The Effect of Aerobic Exercise Volume on Inhibitory Control in Young Adults with ADHD

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DEDICATION

This thesis is dedicated to my parents: for your unwavering belief in me and your willingness to truly understand and support me. Your love and encouragement have made this possible.

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ABSTRACT

Attention-deficit/hyperactivity disorder (ADHD) is frequently associated with difficulties in executive functioning, which can interfere with the management of daily life. Prior research suggests that aerobic exercise may elicit improvements in the inhibitory control aspect of executive functioning among individuals with ADHD. However, all past studies on this topic have examined the impact of acute exercise on task-based inhibitory control measures. Thus, the purpose of the present study was to investigate the effect of weekly aerobic exercise volume on self-reported inhibitory control in young adults who screen positive for ADHD. Additionally, this study aimed to determine which subcomponent of exercise volume has the greatest impact on self-reported inhibitory control among this population. Thirty-nine individuals completed a survey consisting of an ADHD screening, questions assessing their weekly aerobic exercise habits, and two questionnaires assessing aspects of inhibitory control. The BIS-15 and DGI-10 were used to measure impulsivity and delayed gratification, respectively.

Results showed a significant relationship between exercise volume and impulsivity scores (r (37) = -.33, p = .042) but not delayed gratification (r(37) = .231, p = .158). Additionally, results showed that none of the subcomponents— frequency, intensity, or time— significantly predicted impulsivity (F(3, 35) = 1.34, p = .276). The model explained 10% of the variability in impulsivity scores (R^2 = .10, Adjusted R^2 = .03). These findings indicate that increasing exercise volume may be an effective strategy in improving impulsivity, but not delayed gratification, in young adults with ADHD. Furthermore, these results suggest that total exercise volume, rather than the individual subcomponents, may be a greater predictor of impulsivity values among this population.

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CHAPTER 1

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a psychiatric condition that affects an individual's ability to function. It is frequently characterized by impulsivity and an inability to sustain attention (Cormier, 2008). While ADHD was once thought to be a childhood-only disorder (Lange et al., 2010), research has shown that roughly 60% of those diagnosed experience the persistence of symptoms into adulthood (Sibley et al., 2023). Approximately 8.7 million adults in the United States have the disorder (Schein et al., 2022), and many individuals go undiagnosed or are misdiagnosed with other psychiatric disorders (Ginsberg et al., 2014). Unfortunately, studies have shown that fewer than 20% of adults with the disorder seek treatment (Retz et al., 2011). Research also indicates that adults with ADHD may experience greater executive function deficiencies when compared to children with the disorder (Adler et al., 2017). These difficulties often result in issues coordinating the cognitive abilities that allow one to work, learn, and manage daily life. This data shows that ADHD is an often misdiagnosed and undertreated disorder that impacts many adults in the United States.

Executive functions (Efs) encompass several skills that regulate feelings, thoughts, and actions that are necessary for daily functioning (Doebel, 2020). Efs are often divided into three domains: inhibitory control (IC), working memory (WM), and cognitive flexibility (CF; Diamond, 2014). IC includes the ability to direct emotions, attention, behavior, and thoughts. This set of skills allows one to use reasoning to determine appropriate responses, rather than acting on impulse (Diamond, 2014). IC also involves delay discounting, or the ability to give up instant pleasure for a greater long-term reward (Louie & Glimcher, 2010). WM is the ability to work with information in the mind that is not perceptually present (Smith & Jones, 1999). This

skill allows for language comprehension, processing information, and seeing relations between ideas (Diamond, 2014). CF is the ability to shift between thought processes and adapt to a variety of conditions (Kehagia et al., 2010). This skill allows us to see concepts from different spatial or interpersonal perspectives (Diamond, 2014). These subdomains allow individuals to direct behavior, process information, and shift perspectives to complete tasks and manage daily life.

Efs are measured using various neuropsychological tasks and self-report ratings. Due to the many subsets of Efs, no gold standard exists (Pickens et al., 2010). EF tasks are frequently used in research and clinical settings (Faria et al., 2015). However, these tasks have shown low ecological validity in adults (Barkley & Fischer, 2011; Torralva et al., 2013). Research has also suggested that EF ratings are more relevant for assessing deficits in those with ADHD due to their ability to measure declines in long-term, goal-directed behaviors (Barkley & Fischer, 2011). Kamradt et al. (2014) found that EF ratings better accounted for variations in occupational, relational, and daily living impairments above EF tasks among those with ADHD. Thus, self-reported EF ratings may be most valuable when assessing Efs among this population.

Exercise volume (EV) refers to the total amount of work performed over a given period (ACSM, 2021). EV consists of three components: intensity, duration, and frequency. Exercise intensity is known as the rate of metabolic demand during exercise (MacIntosh et al., 2021) and is often expressed as a percentage of one's maximal heart rate (ACSM; 2021). Exercise duration is the length of time of a bout of exercise and is typically expressed in minutes (ACSM; 2021). Exercise frequency is the number of times a bout of exercise is performed and is most often expressed in exercise sessions per week (ACSM, 2021). By assessing these three variables, the sum of work completed over a specified period can be calculated.

