term) and chronic (over the span of several weeks) PA, they can experience notable improvements in their executive functions, including inattention, impulsivity, response inhibition, vigilance, set switching, cognitive control, organization, and planning (Den Heijer et al., 2017; Ng et al., 2017; Pontifex et al., 2014; Quesada et al., 2018; Suarez-Manzano et al., 2018). In turn, PA can improve their academic performance, reading skills, and arithmetic ability (Den Heijer et al., 2017; Ng et al., 2017; Pontifex et al., 2014). It can also reduce certain behavioural symptoms associated with ADHD by boosting self-esteem, wellbeing, and social functioning, while also diminishing interruptive behaviours and comorbid conditions of anxiety and depression (Den Heijer et al., 2017; Pontifex et al., 2014). The sparse evidence available suggests that adults with ADHD experience similar benefits from PA as children with respect to executive functions of inattention, impulsivity, and response inhibition (Den Gapin et al., 2015; Heijer et al., 2017; Mehren et al., 2019). Additionally, physically active adults with ADHD tend to be more motivated, and less worried, tired, and depressed (Den Heijer et al., 2017).

Despite these documented benefits, PA engagement by people with ADHD tends to be lower than their neurotypical peers (i.e., those with typical neurodevelopment; Cook et al., 2015; Fritz & O'Connor, 2018; Quesada et al., 2018) and, in turn, they experience elevated risk of metabolic conditions (e.g., metabolic syndrome and Type 2 diabetes; Landau & Pinhas-Hamiel, 2019). It is conceivable that specific symptoms of ADHD may create unique barriers to engaging in regular PA (Pontifex et al., 2014). For example, given the deficits in the dopamine reward system in the brains of those with ADHD, if a task does not immediately elicit a sense of reward there may be poorer motivation to complete it (Addicott et al., 2019; Barkley et al., 2019). However, to date, there is limited qualitative data directly investigating the lived experiences of adults with ADHD, and their personal accounts of barriers to and facilitators of PA (Bussing et al., 2011; Harvey et al., 2014; Singh & Tuomainen, 2015; Taylor & Foreman, 2019). Identifying barriers and facilitators are important for informing the future development of interventions, and supporting behaviour change in this population (Hussein et al., 2021). The aim of the present study was to fill that gap using semi-structured interviews to capture the lived experiences of adults with ADHD. Questions queried participants' perceived impact of PA on ADHD symptoms, barriers and facilitators to being physically active, and opinions concerning needed supports and directions for future research.

Methods

Participants

Participants were 30 Canadians between the ages of 18–65 years old, who could communicate in spoken English and had a clinical diagnosis of ADHD. In addition to their self-reported clinical diagnosis, the Conner's Adult ADHD Rating Scale (CAARS) was used to confirm the presence of ADHD symptoms (Conners et al., 1998). Given COVID-19 restrictions, participants were recruited primarily using social media—specifically via a Canadian adult ADHD Facebook group and through Twitter. Previous participants from ADHD studies in McMaster's NeuroFit lab were also contacted. The sample size was determined using existing recommendations of 25–30 participants minimum to reach saturation for interview studies (Dworkin, 2012). All procedures were approved by the McMaster Research Ethics Board (#2557), which participants received information about in advance of scheduling their interview. Prior to starting the interview, participants were reminded of the research protocol, that their participation was completely voluntary, that they were able to withdraw their consent at any time, and that their data would be anonymized. Participants provided informed verbal consent to be interviewed and were compensated with a $15 gift card.

Interview Design and Delivery

Semi-structured, one-on-one interviews were conducted via Zoom in an open-ended manner. All interviews were conducted by M.O., a PhD candidate in the NeuroFit lab with training in conducting qualitative work. MO is a woman in her late twenties who studies ADHD and has experience both personally and professionally in connecting with neurodiverse people. Aligning with other qualitative work, the interview consisted of 11 primary questions (see Appendix; Abdelghaffar et al., 2019; Gilbert et al., 2019; Martínez-Andres et al., 2020; Yungblut et al., 2012). We operationally defined PA to participants as any incidental, occupational, and structured movement at all intensities. Given that the interviews took place during the

COVID-19 pandemic (March to April 2022), which may have impacted PA behaviour and wellness (Marashi et al., 2021), specific questions were included to contextualize participant experiences before the pandemic, during lockdowns, and at the time of their interview. The interviews were between 20 to 65 min in length, with an average interview time of 40 min ± 12 SD. Interviews concluded with an open-ended question where participants were given the opportunity to discuss anything else that they thought would be relevant to the subject matter, which introduced variability to interview length. After the interview had concluded, participants were debriefed on the purpose of the study and the current evidence supporting benefits of PA for those with ADHD.

Analysis

A total of 30 interviews were completed, with no participant drop out. All interviews were recorded and automatically transcribed via Zoom. Prior to data analysis, transcripts were reviewed against audio recordings by two members of the team (S.K. and B.M.) to ensure accuracy. The transcripts were then loaded into MAXQDA 2022 (1.1) (Kuckartz & Rädiker, 2019) to be analyzed thematically first using an open-coding approach (Walker & Myrick, 2006). Three coders (B.M., S.K., M.O.) conducted the analysis using a stepwise approach, leveraging suggestions outlined by Maguire and Dalahunt (2017) and Connor and Joffe (2020) to improve rigour. While recognizing that a researcher's personal lens is part of the process when reviewing qualitative data, including multiple coders helped to limit individual bias.

A flow diagram of the analysis process can be seen in Fig. 1. During step one, coders independently reviewed the first five transcripts to familiarize themselves with the data, noting down codes using open coding. Coders then met to create the preliminary codebook. Using the codebook, the coders independently coded the first five interviews. Their codes were compared using the Intercoder Agreement in MAXQDA and resulted in inter-coder reliability (ICR) comparisons > 0.8. ICR is a measure of agreement between different coders reviewing the same data and a score of 0.8 or greater has been noted as an excellent threshold for reliability (Connor & Joffe, 2020). During step two, coders independently reviewed five more interviews (ICR > 0.8) and met to discuss any new codes. After this meeting, all remaining interviews were coded. Anytime a new code was added, previous interviews were recoded (ICR > 0.8). Code saturation was reached when no additional codes were identified and the codebook stabilized (Hennink et al., 2017). In step three, each coded interview was reviewed as a group and themes were generated. Any discrepancies were discussed until a consensus was reached. In step four, the final themes were reviewed and, using a deductive approach, each coder grouped the themes into the domains of the Theoretical Domains Framework (TDF); Atkins et al., 2017). Organization of themes into this behaviour change framework was then reviewed collaboratively and finalized for reporting. Representative excerpts from participants were identified to authentically capture the participants' perspectives.