A few studies have assessed the impact of aerobic exercise on EFs in adults with ADHD. Mehren et al. (2019) evaluated the effect of a single bout of aerobic exercise on attention and Efs in a group of adults with ADHD. Participants performed a 30-minute cycling session at a moderate intensity, followed by a flanker task to assess IC. Individuals then completed the same task after a sedentary control session. The exercise bout significantly improved performance on the IC task among adults with ADHD, but not in the non-ADHD group. Additionally, Rassovsky & Alfassi (2019) investigated the impact of aerobic exercise on the attention of adults with ADHD. Participants completed the Conners Continuous Auditory Test of Attention twice; once while in a seated position, and again while walking on a treadmill at a moderate intensity. Results showed that the ADHD group had faster exercise reaction times when compared to seated times. Interestingly, the non-ADHD group showed faster seated reaction times when compared to exercise times. These findings imply that aerobic exercise may elicit improvements in IC among adults with ADHD. Furthermore, Gapin et al. (2015) examined the impact of acute aerobic exercise on Efs. Participants completed a 30-minute bout of moderate intensity walking. Efs were measured pre- and post-exercise using the Stroop Test, Trail Making Test, and Digit Span Test. The exercise bout improved all aspects of Efs in the non-ADHD group. However, exercise improved only IC among the ADHD group. The literature surrounding this topic suggests that aerobic exercise bouts can elicit improvements in the IC aspect of EF among adults with ADHD.

A few studies have assessed the impact of acute aerobic exercise on overall EF measures of adults with ADHD. The literature indicates that such interventions may improve IC among this population. However, no studies have assessed the effects of self-reported weekly aerobic EV on the IC of adults with ADHD. Additionally, all past studies on this topic have assessed

efficacy by utilizing task-based IC measures. No studies have used self-report IC ratings to determine the real-world effectiveness of aerobic EV on adults with ADHD. Therefore, the purpose of the present study is to investigate the effect of weekly EV on self-reported IC in young adults who screen positive for ADHD. We hypothesize that EV will be associated with IC improvements among this population. Additionally, this study aims to determine which subcomponent of EV has the greatest impact on self-reported IC among young adults who screen positive for ADHD. It is hypothesized that exercise intensity will have the greatest impact on EF measures in the present population.

CHAPTER 2

Literature Review

ADHD

Prevalence

Attention-deficit/hyperactivity disorder (ADHD) is a psychiatric condition that affects an individual's ability to function. It is frequently characterized by impulsivity and an inability to sustain attention (Cormier, 2008). ADHD is one of the most common neurodevelopmental disorders seen in children and adolescents, with an estimated global prevalence of 8% (Ayano et al., 2023). In the United States alone, approximately 6.1 million children and adolescents have been diagnosed with the disorder (Danielson et al., 2018).

ADHD was once thought to be a childhood-only disorder that disappears with age (Lange et al., 2010). However, recent research has shown that roughly 60% of those diagnosed experience the persistence of symptoms into adulthood (Sibley et al., 2023). According to the World Health Organization, the estimated global prevalence of adult ADHD is 2.8% (Fayyad et al., 2017). Roughly 8.7 million adults in the United States have the disorder (Schein et al., 2022), and research shows that this number has greatly increased in past years. Chung et al. (2019) found that the prevalence of adult ADHD in the United States more than doubled from 2007 to 2016. Studies also suggest that adults frequently go undiagnosed, or are misdiagnosed with other psychiatric disorders, such as anxiety disorders, major depressive disorder, and personality disorders (Ginsberg et al., 2014). This frequent misdiagnosis, as well as the limited awareness surrounding adult ADHD, may be responsible for underdiagnosis in this population (Johnson et al., 2020). A qualitative study by French et al. (2020) found that general practitioners had limited knowledge of the disorder in adults, though they are typically the first provider an individual sees

when seeking a diagnosis. It was also found that high-functioning adults with ADHD frequently went unnoticed, as they do not meet the general practitioners' conceptions of ADHD (French et al., 2020). Many adults are also diagnosed late. Faraone et al. (2004) found that 75% of participants with adult ADHD were not diagnosed during childhood. Unfortunately, studies have shown that fewer than 20% of adults with the disorder seek treatment (Retz et al., 2011). Many adults with ADHD are also more likely to seek treatment for comorbid disorders, rather than ADHD itself, leading to limited effectiveness of such treatments (Ginsberg et al., 2014). In addition to adults, females with ADHD are often overlooked. French et al. (2020) found that girls with the disorder frequently went under the radar by GPs. In youth, the male to female ratio is approximately 4:1, whereas in adults, the estimated ratio is 1:1 (Palladino et al., 2019). This data shows that ADHD is an often-misdiagnosed disorder that impacts many adults in the United States.

Etiology

Research has shown that ADHD is largely genetic, with an estimated heritability of 74% (Faraone & Larsen, 2019). Individuals with immediate relatives who have ADHD have a two- to eight-times greater risk of developing the disorder, compared to those who do not have immediate relatives with ADHD (Faraone et al., 2005). The 10-repeat allele of the dopamine transporter gene has been associated with ADHD in several studies (Cook et al., 1995; Gill et al., 1997). The dopamine transporter gene is a protein that aids in dopamine reuptake from the synapse, and its 10-repeat genotype is linked to decreased synaptic dopamine levels (Heinz et al., 2000). Research has also shown significant positive associations between adult ADHD and brain-specific angiogenesis inhibitor 1-associated protein (Bonvicini et al., 2016). Brain-specific

angiogenesis inhibitor 1-associated protein facilitates the proliferation, survival, and maturation of neurons (Bonvicini et al., 2016).

Some studies have also determined that environmental factors are related to ADHD. Such factors can be divided into four categories: prenatal factors, exposure to toxins, dietary deficiencies, and psychosocial adversity (Thapar et al., 2013). Prenatal factors include smoking and substance misuse (Langley et al., 2005), high levels of maternal stress (Glover, 2011), and low birth weight (Bhutta et al., 2002). Environmental toxins that may relate to ADHD include exposure to organophosphate pesticides (Marks et al., 2010), polychlorinated biphenyls (Savig et al., 2010), and lead (Nigg et al., 2010). Studies have shown that specific nutritional deficiencies, including magnesium (Kozielec & Starobrat-Hermelin, 1997) and zinc (Arnols & DiSilvestro, 2005) may be correlated with ADHD. The experience of adversity, such as maltreatment, parental incarceration, single parenthood (Claussen et al., 2022), low income (Pheula et al., 2011), and early deprivation (Rutter et al., 2007) has also been associated with the disorder. However, many of these risk factors have small effect sizes, and there is no clear consensus on whether they are causal (Thapar et al., 2013). Overall, the literature indicates that there is no one factor that causes ADHD. Further research is needed to determine the causality, or lack thereof, of the aforementioned risk factors.

Physiology

The frontal lobe is largely responsible for managing executive functions and is the primary part of the brain affected by ADHD (Wilens & Spencer, 2010). A study by Seidman et al. (2006) found that adults with ADHD had a smaller anterior cingulate cortex and dorsolateral prefrontal cortex compared to adults without the disorder. The anterior cingulate cortex regulates decision-making and emotional control, while the dorsolateral prefrontal cortex controls working

memory and the ability to process and retain information (Seidman et al., 2006). Research has also found changes in the rate of brain development among those with ADHD. Shaw et al. (2007) conducted a study to compare the age at which children and adolescents with and without ADHD reach peak cortical thickness. Results showed a delay in cortical thickness and peak development in participants with ADHD. Researchers discovered that the greatest delay was present in the prefrontal regions (Shaw et al., 2007). Literature has also found changes in brain activity during tasks requiring high levels of cognitive function in those with ADHD. Epstein et al. (2007) compared brain activity among youth and adults with ADHD during completion of a response inhibition task. It was found that both groups showed decreased activity in fronto-striatal regions of the brain. Adults with ADHD also activated non-fronto-striatal regions more than those without the disorder. The fronto-striatal circuit is essential in cognitive control and the execution of goal directed behaviors. Thus, deficits in this circuit may be responsible for ADHD related behaviors (Epstein et al., 2007). Results of these studies suggest that individuals with ADHD may experience developmental delays, altered brain activity, and decreased size in areas of the brain that control essential cognitive functions.

Symptoms

The American Psychiatric Association (2013) divides ADHD into three subtypes based on signs and symptoms: predominantly inattentive, predominantly hyperactive/impulsive, and combined inattentive and hyperactive/impulsive. Signs of inattentiveness include distractibility, lack of attention to detail, forgetfulness, inability to concentrate or follow through in task completion, difficulty listening to or following instructions, making careless mistakes, not appearing to listen when spoken to, and difficulty with organization. Signs of hyperactivity/impulsivity include excessive fidgeting, movement, or talking, difficulty waiting

one's turn, interrupting conversations, and being always "on the go." In those diagnosed with ADHD, these symptoms were present before age 12, interfere with daily functioning, and are present in two or more settings, such as work, school, or home (American Psychiatric Association, 2013).

Recent research has also found that individuals with any subtype of the disorder often experience social difficulties. McKay et al. (2023) discovered that adolescents with ADHD were significantly more likely to experience issues with all measured domains of social functioning, including social awareness, cognition, communication, motivation, and restricted interests/repetitive behaviors, when compared to controls. This same association has been found in adults with the disorder. Bjerrum et al. (2017) reviewed qualitative evidence on the experience of living with adult ADHD. Researchers found that participants frequently had difficulties with social relationships and being part of the community at one's workplace, despite working harder to complete tasks and striving to be accepted. Literature has also shown rejection sensitivity to be a common ADHD symptom. Babinski et al. (2019) found that youth with greater ADHD symptoms reported increased sensitivity to peer rejection, and decreased reactivity to peer acceptance. Similarly, a qualitative study by Beaton (2022) found that adults with ADHD reported particularly strong reactions to receiving criticism, including decreased self-worth and obsessive thinking.