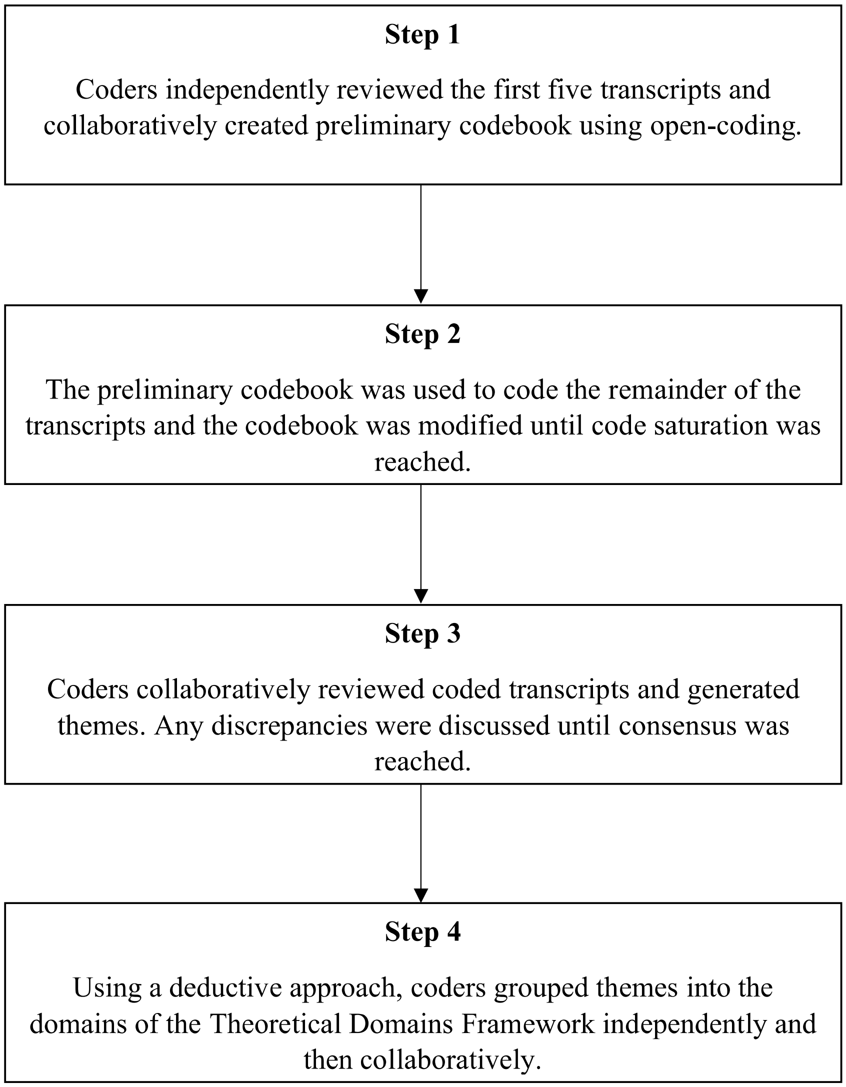

Fig. 1 Overview of steps of thematic analysis

The TDF consists of twelve tenets to explain how behaviour change occurs, including: knowledge; identity; memory, attention, and decision processes; emotions; beliefs about consequences; social influences; beliefs about capabilities; motivation and goals; behavioural regulation; nature of the behaviours; skills, and; environmental context and resources (Atkins et al., 2017).

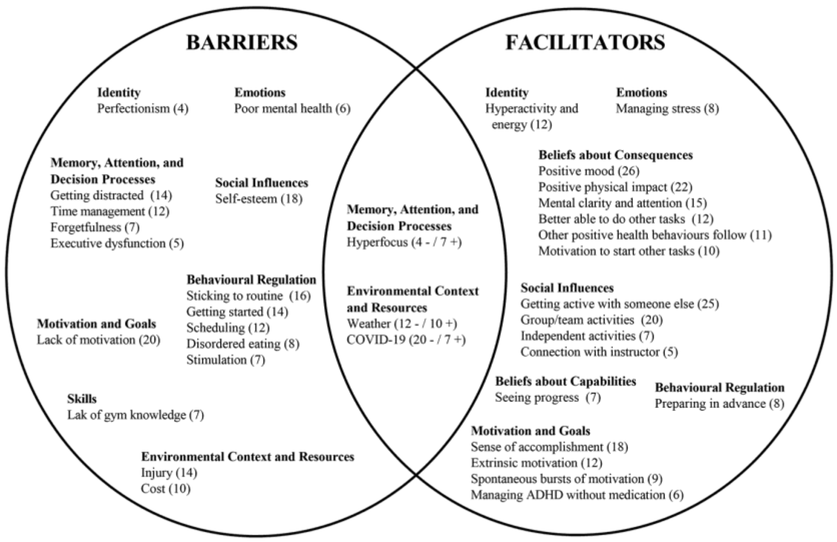

Fig. 2 Barriers and facilitators to physical activity for adults with ADHD, categorized within the Theoretical Domains Framework. *Bolded headings represent domains from the TDF. Written words below represent identified themes. Numbers represent frequency of theme out of 30 total interviews [when theme overlapped, barrier (-) and facilitator (+)]*

This framework has been previously applied when analyzing and reporting qualitative data assessing PA barriers and facilitators in stroke survivors, pregnant women, school-based programs, and adults (Flannery et al., 2018; Nicholson et al., 2014; Spiteri et al., 2019; Weatherson et al., 2017). Results of the analysis are organized below using participant quotes within the context of the 12 domains from the TDF. See Fig. 2 for an overview and frequency count of themes within each domain.

Results

Demographics

Participants were 18 to 56 years old (Mean = 29.6, SD = 9.9) and consisted of 25 women and five men, all cis gender. Age of ADHD diagnosis ranged from seven to 56 years old. Twenty-seven participants had a CAARS score > 65; three participants scored below (two participants scored 64, one scored 52). While a score of 65 has been listed as a suggested cut-off, individuals with scores below 65 have been noted to experience similar symptomology (Harrison et al., 2019). As such, all participants were included in the analysis.

Seventy-seven percent reported using ADHD medication at some point since their diagnosis, and 70% were currently using medication. Sixty-seven percent had another diagnosed disorder—most commonly anxiety (40%) and/or depressive (40%) disorder. See Table 1 for a description of participant demographics and Fig. 2 for an overview of identified barriers and facilitators.

Table 1 Participant Demographic Characteristics

Characteristic	Variables	N
	Total	30
Age		
	18–24	10
	25–34	13
	35–44	5
	45–54	0
	55–64	2
	Mean Age (SD)	29.63 (9.85)
Gender		
	Man	5
	Woman	25
	Non-Binary	0
Highest Level of Education		
	Less Than High School	2
	High School Diploma	10
	College Degree/Certificate	5
	Bachelor's Degree	11
	Master's/Professional Degree	2
Age of ADHD Diagnosis		
	Under 12 Years Old	5
	12–17	6
	18–24	9
	25–34	5
	35–44	3
	45–54	1
	55–64	1
ADHD Subtype		
	Hyperactive	0
	Inattentive	6
	Combined	4
	Unsure/Not Identified	20
Comorbid Diagnoses		
	Anxiety Disorders	12
	Mood Disorders	12
	Autism Spectrum Disorder	0
	Other Disorder Not Specified Above	10

Knowledge – Knowledge About PA and the Effects of PA for ADHD

Almost a third of participants reported having no formal knowledge about the relationship between PA and ADHD symptoms. Half reported knowing "a little bit", but very few were confident in this knowledge. Yet, when asked to reflect on their own experiences with PA, more than half believed that exercise likely benefited people with ADHD more than neurotypical people.

> *"I think it's one of those things where if I don't exercise, I'm a terrible person like for myself and others around me where I feel like if somebody who is neurotypical doesn't exercise they're still able to function in the world."*

Identity – Personal Factors that Influence PA Engagement

Hyperactivity and high energy levels were noted as a PA facilitator for over a third of participants. However, not all people with ADHD experience hyperactivity (Mowlem et al., 2019; Roberts et al., 2017), and therefore, its role as a PA facilitator may be limited to a subset of individuals with ADHD. *"If you're hyperactive, one way to quench that is to be active."*

Perfectionism was identified as a PA barrier by participants, who likened their need to be 'perfect' to their ADHD. *"[Those with ADHD] get too nuanced in having the right stuff I find. A lot want to be perfect about it from the outset. Because you feel imperfect."*

Memory, Attention, and Decision Process – Influence of Memory, Attention, and Decision on Engagement in PA

"Executive dysfunction", a hallmark symptom of ADHD, was explicitly identified by participants as a PA barrier. Executive dysfunction made goal-oriented, planned behaviour challenging, such that participants wanted to be physically active but felt that they could not follow through.

> *"...there are times where you know I really want to go to the gym but that executive dysfunction kicks in and I just don't want to go, or my brain is telling me like go to the gym you have to do it, but my body is like no you're just going to stay here in bed."*

Getting distracted, whether it be following instructions or during active participation, was a significant PA barrier, reported by almost half of participants. *"When I'm working out, if I'm lifting weights by myself like I just get so distracted and then it takes me so long to get through my workout because I just get distracted."*

Forgetfulness (i.e., forgetting to be physically active or forgetting equipment) was identified as a PA barrier. *"I would say it's mostly the working memory and the forgetting to exercise because some days I'll be like oh yeah I really I intended to work out today, but now I'm in bed and it's 10 o'clock."*

Time-management difficulties, including experiences with time-blindness (i.e., being unaware of how much time is passing) and taking longer to do other tasks, was a PA barrier for over a third of participants. *"In between sets, I go on my phone and then sometimes…a lot of the time I don't realize how long I've been on my phone. And then I never remember that I'm at the gym."*

Hyper-fixation (i.e., being particularly concentrated on one thing; Hupfeld et al., 2019), was identified as both a barrier and facilitator. While fixating on another task (that was not PA) was a barrier for participants, hyper-fixating on PA was a facilitator.

> *"Like if it's work, for example, I'll get hyper-focused on that, and then I forget oh it's 10 o'clock at night and I wanted to do something like a yoga practice."*
> *"When I decide that I want to go to the gym, I can't stop thinking about it until I go."*

Emotions – Affective States that Influence PA Engagement or Result from PA Engagement

Poor mental health was a barrier for participants who found that feeling depressed or anxious made it difficult to engage in PA. *"And especially since comorbidities [alongside having ADHD] with anxiety and depression can come by which can just make it a lot harder to like just get the basic exercise."*

Using PA to manage stress and feeling well-rested was identified as a facilitator.

> *"Exercise helps to process stress and I think it's even more important because I went up into a manager role, which is increasing executive functioning requirements, which is more difficult for ADHD-ers. Access to lunch hour and that exercise at lunch was removed, and it was really, really challenging."*

Beliefs About Consequences – Expectations About Being Physically Active

The positive impact of PA on mood was a facilitator for almost all participants. Being physically active increased mental clarity and attention on subsequent tasks for half of the participants. Two thirds of participants reported that being less physically active decreased their mood and mental health and led to poorer focus.

> *"Some of the noise quiets down [after being active], and I'm able to focus more on what's happening immediately in front of me."*
> *"But I do find that when my activity is down, my depression does increase, and I do get more anxiety and more scattered brain and less focused."*

Positive physical health outcomes (i.e., fitness, weight management, relaxation) and feeling physically better were described as PA facilitators by the majority of participants. Additionally, a third of participants noted how once they engaged in PA, other positive health behaviours followed (i.e., routine, sleeping habits, eating habits). *"[Exercising] start[s] cascading effects for every other kind of health benefit in my life. So yeah, kind of started that first domino for me."*

A third of participants identified that being physically active resulted in the motivation to start other tasks. Participants also noted that they were not only more motivated to start other tasks, but better able to do them after being physically active. *"That's a really productive way for my ADHD to be and it gives me so much energy to keep going and doing stuff."*

When discussing the benefits of being physically active, most participants acknowledged that the benefits were most prominent following activity and that those benefits lasted anywhere from a few hours to the full day, with a few identifying benefits beyond the day.

Social Influences – Social Aspects that Influenced PA Engagement

Social pressures and feelings of self-consciousness relating to body image and self-esteem were PA barriers for over half of participants.

> *"People that struggle with having a lack of exercise with ADHD oftentimes it's something else too, it's not just an ADHD symptom, you know its body dysphoria which could be a symptom from ADHD or something comorbid that maybe isn't diagnosed."*

Almost all participants highlighted that the social support from getting active with someone, or "body-doubling", was a facilitator to being physically active. *"Since finding out about my ADHD, I found that body doubling is a very strong motivator. It makes things easier."*

Group or team activities were PA facilitators for the majority of participants, who reported feeling a sense of community that led to less loneliness and more fun. However, seven participants felt deterred by group activities and preferred to be physically active alone because it meant they could avoid the fear of letting someone else down.

> *"I also play soccer in the men's league just to get a bit more group activity, because the gym is typically a lonely thing."*
> *"But things like running, yoga, I'm like okay, no one's depending on me, I could do this myself."*

A meaningful connection with the instructor (i.e., they were friendly, provided well-paced instructions that avoided cognitive overload) was identified as a PA facilitator by a few participants. *"It's a little different when you have someone that is like a drill sergeant and you're like okay you're a little scary, and this is too fast, and this is too much stuff for my brain."*

Beliefs About Capabilities – Self-perceptions of Abilities to Engage in PA

A third of participants reported that "seeing progress" with perceived increases in competence, confidence, and self-esteem was an important PA facilitator. *"A lot with going to the gym you're going to see progress, and the progress is what really keeps me going."*

Motivation and Goals – Reasons Participants Did or Did Not Want to Engage in PA

Not being motivated (in general) was a PA barrier for many participants, and was particularly true during the COVID-19 lockdowns. *"I really wish [getting physically* *active] was easier. I like being active. I like feeling active it's just… it feels like such a Herculean task."*

When discussing specific facilitators for PA, examples could be categorized into extrinsic and intrinsic motivators. Extrinsic motivators (i.e., looking good, training for a competition, or being a good role model) and being goal-oriented were PA facilitators. *"So a couple weeks ago I was at a wedding it motivated me to work out a little bit wanted to fit into my suit nicely."*

Intrinsic motivators (i.e., feeling a sense of accomplishment, capitalizing on bursts of motivation, and managing ADHD symptoms) were PA facilitators. More than half of participants described that the sense of accomplishment felt from being physically active motivated them.

> *"I feel in control like hey look, I was able to do something I wasn't motivated to do, I was able to put a plan into action that I wanted to do, and with ADHD, that's a really big success."*

Experiencing spontaneous bursts of motivation, attributed to their ADHD, was a PA facilitator for participants**.** As one participant shared, predicting "when the spirit will move [them]" is difficult, but when a burst in motivation occurs, they are compelled to be active and follow through. *"Let's say like for three weeks, you haven't been doing a lot of physical activity and then one day ADHD is just like we have to do this right now."*

Participants were motivated to be physically active to manage their ADHD without medication, as they felt similar benefits without negative side effects.