Comorbid disorders such as mood and anxiety disorders, personality disorders, and substance use disorders, are frequently seen in those with ADHD, and often have overlapping symptoms (Katzman et al., 2017). Research has shown that adults with ADHD are at least four times as likely to have a mood disorder when compared to those without ADHD (Kessler et al., 2006). Mood and anxiety disorders that frequently accompany ADHD include bipolar disorder,

major depressive disorder, and generalized anxiety disorder (Kessler et al., 2006). Furthermore, Miller et al. (2009) found that youth with ADHD had an increased risk of developing personality disorders in late adolescence, including borderline, antisocial, avoidant, narcissistic, and paranoid personality disorders. Additionally, this population is twice as likely to abuse or become dependent on substances (Martinex-Raga et al., 2013). Literature suggests that hyperactive/impulsive symptoms may be more strongly associated with substance dependence when compared to inattentive symptoms (De Alwis et al., 2014). The frequent presence of these comorbidities may be due to the similarities in the regions of the brain affected by multiple psychiatric disorders (Klassan et al., 2010).

It is estimated that 60-80% of ADHD symptoms continue into adulthood (Childress & Berry, 2012), and frequently interfere with individuals' professional, social, and family lives (Biederman et al., 2006). Studies have also shown that symptoms of adult ADHD rise above many of the typical symptoms seen in children and adolescents and often consist of greater emotional regulation difficulties (Katzman et al., 2017). Additionally, research indicates that adults with ADHD may experience greater executive function deficiencies when compared to children who have the disorder (Adler et al., 2017). These difficulties frequently result in issues coordinating the cognitive abilities that allow one to work, learn, and manage daily life. Adult ADHD has been associated with educational issues, including decreased grade point averages and graduation rates when compared to those without ADHD (DuPaul et al., 2009). Additionally, research has shown that adults with the disorder have significantly lower rates of full-time employment and average incomes compared to controls (Biederman & Faraone, 2006). These findings are likely due to the aforementioned issues with executive dysfunction that are frequently seen in adult ADHD.

Screening

To diagnose ADHD, mental health specialists typically conduct comprehensive assessments utilizing various clinical instruments (Chamberlain et al., 2021). However, with adult ADHD's prevalence of 2.8% (Fayyad et al., 2017), the restricted understanding of the disorder among general practitioners (French et al., 2020), and limited healthcare resources, methods are needed to conveniently screen potential cases of ADHD (Chamberlain et al., 2021). Validated screening tools assist clinicians in determining whether individuals need further evaluation for ADHD (Adler et al., 2019). Additionally, these tools allow ADHD to be studied reliably in populations who are at risk for the disorder (Chamberlain et al., 2021).

The World Health Organization Adult ADHD Self-Report Scale (ASRS) is a widely used and validated screening tool to assess ADHD among adults (Kessler et al., 2005). This self-report scale was designed to screen for ADHD according to the American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition criteria (Kessler et al., 2005). The ASRS consists of six questions that instruct individuals to rate their symptom frequency over the past six months on a scale of 0 (never) to 5 (very often) (Kessler et al., 2005). Several studies have found ASRS to be valid and reliable in screening adults for ADHD (Adler et al., 2006). The ASRS has shown a high internal consistency and current validity with the clinician administered ADHD Rating Scale (Adler et al., 2006). Additionally, research indicates that there is agreement between screening positive for ADHD on the ASRS and receiving a formal diagnosis (Able et al., 2007).

In summary, ADHD is a frequently misdiagnosed psychiatric condition that affects many individuals in the United States (Ginsberg et al., 2014). Though the disorder is largely genetic (Faraone & Larsen, 2019), research has shown that environmental factors may also play a role

(Thapar et al., 2013). Individuals with ADHD may experience developmental delays (Shaw et al., 2007), altered brain activity (Epstein et al., 2007), and decreased size in areas of the brain that control essential cognitive functions (Seidman et al., 2006). Core ADHD symptoms include hyperactivity, impulsivity, and inattention (American Psychiatric Association, 2013). Research also suggests that adults with the disorder experience greater difficulties with executive functioning when compared to children with ADHD (Adler et al., 2017). These deficits often result in difficulties completing essential tasks and managing daily life. Validated screening tools, such as the ASRS (Kessler et al., 2005), can help clinicians identify individuals experiencing these symptoms who may need further evaluation for ADHD.

Executive Function

Definition and Domains

Executive functions (EFs) encompass several skills that facilitate the regulation of feelings, thoughts, and actions that are necessary for daily functioning (Doebel, 2020). EFs are often divided into three central domains: inhibitory control (IC), working memory (WM), and cognitive flexibility (CF; Diamond, 2014).). IC includes the ability to direct emotions, attention, behavior, and thoughts. This set of skills allows one to use reasoning to determine appropriate behavioral responses, rather than acting on impulse (Diamond, 2014). IC also involves delay discounting, or the ability to give up instant pleasure for a greater long-term reward (Louie & Glimcher, 2010). Without this skill, individuals cannot complete extensive, time-consuming tasks. Additionally, IC enables individuals to selectively place attention on what is important, while suppressing unnecessary stimuli. This is known as attentional control (Diamond, 2014). WM is the ability to hold and work with information in the mind that is not perceptually present

(Smith & Jones, 1999). This skill is necessary for the completion of several daily tasks, including making sense of language, incorporating new information into one's plans or way of thinking, completing actions based on instructions, and seeing relations between ideas (Diamond, 2014). WM is typically divided into two categories: verbal and nonverbal. Verbal WM allows for the processing of auditory information, while nonverbal WM deals with visual-spatial information (Berenbaum et al., 2023). CF is the ability to shift between multiple thought processes and adapt to a variety of conditions or environments (Kehagia et al., 2010). Without CF, one would struggle to see concepts from different spatial or interpersonal perspectives (Diamond, 2014). CF is thought to be the opposite of rigidity and thus allows for flexible thinking when new opportunities or issues arise (Diamond, 2014). These three subdomains allow individuals to direct behavior, process information, and shift perspectives in order to complete tasks and manage daily life.

Measurement

EFs are measured using various neuropsychological tests and self-report scales. Due to the many EF subsets, no gold standard exists (Pickens et al., 2010). Standardized neuropsychological assessments are often used to assess each domain of EFs in a variety of research and clinical settings (Faria et al., 2015). Commonly used standardized EF assessments include the Wisconsin Card Sorting Test, Trail Making Test, Stroop Test, Arrow Flanker Task, Digits Forward and Backwards Subtests, and the Tower of London Task (Faria et al., 2015; Miles et al., 2021; Ridderinkhof et al., 2021; Phillips et al., 1999). The Wisconsin Card Sorting Test and Trail Making Test measure CF (Faria et al., 2015), with the former being the most frequently used to assess this EF domain (Miles et al., 2021). The Stroop and Arrow Flanker Tasks are used to measure IC (Faria et al., 2015; Ridderinkhof et al., 2021), while the Digits

Forward and Backward Subtests and the Tower of London Task measure WM (Faria et al., 2015; Phillips et al., 1999).

Studies have shown variability between the results of EF tasks and self-reported ratings, suggesting that these means of measurement are tapping into different constructs (Kamradt et al., 2014). Research has shown that laboratory-based EF tasks measure moment-to-moment EF and thus may not accurately predict an individual's performance on long-term tasks in real life (Kamradt et al., 2014). Additionally, EF ratings have been found to be more strongly associated with deficits in major life activities when compared to EF tasks (Barkley & Fischer, 2011). Furthermore, EF tasks have shown low ecological validity in adults, suggesting that scores may not translate to real life situations that require high levels of EF (Barkley & Fischer, 2011; Torralva et al., 2013).

Research has also shown value in self-reported measures of EFs among individuals with ADHD. Barkley & Fischer (2011) suggested that EF ratings may be more relevant for understanding deficits in those with ADHD due to their ability to measure declines in long-term, goal-directed behaviors and processes. Additionally, Kamradt et al. (2014) conducted a study to compare the results of EF tasks and ratings among a group of adults with ADHD. These researchers found that ratings of EFs better accounted for variations in occupational, relational, and daily living impairments above EF tasks. These studies suggest that self-reported ratings of EF may be most valuable when measuring EF deficits in individuals with ADHD.

Commonly used self-reported EF assessments include the Web-based Executive Functioning Questionnaire (Buchanan et al., 2010), the Frontal Behavior Systems Scale (Grace & Malloy, 2001), the Dysexecutive Questionnaire (Wilson et al., 1996), the Barkley Deficits in Executive Functioning scale (Barkley, 2011), and the Behavior Rating Inventory of Executive

Function for Adults (Roth et al., 2005). These self-reported assessments are typically comprehensive and thus designed to measure each subdomain of EFs (Barkley, 2011). Though many assessments and questionnaires have been developed to measure executive function, gold standards have not been established. Future research should test the reliability and validity of these methods among a variety of populations.

Questionnaires such as the Barratt Impulsiveness Scale (BIS; Patton et al., 1995) and Delaying Gratification Inventory (DGI; Hoerger et al., 2011) have been used to measure the IC aspect of EFs (Bartholdy et al., 2016), as decreased levels of impulsivity and the ability to delay gratification require higher levels of IC (Diamond, 2014). The BIS is among the most widely used tools to measure impulsivity in research and clinical settings (Stanford et al., 2009). This self-report instrument consists of 30 items that measure non-planning, attentional, and motor impulsivity (Patton et al., 1995). Individuals rate each item on a 4-point scale, from 1 (rarely/never) to 4 (almost always) (Patton et al., 1995). Scores range from 30 to 120, with higher scores representing higher levels of impulsivity (Patton et al., 1995). A 15-item version of the BIS (BIS-15) was developed by Spinella (2007). This shorter form maintains the same 3-factor structure by including five items for each subscale (Spinella, 2007). The BIS-15 has been shown to be valid and reliable among both general and psychiatric populations (Spinella, 2007; Meule et al., 2020). Additionally, the BIS-15 has shown high retest-reliability among a sample of female university students (Meule et al., 2015). Scores on the BIS-15 have been found to be highly correlated with the BIS, suggesting that it can be utilized as a substitute for the 30-item version (Spinella, 2007). The DGI measures five aspects of delayed gratification: food, physical pleasure, social interaction, money, and achievement (Hoerger et al., 2011). Participants are asked to rate each item from a scale of 1 (strongly disagree) to 5 (strongly agree) (Hoerger et al.,