> *"I didn't want to jump right into medication, and it's still something that I'm on the fence about but I'm willing to try, but I wanted to see if there were ways to manage my ADHD without relying on medication per se."*

Behavioural Regulation – Planning Processes for Engaging in PA

Both in relation to their ADHD and more broadly, scheduling (i.e., not enough time, inconvenient timing) PA was a barrier. Over half of participants felt that even after scheduling in PA, it was difficult to stick to their plan and noted a disconnect between their intentions and ability to follow through. *"I feel like it's never a good time [to be active] because I make myself believe that it's not a good time."*

Participants commented that the ability to "get going" or start being physically active was "a big hurdle". Once PA was initiated, participants highlighted a lack of structure and boredom as significant barriers to regulating their behaviour and completing PA. *"Sometimes it's harder, again executive functioning, we're not on the same level as like people who probably don't have ADHD so it's like when you don't have that motivation its harder to get it and to start."*

Disordered eating (i.e., lack of hunger cues as a side effect from ADHD medication, concurrent diagnoses of eating disorders) was a PA barrier for participants, as having limited energy input made engaging in and following through with PA difficult.

"When I was on Adderall, I ended up losing almost 40 pounds in the span of a year... yes, I can work out every morning, but then I'm not putting back in the energy in my body, so the rest of the day I would be mentally like, "great I did a workout" but physically I'd be exhausted, I'd be starving, I'd feel groggy. I think that also could be the reason why I stopped working out. Instead of feeding myself, I'm just going to end the thing that's making me hungry."

Some participants mentioned that "stimulation" impacted PA levels. As a barrier, feeling overstimulated by other tasks outside of being physically active could lead to feeling "couch locked". As a facilitator, the PA needed to be mentally and physically stimulating to make engagement worthwhile. *"I prefer to do things with friends or like physically stimulating and mentally stimulating things so if there's nothing to encourage me it's just not going to happen. I feel like that's the ADHD version."*

Preparing in advance or taking pre-planned actions was a PA facilitator for a few participants. *"The night before I'll usually have my gym bag packed, I'll usually have breakfast half meal prepped in the fridge. All those things add up to just getting going in the morning."*

Nature of the Behaviours – Developed Routines and Past Experiences with PA

Over half of the participants believed that their previous experiences and past PA behaviours impacted their current decisions to be active. Habitual PA early in life was a PA facilitator for most participants because it established a framework for how to build a routine and use PA to manage ADHD symptoms.

"I never realized the impact [of exercise] on my ADHD until definitely later in life... I feel like I've always had an urge to be physically active. I don't know if that's innate or if that's because I started early."

Skills – Abilities and Strategies for Engaging in PA

A lack of gym knowledge was a PA barrier for a few participants. They discussed skills in the context of having (or not having) the competency or ability necessary to do their PA of interest. *"Or not knowing how to like... not knowing gym equipment very well, but wanting to learn, but being too scared to try learning on my own, where there could be other people watching me or judging me."*

Environmental Context and Resources – Circumstances and Conditions Impacting PA Engagement

Physical injuries, weather, and cost were acknowledged as PA barriers by many participants. The COVID-19 pandemic was an environmental stressor for most participants who noted that pandemic-related changes (i.e., self-isolation, gym closures, and fear of contracting COVID) created PA barriers and led them to be more sedentary.

"These places want to charge you an arm and a leg and the government doesn't support you, because they don't think ADHD is a disability. Then it's like, if you don't have the financial means, you can't do the physical."
"Once the pandemic hit there was a good period of time where I didn't leave the house at all. I barely left my room so there was no physical activity."

Convenience and accessibility (i.e., access to transportation, proximity to activity space, and having time) were identified by two thirds of participants as PA facilitators. While most participants reported negative impacts pertaining to COVID, seven participants described being more active during the pandemic because they had more free time.

"Pandemic was nice because I was able to put in that time to start building that sort of dopamine reward system in an environment that was very low on barriers. I didn't have to worry about, you know, showering right after for a meeting."

Beyond TDF Domains – Future Considerations

After reflecting on their relationship with PA, participants were asked to share their thoughts on the next steps for future ADHD supports and research. While opinions varied, examples brought up included increasing knowledge about ADHD in adulthood and in women. Over half of participants mentioned wanting tailored, credible, and accessible information about being physically active with ADHD. Participants felt that general guidelines did not always work for them and wanted specific information about how PA impacts symptoms of ADHD, as well as specific strategies for navigating executive dysfunction during exercise. For example, a participant explained how coaches and instructors should be aware that people with ADHD may have different cognitive needs and should be mindful of factors such as instruction pace and detail to ensure everyone can comfortably participate. Finally, a few participants spoke of wanting a sense of community in the form of community classes, events, or support groups specific to those with ADHD.

"ADHD is still one of those invisible illnesses that's not so understood. You're really trying to advocate for yourself against people who don't have resources themselves."
"…where it's like well that could work for them, but I don't see how that could work for me."

Discussion

This is the first study to identify the perceived barriers and facilitators of PA by adults with ADHD. Thirty semi-structured interviews were conducted, analyzed into prominent themes and categorized using the Theoretical Domains Framework (TDF), which has been previously used to organize and conceptualize barriers and facilitators to PA in qualitative work (Flannery et al., 2018; Nicholson et al., 2014; Spiteri et al., 2019; Weatherson et al., 2017). Given the documented benefits of PA for ADHD (Den Heijer et al., 2017; Gapin et al., 2015; Mehren et al., 2019), recognizing what factors prevent and encourage adults with ADHD to engage in PA is important for behaviour change and making decisions about future research. In fact, methods for behaviour change underscore that the first step is to identify barriers and facilitators, from the population's perspective, that need to be overcome or leveraged (Atkins et al., 2017). Figure 2 provides an overview of the key barriers and facilitators noted by participants.

Based on individual accounts, one major barrier identified was a *knowledge gap* between adults with ADHD and the benefits of PA. When facilitators were identified, almost all were tied to anecdotal experiences of the positive outcomes from PA including the expected benefits to executive functioning, mood, and mental health during or after being physically active. However, most participants reported having no formal education about the benefits of PA to help manage their ADHD symptoms. Additionally, participants who were not previously active—and therefore had not experienced the benefits of PA through past behaviours—were less likely to be active, a finding that is consistent with prior research (Telama, 2009). Ensuring that people are both knowledgeable about the benefits of PA and can get firsthand opportunities to experience the expected outcomes, may help create a positive cycle to increase PA engagement. Providing formal and credible education that is communicated by doctors, psychologists, teachers, and other care providers about the benefits of PA for individuals with ADHD is needed. Creating resources that educate about the connection between PA and ADHD and making them more accessible through avenues such as social media can also help bridge the knowledge gap. In behaviour change settings, communication from credible sources via social media has been beneficial for supporting health and weight management in the general population (Jane et al., 2018; Laverack, 2017) and may be valuable in promoting PA engagement for adults with ADHD.

Additionally, supports on how to navigate symptoms of ADHD when being physically active should be developed and, as revealed by the current findings, are critical for the initiation of PA. Almost all participants commented on feeling less inclined to engage in PA due to their executive dysfunction, a cognitive symptom of ADHD. Executive dysfunction caused problems with forgetfulness, sustained focus, and time management, and made it difficult for participants to initiate PA, despite their best intentions. Like executive dysfunction, hyper-focus, a symptom of ADHD, was a barrier when the focus was directed toward other non-PA tasks. Coping strategies like action planning and advanced preparation were noted by participants as effective for helping to overcome their ADHD-symptom barriers and increasing PA participation. When reflecting on being physically active, participants noted benefits to their executive functioning, which aligns with previous research (Mehren et al., 2019). Having participants engage in more PA may, in turn, improve executive function and the self-regulatory skills needed to be physically active in the future (Daly et al., 2015). Another facilitator connecting to self-regulatory skills was "body doubling", a common term to describe completing a task with someone else, which can encourage accountability (Burke et al., 2006) and may be particularly useful for adults with ADHD who struggle to self-regulate behaviour. Strategies on how to overcome executive dysfunction and break up periods of hyper-focus such as using overt prompts (e.g., setting an alarm or having someone to check-in or be active with) may help promote PA engagement among adults with ADHD.

Poor self-esteem also prevented adults with ADHD from initiating PA. Compared to their neurotypical peers, children with ADHD tend to have lower self-esteem and more difficulty building relationships, which can carry on into adulthood (Gardner & Gerdes, 2015; Mikami & Normand, 2015), causing anti-social and avoidance behaviours that make it harder to engage in PA (Carter, 2018; Donnellan et al., 2005). As such, inclusive communities (e.g., ADHD groups) and social supports focused on building self-esteem and developing healthy relationships could also bolster PA participation among adults with ADHD. This may simultaneously benefit self-regulation through "body doubling" as mentioned above. Previous research has demonstrated that a sense of belonging or identity with a group is related to increased PA engagement and adherence in local neighborhood communities (Ross & Searle, 2019; Wood et al., 2010). Fostering a sense of community, beyond geographical location, may be valuable for increasing PA engagement in adults with ADHD.

Finally, level of "stimulation" was an ADHD-specific barrier that interfered with both the initiation and maintenance of activity. Being "overstimulated" prior to PA fostered a sense of overwhelm and posed as a barrier to initiating activity. However, the actual PA itself needed to be mentally and physically stimulating enough to maintain the activity, hold engagement, and avoid boredom. To help keep individuals with ADHD interested but not overwhelmed, simple adaptations can be made, such as keeping distractions out of sight and following a logical sequence of engaging activities (Taylor et al., 2019). Additionally, within the context of being physically active, creating more structure may not only reduce overstimulation but also symptoms of impulsivity, hyperactivity, and inattention that tend to worsen when the environment is too unstructured (Higgins et al., 2018; Taylor et al., 2019).

It is important to contextualize the data within our sample. Specifically, participants were mostly women (25/30) who were diagnosed later in life (17/25 diagnosed after 18 years of age) and who had struggled without treatment. Girls and women are more likely to be "missed" in childhood, and go undiagnosed (Quinn & Madhoo, 2014), because their symptoms differ from boys and men (i.e., suppressing hyperactivity symptoms, masking inattentive nature etc.; Holthe & Langvik, 2017). Many participants with late diagnoses voiced that it was "life changing" when they received their diagnosis. This underscores the value of this project in bringing to light the voices of those who often are underrepresented. There were also participants diagnosed with comorbid mental illnesses; 12 noted having an anxiety disorder and 12 noted having a mood disorder. While it is common for those with ADHD to suffer from comorbid mental illnesses (Gnanavel et al., 2019), participants' accounts of the benefits of PA on their ADHD symptoms may not be independent of the benefits to mental health (Kandola et al., 2019).

Strengths and Limitations

Strengths of the current work include the qualitative approach—as semi-structured interviews allow for more open-ended discussion that captures authentic experiences—and the large sample size of 30 participants. Although using a virtual platform allowed researchers to capture the experiences of adults with ADHD from across Canada, it limited participation to those who have access to some form of technology and social media. Additionally, participants self-reported their formal clinical diagnosis, and many were unsure of whether they were diagnosed with a particular ADHD subtype; no participants explicitly noted having a hyperactive subtype. While most participants were women, it is unclear why. Perhaps women who received later diagnoses are more likely to turn to social media for information and a sense of community. It has been previously documented that women with ADHD have higher rates of social media use (Young et al., 2020), which was our primary recruitment strategy.

While this work captures the lived experiences of 30 adults with ADHD, it does not capture everyone's experience. For example, no participants in our sample expressed their gender beyond the binary. Also, gender is only one component of social identity; other pieces including race, ethnicity, class, and sexual orientation influence access, power, and privilege, which can impact PA participation (Black et al., 2019; Choi et al., 2017). We did not collect complete information about social location, including race and ethnicity. Given these limitations, it is important to acknowledge that not all perspectives of those with ADHD may be captured by our work. Future research on the barriers and facilitators of PA for those with ADHD should examine different lived experiences from an intersectional lens (Cho et al., 2013). It is possible that if there was a different sample, there may be different barriers and facilitators noted.

Finally, it is important to acknowledge that part of the analysis process incorporated a deductive approach, where themes were organized into domains of the TDF. Though previous work exploring barriers and facilitators has used the TDF to guide their analysis, deductive analysis runs the risk of influencing researcher perspective and that unexpected or unplanned phenomena may be missed. While using an open coding process to generate themes prior to categorizing by the TDF domains helped minimize the risk of missing unexpected phenomena, the limitations of employing a deductive analysis process should be acknowledged.

Conclusion

This is the first study to examine the perceived barriers and facilitators to being physically active as expressed by adults with ADHD. Participants identified unique barriers to being physically active that were often tied to their symptomology including executive dysfunction, hyperfocus, and overstimulation, which made it more difficult for them to initiate PA. Identified facilitators were tied to their beliefs that PA reduced their cognitive symptoms of ADHD and improved their mental health. Many participants expressed never receiving any formal education about the benefits of PA for their ADHD symptoms; however, for those who had been previously active, their prior experience being active was valuable in that it allowed them to recognize the benefits through their experience. Therefore, ensuring those with ADHD are exposed to the benefits of PA (i.e., improved executive functioning, mood, and mental health) early on and receive formal education about the benefits of PA may motivate participation across the lifespan and improve symptoms. Although some strategies have been identified to improve PA engagement for those with ADHD (i.e., removing distractions, action planning, scheduling), our research highlights the need for more individualized supports alongside societal shifts that are inclusive of neurodiverse perspectives. It is essential to not frame ADHD as a problem to solve, but rather to recognize that neurodiverse ways of thinking are not always supported in society (Oliver, 2013). These findings serve as an important foundation for researchers and clinicians who aim to help adults with ADHD become more physically active.

Appendix: Semi-Structured Interview Questions

1. What sort of physical activity do you currently participate in?
2. What sort of physical activity have you participated in, in the past?
3. How, if at all, has your physical activity levels changed since the onset of the COVID-19 pandemic?
4. How, if at all, do your previous physical activity levels influence your current decisions to participate in physical activity?
5. When you are being physically active, how do you feel like it impacts you?
6. What do you believe are the greatest barriers to you being physically active?
7. What do you believe are the greatest facilitators to you being physically active?
8. How, if at all, do you feel your ADHD symptoms impact your ability to participate in physical activity?
9. What, if at all, do you know about the relationship between physical activity and ADHD symptoms?
10. What information, if any, informed your knowledge about the relationship between physical activity and ADHD symptoms?
11. How, if at all, would you want to learn about future research related to physical activity and ADHD?

Funding This work was supported by the Canada Research Chair Program (950–232967).

Compliance with Ethical Standards

Conflict of Interest The authors have no conflicts of interest to declare.