2011). Higher scores represent an increased ability to self-regulate in order to delay immediate gratification and achieve greater long-term reward (Liang et al., 2023). This questionnaire can be administered as a 35-item long form, or a 15-item short form (Hoerger et al., 2011). The DGI has shown high internal consistency and test-retest reliability for both forms and for each of the five aspects of delayed gratification (Hoerger et al., 2011). Hoerger et al. (2011) also found that DGI-10 and DGI-35 scores correlated well with additional measures of self-control, conscientiousness, self-discipline, and achievement striving. These findings support the construct validity of both forms of the DGI. Results of these articles suggest that the BIS and DGI are valid and reliable methods to assess impulsivity and delaying gratification, respectively.

Factors Impacting Executive Function

Social, emotional, and physical health have been shown to have a profound impact on EFs. Liston et al. (2009) found that a group of adults who were exposed to psychosocial stress had decreases in attentional control and interruptions in the network responsible for mediating shifts in attention. However, it was found that these results were reversible. After one month of decreased stress, the experimental group showed very little difference to the control group. Additionally, a study by Tun et al. (2012) emphasized the importance of human connection for the maintenance of EFs. Results showed that self-reported social strain was associated with decreased processing speed among a sample of adults. Hirt et al. (2008) also found that adults who exhibited positive moods had increased levels of cognitive flexibility, emphasizing the impact of one's emotional state on EFs. Issues with sleep quality and deprivation have also been found to impact executive functioning. Tai et al. (2022) found that individuals who slept seven hours per night had the highest levels of cognitive performance. It was shown that cognitive performance decreased with each hour below and above this duration.

Physical activity and cardiorespiratory fitness have also been associated with EFs. Wang et al. (2022) found associations between higher levels of executive functioning, absolute physical activity intensities, and cardiorespiratory fitness levels among a group of adults. Similarly, Stern et al. (2019) found that a group of adults who completed a six-month aerobic exercise intervention showed significant improvements in EFs when compared to a lighter intensity stretching/toning group.

Impacts of Executive Dysfunction

Declines in EFs are associated with difficulties with several aspects of one's life, including school, work, mental health, and physical health. Research has suggested that EFs are more predictive of school readiness than reading or math skill-level (Blair & Razza, 2007). Issues with EFs can also lead to difficulties with productivity and job stability (Bailey, 2007). Research has also associated impairments in EF with a variety of mental disorders, including ADHD, addiction, depression, obsessive compulsive disorder, and schizophrenia (Esmaili et al., 2023). Additionally, Crescioni et al. (2011) found that self-control, an aspect of EF, was predictive of health behaviors in a group of adults following a weight-loss program. Similarly, a study by Miller & Beaver (2011) found that adolescents with low self-control had significantly greater chances of experiencing adverse health outcomes. EF deficits have also been associated with decreased quality of life in individuals with and without ADHD. Brown & Landgraf (2010) found that declines in EFs were correlated with decreased health-related quality of life in a group of adults with ADHD. Overall, research suggests that EF deficits are associated with decreased school readiness, mental and physical health, productivity, job stability, and quality of life.

Exercise Volume

Definition and Components

Exercise volume (EV) refers to the total amount of work performed over a given training period (ACSM, 2021). EV consists of three components: intensity, duration, and frequency. Exercise intensity is known as the rate of metabolic demand during exercise (MacIntosh et al., 2021). Intensity is often expressed in absolute terms, such as oxygen uptake, heart rate (HR), metabolic equivalents (METs), or power output. Relative terms can also be utilized to indicate intensity by expressing measures as relative to one's maximal heart rate, maximal oxygen uptake, or heart rate reserve (MacIntosh et al., 2021). According to the American College of Sports Medicine (ACSM; 2021), light intensity exercise is reached at 50-63% of one's age predicted maximal heart rate (MHR). Moderate intensity exercise is achieved at 64%-76% of age predicted MHR, while vigorous intensity exercise is considered 77%-93% of age predicted MHR (ACSM, 2021). The talk test is also frequently used to measure intensity, particularly when HR readings are not feasible. The talk test gauges intensity by monitoring one's ability to carry on a conversation. According to ACSM (2021), during moderate intensity aerobic exercise, the individual can hold a conversation but cannot sing. During vigorous intensity aerobic exercise, only a few words are typically sustainable (ACSM, 2021). Research has suggested the talk test to be a surrogate of one's ventilatory threshold (Foster et al., 2008), and thus is likely a valid, reliable, and practical means of assessing exercise intensity in both special and healthy populations (Reed & Pipe, 2014). Exercise duration is the length of time of a bout of exercise, and is typically expressed in minutes (ACSM, 2021). Exercise frequency is the number of times a bout of exercise is performed. This is most commonly expressed in exercise sessions per week (ACSM, 2021).