Ethical Approval This study was performed in accordance with the ethical standards outlined in the 1964 Declaration of Helsinki and its later amendment.

Informed Consent The current research involved human participants who gave informed consent before participating in the study.

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CHAPTER 5:

GENERAL DISCUSSION

Adults with ADHD have been largely excluded from health and exercise psychology research. My dissertation provides novel insights into the unique challenges and opportunities to getting physically active faced by adults with ADHD and identifies cardiorespiratory fitness (CRF) as a marker associated with some better cognitive and mental health outcomes. Data from Study 1 support that higher estimated CRF is associated with better inhibitory control in an adult ADHD sample. This finding aligns with prior work by Jeoung (2014) and Merhen and colleagues (2019) and adds critical information about the specificity of that association by showing that the same associations with CRF were not observed for other executive functions, namely cognitive flexibility and working memory. Study 2 serves as an important reminder that adults with ADHD are not only struggling with executive dysfunction, but that their mental health suffers too. In Study 2, adults with ADHD reported significantly higher depression, anxiety, and stress symptoms than neurotypical controls. Sixty seven percent of our participants with ADHD reported moderate to extremely severe mental health concerns in at least one subscale, compared to 36% of controls. Study 2 was also the first to document an association between CRF and mental health in adults with ADHD; higher *estimated* CRF was associated with lower perceived stress, and higher *perceived* CRF was associated with lower depression, anxiety, and perceived stress symptoms. Exploratory analyses revealed that some of these associations were stronger in adults with ADHD than in controls and the strength of some of those associations differed depending on ADHD symptom severity. For example, higher perceived CRF was associated with fewer depressive symptoms but only among those with less severe ADHD symptoms, suggesting that potential positive impacts of CRF may not benefit everyone equally. Finally, Study 3 was the first to document unique barriers and facilitators to getting physically active as described by adults with ADHD through semi-structured interviews. Interestingly, the results revealed unique ADHD-related barriers and facilitators to being physically active. For example, some symptoms (e.g., feeling over/under-stimulated or executive dysfunction) made goal-oriented, planned behaviour challenging to follow through whereas being physically active was seen as a great way to "quench" experiences of hyperactivity. This highlights the often-overlooked duality of neurodivergence where there are both challenges and strengths depending on the contexts. The implications of these contributions are discussed below before acknowledging the limitations of this work and providing suggestions for the future.

5.1 Implications of the Research

Study 1 prompts reflection on optimal approaches to investigating executive dysfunction in an adult ADHD context. In our sample, those with ADHD performed comparably to controls on measures of executive function. This was contrary to the authors' hypotheses and to some prior research demonstrating group differences in performance (e.g., Alderson et al., 2013; Boonstra et al., 2005; Müller et al., 2007). However, not all prior research has found significant group differences between adults with and without ADHD on measures of executive function (Barkley & Murphy, 2011). Furthermore, self-reported executive dysfunction may be more discriminatory than objective measures, as noted by Fuermaier and colleagues (2015). Arguably, in comparison to highly controlled and contrived lab-based evaluations, one's perceptions of their own executive dysfunction may be more closely connected to the impairments one experiences in daily life (Barkley & Murphy, 2011). As such, subjective rating scales may be more ecologically valid to understand executive dysfunction in adult ADHD than objective lab-based measures (Barkley, 2011; Kamradt et al., 2021; Baggio et al., 2020). Therefore, incorporating rating scales of executive functioning such as the *Barkley Deficits in Executive Functioning Scale* (BDEFS) is recommended for future work.

That said, the lab-based objective measure of inhibitory control was the only performance metric that correlated with CRF. Previous research has documented associations between CRF and inhibitory control for children and adolescents with high ADHD risk (Brassel et al., 2017) and adults with ADHD (Mehren et al., 2019). Interestingly, adiposity has also been selectively associated with inhibitory control (Song et al., 2016). However, it is unclear why inhibitory control may have a particular connection with physiological measures in comparison to other executive functions. Given that inhibitory control has been previously described as the hallmark of executive dysfunction in ADHD (Chmielewski et al., 2019; Wodka et al., 2007), future research is needed to unpack this.

In addition to physiological measurements of CRF, Study 2 suggests merit in capturing one's psychological perceptions of CRF where higher self-perceived CRF was associated with better mental health overall, whereas estimated CRF was only associated with less perceived stress. While it is true that physiological CRF has a direct impact on the reactivity of the stress system (Forcier et al., 2006), self-perceptions of CRF may be influenced by psychosocial concepts related to self-esteem, which tends to be lower in adults with ADHD (Cook et al., 2014; Newark et al., 2016) and in individuals suffering from anxiety and depression (Sowislo & Orth, 2013). While not part of the published paper, Study 1 also included a measure of perceived CRF, but it was not related to executive functions in any way. This may suggest that aspects of executive functioning may be best supported by the physiological adaptations (rather than the psychological changes) associated with having higher CRF, whereas mental health may be supported by both; however, this mere speculation needs to be tested.

Associations between CRF and mental health were also more sensitive to individual differences in ADHD symptom severity. In Study 2, a positive association between higher CRF and lower depressive symptoms was only observed for participants whose ADHD symptoms were less severe. While this analysis was exploratory in nature and results cannot conclude why this is true, the results point to the possibility that strategies for increasing CRF in adults with ADHD may provide measurable support when symptoms are less severe, but it may not provide measurable support when symptoms are more severe. Indeed, adult ADHD symptom severity can impact learning through reward or punishment and even rates of criminal convictions (Anker et al., 2021; Morris et al., 2023), suggesting important individual differences among individuals with ADHD that cannot be met with a one-sized-fits-all approach to symptom management. When considering not only ADHD symptom management, individual differences in mental health and psychiatric comorbidities tend to increase with ADHD symptom severity (Saccaro et al., 2021). Sadly, the poor mental health rates noted in Study 2 are alarming but not surprising, given prior reports that this population suffers from high rates of attempted suicide and an increased risk of death from self-harm (Fuller-Thomson et al., 2022; Sun et al., 2019); emphasizing the need for supports to improve the mental health of those with ADHD.

Overall, data from Studies 1 and 2 provide evidence of an association between CRF and inhibitory control, and mental health, which lends support to the cardiorespiratory hypothesis (Salzman et al., 2022; Stimpson et al., 2018). While Studies 1 and 2 cannot speak to whether *improved* CRF impacted outcomes or whether this was a result of enhanced cerebral oxygenation (which is a central tenant of the cardiorespiratory hypothesis) the results do provide preliminary evidence that higher CRF is better when it comes to inhibitory control and mental health in adults with ADHD. This work represents an important launch point for future interventional work. Of particular interest would be high-quality randomized control trials that incorporate a neuroimaging component to directly assess whether *increasing* CRF improves executive functioning and/or mental health, whether improvements are related to increased cerebral oxygenation, and to identify the best type of physical activity to do so.