By assessing these three variables, the sum of work completed over a specified period can be calculated.

Impact of Aerobic Exercise Volume on Executive Function

Aerobic EV has been shown to be associated with EF improvements in a variety of populations. A meta-analysis by Moreau & Chou (2019) reviewed the literature on the impact of high-intensity exercise on EFs. It was found that high-intensity aerobic exercise had a significant facilitating effect on EFs when compared to rest. However, this effect was insignificant when compared to low-to-moderate intensity exercise, suggesting that these exercise intensities improve EFs in a similar way. Additionally, a study by Chen et al. (2018) found that a 20-minute moderate-intensity aerobic exercise session resulted in greater EF improvements among a group of older adults when compared to both a 10-minute session and a control group (who completed a 30-minute reading session). No significant differences in EF measures were found between 45-minute sessions and the other three sessions. These results suggest that a greater duration of exercise, to a certain point, may result in greater performance on EF tasks. Furthermore, a systematic review by Lin et al. (2022) assessed the impact of exercise interventions on the EF of older adults with mild cognitive impairment. It was found that moderate frequency exercise (3-4 times/week) improved task switching performance and had a greater effect size when compared to low frequency exercise (1-2 times/week). The authors conclude that exercise improves each subdomain of EF in this population. Findings of these studies indicate that aerobic EV is associated with improved EFs. However, further research must be conducted to determine the exact intensity, duration, and frequency needed to maximize these improvements.

Impact of Aerobic Exercise on ADHD

Research has generally shown that aerobic exercise is associated with positive cognitive outcomes in individuals with ADHD. This association has been frequently found in children and adolescents. Hattabi et al. (2022) conducted a study to determine the impact of a 12-week swimming intervention on the cognitive function and academic performance of school children with ADHD. The intervention consisted of three 90-minute exercise sessions per week at a moderate-to-vigorous intensity. Results showed significant improvements in ADHD induced behaviors, inhibitory processes, and academic performance among the intervention group compared to the control group. These results suggest that aerobic exercise may improve overall cognitive function and reduce symptoms of ADHD in children, which likely results in an increase in student achievement.

Acute exercise has also been shown to improve symptoms of ADHD among children. Huang et al. (2020) intended to assess the impact of acute aerobic exercise on sustained attention and discerning ability among children with and without learning disabilities, including ADHD. The experimental group completed a 30-minute session of moderate-intensity aerobic exercise, while the control group watched a running-related video. It was found that the exercise group had significantly higher scores on determination and sustained attention tests when compared to the control group. Furthermore, results showed that participants in the exercise group who had a learning disability had significantly higher improvements between pre- and post- intervention scores on both tests. These findings suggest that acute aerobic exercise can improve attentional control and discriminatory function in the present population. Additionally, these results show that children with learning disabilities, such as ADHD, may experience greater improvements in

cognitive function measures after acute aerobic exercise when compared to children without learning disabilities.

Though the majority of literature on this topic focuses on children and adolescents, a few studies have shown associations between aerobic exercise interventions and improved functioning in adult populations. Fritz & O'Connor (2016) aimed to investigate the impact of moderate-intensity, acute aerobic exercise on ADHD symptoms among a group of adult men. Results showed significantly increased motivation and energy following a 20-minute bout of moderate-intensity cycling. Significantly decreased feelings of fatigue, depression, and confusion were also found. Additionally, Svedell et al. (2023) assessed the tolerability of a 12-week moderate-intensity aerobic, strength, and mobility exercise intervention in a group of adults with ADHD. Participants completed three 50-minute exercise sessions per week. Results showed that the intervention was practical among this population, and statistically significant improvements in several ADHD symptoms were found. Findings of this study also indicated potential benefits in quality of life, sleep, body awareness, and cognitive functioning among the participants. However, further research is needed to determine whether the aerobic component of this program was responsible for these improvements. Though studies on the present topic in adult populations are limited, the results of the literature suggest that aerobic exercise may improve cognitive function and overall quality of life in adults with ADHD.

Impact of Exercise on Executive Function in ADHD

Research has shown that aerobic exercise may improve EFs in individuals with ADHD. A study by Liang et al. (2022) assessed the impact of a 12-week aerobic and neurocognitive exercise program on EFs and quality of sleep among children with ADHD. The intervention