As we look to find more ways to support adults with ADHD, the observed associations between CRF, inhibitory control and mental health suggest that strategies to improve CRF may be a promising way to provide additional support. Physical activity is a modifiable lifestyle intervention that improves CRF and has demonstrated promising results for adults with ADHD (e.g., Abramovitch et al., 2013; Gapin et al., 2015; Koch et al., 2022; LaCount et al., 2022; Mehren et al., 2019). The results from Study 3 reveal unique barriers and facilitators that could impact the implementation of physical activity as a support strategy. For example, if a personal trainer discussed the value of getting active in the context of managing symptoms of hyperactivity, this may be a helpful motivator. Additionally, if the personal trainer provided check-in opportunities to their client with ADHD around whether they were feeling over or under-stimulated by the activity and adjusted accordingly, this may help develop a positive relationship with both the trainer and the activity itself. Generally, discussing barriers and facilitators in the context of experiencing executive dysfunction may also help someone with ADHD feel understood. As a participant described, "*ADHD is still one of those invisible illnesses that's not so understood. You're really trying to advocate for yourself against people who don't have resources themselves*." Learning about ADHD and recognizing that there are unique barriers and facilitators to getting physically active for this population may help adults with ADHD feel more supported by professionals. Over half of the participants indicated that they wanted credible and accessible information about physical activity that was tailored to their ADHD needs. The results are in line with a recent online survey of 117 adults with ADHD where participants expressed the desire for in-person support from an exercise professional or a personalized exercise plan (Cochrane et al., 2022). Designing personalized physical activity interventions for individuals with ADHD that considers the unique barriers and facilitators revealed in Study 3 has the potential to not only improve ADHD symptoms and comorbidities but also create a more inclusive context around movement that is more enjoyable, feasible, and adherable over the long term.

Interestingly, participants in Study 3 identified that managing their ADHD symptoms without medication was a facilitator to being physically active. For example, one participant noted, "*I didn't want to jump right into medication…but I wanted to see if there were ways to manage my ADHD without relying on medication*." This was also noted by Cochrane and colleagues (2022) who found that unmedicated participants were more willing to engage in exercise as a standalone treatment option while all participants, medicated or not, were willing to engage in exercise as an adjunct treatment. Moving forward, interventions designed to support ADHD should consider the combined effects of exercise and medication for adults with ADHD.

Finally, this program of research underscores the importance of collecting demographic information to capture the heterogeneity of the sample to inform the interpretation and application of the results. For example, our sample was highly educated and more physically active than other ADHD samples (Canu et al., 2021; Fritz & O'Connor, 2018). Consequently, our participants may have already developed useful cognitive support strategies to manage their executive dysfunction, which may have contributed to the null group effect for executive functioning in Study 1. Furthermore, in Study 3, our sample was also predominantly women who had been diagnosed later in life. While it was great to capture these voices, their unique experiences may be different from men with ADHD and those who were diagnosed earlier in life. Again, this underscores the importance of capturing demographic information and this practice should be continued in future work.

5.2 Limitations and Future Considerations

While this dissertation makes a substantial contribution to the adult ADHD literature, this program of research is not without limitations. First and foremost, it is important to remember that this dissertation happened during the COVID-19 pandemic. Unprecedented restrictions on research meant that my original lab-based research was halted, and a new virtual program of research was designed and executed. The virtual protocol was favourable because it made data collection resilient against the everchanging public health measures, including the potential for further lockdowns and restrictions on in-person activities. The virtual protocol also meant that we could recruit adults with ADHD from different geographic locations. However, going virtual put restrictions on the types of methods that could be used. Ideally, we would have collected physiological measurements of CRF using the gold standard VO_{2max} test (Fletcher et al., 2001) and measured cerebral oxygenation using functional Near Infrared Spectroscopy (Albinet et al., 2014; Ferrari & Quaresima et al., 2012) but that was not possible in the virtual space. Instead, we opted for an estimated CRF protocol that could be administered and executed by the participant independently.

Changes to COVID-19 health and safety protocols also impacted our measure of physical activity using the 7-Day Physical Activity Recall interview (Sallis et al., 1985). Note that these data were not included in the published papers because many participants reported additional constraints to being physically active such as self-isolation and avoiding public spaces or limited access to recreational facilities. Fifty percent of participants indicated that their physical activity levels over the past three months were different from their physical activity level over the past week, the latter being what was captured by the 7-Day Physical Activity Recall interview they completed (See Table 1). Previous research has documented that the physical activity recall interview provides useful estimates of habitual physical activity (e.g., Blair et al., 1985; Steinhardt & Dishman, 1989); however, this was likely not the case during the unique context of the COVID-19 pandemic. As such, this dissertation focused on CRF without including chronic physical activity behaviour for Studies 1 and 2. However, future research should consider incorporating measures of chronic physical activity when testing the cardiorespiratory hypothesis.

It is important to recognize that Studies 1 and 2 were cross-sectional projects, and as such, we are unable to inform on the causality of the relationships that were observed. Although we have framed the results around the cardiorespiratory hypothesis which postulates that increases in CRF improve executive functioning and mental health, we also acknowledge that the reverse causation is equally possible: that individuals with better executive functioning are more likely to engage in health protective behaviours like physical activity that can increase CRF and benefit other health outcomes (Gray-Burrows et al., 2019). Furthermore, it is important to consider the contribution of psychosocial changes that can occur alongside physiological adaptations. For example, improved self-esteem may arise from less executive dysfunction, better mental health, and more physical activity. For example, a recent study by Aviv and colleagues (2021) found that adding a 10-week horseback riding program as adjunctive therapy for children medicated for ADHD improved their self-reported executive functioning and self-esteem but it was their improved self-esteem that predicted subsequent executive functioning at follow-up.

It is also important to recognize that this dissertation only included participants who self-reported a formal diagnosis of ADHD. While there is value in working with those who have a formal diagnosis, it can also exclude people who suffer from ADHD and are undiagnosed. The reality is that obtaining an official diagnosis of ADHD can be a lengthy process. It has been described as "an uphill struggle" (Matheson et al., 2013) that can be precluded by financial costs, a lack of access to the necessary healthcare providers, and undo exposure to negative stigmatization. Consequently, not everyone who experiences ADHD symptoms can or will seek a diagnosis. As one participant in a study by Matheson and colleagues (2013) described, "*Putting somebody with ADHD through a bureaucracy is torture… it's like treating a diabetic in a bakery shop*." Future work with psychologists and physicians to add assessments that can classify individuals who self-identify as having ADHD but are undiagnosed may be one way to reduce this barrier. Adding to the complexity of diagnosis is the fact that the diagnostic criterion for adult ADHD, in general, is not perfect, with many clinicians reporting a lack of confidence to diagnose adult cases (Schneider et al., 2019). The diagnostic criteria also differ by geographic location; for example, in Europe, emotional dysregulation is a key criterion whereas this is not included in the DSM-5 (Kooij et al., 2019). Many people with ADHD self-report experiencing emotional dysregulation, or what some in the community describe as rejection-sensitive dysphoria (RSD) where they experience extreme and severe emotional pain in response to feelings of rejection or failure (Dodson, 2023).

Alongside understanding supports for those with ADHD, continued work and consensus on diagnostic criteria and processes for adult ADHD are needed.

Finally, data from Study 3 focused on barriers and facilitators to physical activity through the lens of adults with ADHD. Although we did not use an intersectional framework (Cho et al., 2013; Crenshaw, 1990), we recognize that each person has many different pieces to their identity—whether that be related to race, ethnicity, gender, sexuality, partner status, additional disabilities, caregiver status etc.—and all of which can interact with each other and with their experiences of having ADHD and getting physically active. For example, experiencing ableism, racism, sexism, homophobia, and/or transphobia have been shown to negatively impact physical activity engagement (e.g., Herrick & Duncan, 2018a; Herrick & Duncan, 2018b; Jones et al., 2017; Mason & Koehli, 2012; Smith et al., 2021) and should be considered in future work. Alongside social location, considering societal context is important. For example, current Western societies are rooted in both capitalistic views (i.e., the need to consistently work to produce output) and neurotypical expectations (i.e., the consistent reliance on executive functioning to produce these outputs). These systems and expectations are challenging and stressful for those with ADHD and can lead to negative health outcomes. Therefore, while understanding ways to support individuals with ADHD using modifiable lifestyle changes, we acknowledge that this is a Band-Aid solution to a more systemic problem; it is also important to shift sociocultural ideas, norms, and spaces to whole-heartedly include those with disabilities and recognize the value in neurodiversity.

5.3 Conclusion

In conclusion, this work provides insight into the potential benefit of CRF for inhibitory control and mental health. This mixed-methods dissertation provides novel insights into the adult ADHD health and exercise psychology literature, an understudied area of research. Quantitatively, we observed a selective positive association between higher CRF and inhibitory control that was not observed for cognitive flexibility and working memory (Study 1) alongside positive associations between higher CRF and measures of mental health, including depression, anxiety, and stress symptoms (Study 2). Some associations were stronger in adults with ADHD and differed depending on ADHD symptom severity, suggesting that future research should not assume that the potential positive impacts of CRF will benefit everyone equally. Qualitatively, this dissertation contributed valuable knowledge regarding the unique barriers and facilitators to getting physically active as identified by adults with ADHD, which will help to inform future interventions to support those with ADHD.

Table 1.

Self-reported difference between physical activity as captured by the 7-Day Physical Activity Recall Interview and physical activity over the last three months

Response Options	**ADHD # of Responses (%) n = 36**	**Control # of Responses (%) n = 36**
More	7 (19%)	5 (14%)
About the same	19 (53%)	17 (47%)
Less	10 (28%)	14 (39%)

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APPENDIX A: STUDY 1 & 2 MATERIALS

A.1 Connors Adult ADHD Rating Scale

Six sample items of 30 total.

1. Things I hear or see distract me from what I'm doing.
2. I have problems organizing my tasks and activities.
3. Sometimes my attention narrows so much that I'm oblivious to everything else; other times it's so broad that everything distracts me.
4. I make careless mistakes or have trouble paying close attention to detail.
5. I interrupt others when they are working or playing.
6. I have trouble finishing job tasks or schoolwork.

A.2 Physical Activity Readiness Questionnaire

1. Do you have a medical condition that requires you to avoid strenuous exercise?
2. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
3. Do you feel pain in your chest when you do physical activity?
4. In the past month, have you had chest pain when you were not doing physical activity?
5. Do you lose balance because of dizziness or do you lose consciousness?
6. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
7. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
8. Do you know of any other reason why you should not do physical activity?
9. Are you colour blind?

A.3 Depression Anxiety Stress Scale

DASS

Name: *Date:*

Please read each statement and circle a number 0, 1, 2 or 3 which indicates how much the statement applied to you *over the past week*. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

1	I found myself getting upset by quite trivial things	0	1	2	3
2	I was aware of dryness of my mouth	0	1	2	3
3	I couldn't seem to experience any positive feeling at all	0	1	2	3
4	I experienced breathing difficulty (eg, excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3
5	I just couldn't seem to get going	0	1	2	3
6	I tended to over-react to situations	0	1	2	3
7	I had a feeling of shakiness (eg, legs going to give way)	0	1	2	3
8	I found it difficult to relax	0	1	2	3
9	I found myself in situations that made me so anxious I was most relieved when they ended	0	1	2	3
10	I felt that I had nothing to look forward to	0	1	2	3
11	I found myself getting upset rather easily	0	1	2	3
12	I felt that I was using a lot of nervous energy	0	1	2	3
13	I felt sad and depressed	0	1	2	3
14	I found myself getting impatient when I was delayed in any way (eg, elevators, traffic lights, being kept waiting)	0	1	2	3
15	I had a feeling of faintness	0	1	2	3
16	I felt that I had lost interest in just about everything	0	1	2	3
17	I felt I wasn't worth much as a person	0	1	2	3
18	I felt that I was rather touchy	0	1	2	3
19	I perspired noticeably (eg, hands sweaty) in the absence of high temperatures or physical exertion	0	1	2	3
20	I felt scared without any good reason	0	1	2	3
21	I felt that life wasn't worthwhile	0	1	2	3

Reminder of rating scale:

0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

22	I found it hard to wind down	0	1	2	3
23	I had difficulty in swallowing	0	1	2	3
24	I couldn't seem to get any enjoyment out of the things I did	0	1	2	3
25	I was aware of the action of my heart in the absence of physical exertion (eg, sense of heart rate increase, heart missing a beat)	0	1	2	3
26	I felt down-hearted and blue	0	1	2	3
27	I found that I was very irritable	0	1	2	3
28	I felt I was close to panic	0	1	2	3
29	I found it hard to calm down after something upset me	0	1	2	3
30	I feared that I would be "thrown" by some trivial but unfamiliar task	0	1	2	3
31	I was unable to become enthusiastic about anything	0	1	2	3
32	I found it difficult to tolerate interruptions to what I was doing	0	1	2	3
33	I was in a state of nervous tension	0	1	2	3
34	I felt I was pretty worthless	0	1	2	3
35	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3
36	I felt terrified	0	1	2	3
37	I could see nothing in the future to be hopeful about	0	1	2	3
38	I felt that life was meaningless	0	1	2	3
39	I found myself getting agitated	0	1	2	3
40	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3
41	I experienced trembling (eg, in the hands)	0	1	2	3
42	I found it difficult to work up the initiative to do things	0	1	2	3

APPENDIX B: STUDY 3 MATERIALS

B.1 Connors Adult ADHD Rating Scale
B.2 Semi-Structured Interview Questions

B.1 Connors Adult ADHD Rating Scale

Six sample items of 30 total.

1. Things I hear or see distract me from what I'm doing.
2. I have problems organizing my tasks and activities.
3. Sometimes my attention narrows so much that I'm oblivious to everything else; other times it's so broad that everything distracts me.
4. I make careless mistakes or have trouble paying close attention to detail.
5. I interrupt others when they are working or playing.
6. I have trouble finishing job tasks or schoolwork.

B.2 Semi-Structured Interview Questions

1. What sort of physical activity do you currently participate in?
2. What sort of physical activity have you participated in the past?
3. How, if at all, has your physical activity levels changed since the onset of the COVID-19 pandemic?
4. How, if at all, do your previous physical activity levels influence your current decisions to participate in physical activity?
5. When you being physically active, how do you feel like it impacts you?
6. What do you believe are the greatest barriers to you being physically active?
7. What do you believe are the greatest facilitators to you being physically active?
8. How, if at all, do you feel your ADHD symptoms impact your ability to participate in physical activity?
9. What, if at all, do you know about the relationship between physical activity and ADHD symptoms?
10. What information, if any, informed your knowledge about the relationship between physical activity and ADHD symptoms?
11. How, if at all, would you want to learn about future research related to physical activity and ADHD research?

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Article	**Mental health in adults with ADHD: Examining the relationship with cardiorespiratory fitness**
DOI	**10.1177/10870547231158383**
Journal	**Journal of Attention Disorders**
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