consisted of three 60-minute moderate-intensity aerobic and neurocognitive exercise sessions per week. Three tests were utilized to measure each core component of EFs: the Arrow Flanker Task (IC), the Trail Making Test (CF), and the Tower of London (WM). These tests were completed at baseline, post-intervention, and 12 weeks following the intervention. Results showed improvements in each component of EFs and quality of sleep among participants with ADHD. 12-week follow-up measures showed that improvements were consistent with post-intervention measures. Similarly, Memarmoghaddam et al. (2016) investigated the impact of an exercise program on EFs of children with ADHD. The intervention lasted eight weeks and consisted of three 90-minute moderate-intensity aerobic and goal-directed exercise sessions per week. Pre- and post-measurements were collected using the Stroop task for cognitive inhibition and the go-no-go task for behavioral inhibition. Results showed significant increases in cognitive and behavioral inhibition measures among children with ADHD when compared to the control group, who continued normal activities. Additionally, Jiang et al. (2022) used functional magnetic resonance imaging (fMRI) to examine possible mechanisms of exercise-related improvements in EFs among children with ADHD. The intervention consisted of eight weeks of moderate-intensity rope skipping aerobic exercise. Participants completed three 30-minute sessions per week. Measurements were taken at baseline and post-intervention and consisted of fMRIs and the Arrow Flanker Task to assess IC. Results showed significantly improved performance on the Flanker task. Furthermore, significant increases in activity were found in the left middle frontal gyrus and right superior frontal gyrus. These findings indicate that aerobic exercise may improve IC in children with ADHD. Additionally, this fMRI data suggests that increases in spontaneous prefrontal lobe activity may be the mechanism for these changes.

A few studies have assessed the impact of aerobic exercise on EFs in adults with ADHD. Mehren et al. (2019) evaluated the effect of a single bout of aerobic exercise on attention and EFs in a group of adults with ADHD. Participants performed a 30-minute cycling session at a moderate intensity, followed by a flanker task to assess EF. Functional MRI images were also collected. Individuals then completed the same flanker task after a control session, which consisted of watching a movie. Results showed that the exercise bout significantly improved reaction times among adults with ADHD, but not in the non-ADHD control group. MRI images did not show changes in brain activation among either condition or group. These findings suggest that adults with ADHD may experience improvements in attention, processing speed, and IC after a single bout of aerobic exercise. Additionally, Rassovsky & Alfassi (2019) investigated the impact of aerobic exercise on attention among adults with ADHD. Participants completed the Conners Continuous Auditory Test of Attention twice; once while in a seated position, and again while walking on a treadmill at a moderate intensity. The order of completion was counterbalanced among each group. Results showed that the ADHD group had faster reaction times during exercise when compared to seated times. Interestingly, the non-ADHD control group showed faster reaction times while seated when compared to exercise times. These findings imply that aerobic exercise may elicit improvements in attention, auditory processing, and IC among adults with ADHD. Furthermore, Gapin et al. (2015) aimed to determine differences in cognitive function in college students with and without ADHD. Additionally, these researchers examined the impact of acute aerobic exercise on EFs. Participants completed a 30-minute bout of moderate intensity walking. EFs were measured before and after the exercise bout using the Stroop Test, Trail Making Test, and Digit Span Test. The exercise bout improved all aspects of EFs in the non-ADHD group. However, acute exercise improved only inhibitory

performance among the ADHD group. Results of this study imply that acute exercise may improve the IC aspect of EFs among college-aged adults with ADHD. The literature surrounding this topic suggests that aerobic exercise bouts can elicit improvements in some, or all, domains of EF among adults with ADHD. Specifically, the results of each of these studies show improvements in the IC aspect of EF.

A few studies have assessed the impact of acute aerobic exercise on overall EF measures of adults with ADHD. The literature indicates that such interventions may improve IC among this population. However, no research has been found assessing the effects of self-reported weekly aerobic EV on the IC of adults with ADHD. Additionally, all past studies on this topic have assessed efficacy by utilizing task-based IC measures. Research suggests that EF ratings are more strongly associated with deficits in real life activities when compared to EF tasks (Barkley & Fischer, 2011). However, no studies have used self-report IC ratings to determine the real-world effectiveness of aerobic EV on adults with ADHD.

The purpose of the present study is to investigate the effect of weekly aerobic EV on self-reported IC in young adults who screen positive for ADHD. We hypothesize that EV will be associated with improvements in IC measures among this population. Additionally, this study aims to determine which subcomponent of EV has the greatest impact on self-reported IC among young adults who screen positive for ADHD. It is hypothesized that exercise intensity will have the greatest impact on EF measures in the present population.

CHAPTER 3

Methodology

Participants

All participants in the present study were between 18 and 30 years of age and screened positive for ADHD according to the World Health Organization Adult ADHD Self-Report Scale (ASRS; Kessler et al., 2005). The ASRS has been shown to be valid and reliable in screening adults for ADHD (Adler et al., 2006), with research showing agreement between screening positive for ADHD on the ASRS and receiving a formal diagnosis (Able et al., 2007). Individuals were excluded from participation if they do not screen positive for ADHD or were outside of the specified age range. Participants were recruited through email, social media, and various online communities for individuals with ADHD. Approval from the Institutional Review Board was obtained prior to beginning the study.

Protocol

Participants received an email containing a survey with questions assessing their weekly aerobic exercise volume and inhibitory control.

Aerobic Exercise Volume

Aerobic exercise volume was measured by collecting data on intensity, frequency, duration, and exercise type(s). Intensity was measured in metabolic equivalents (METs) and was assessed by asking individuals to provide details associated with each type of aerobic exercise they reported performing weekly. Respondents were first asked to indicate how easily they can carry on a conversation during their selected type(s) of aerobic exercise. Answer options were associated with light, moderate, or vigorous intensity levels, as seen in the talk test (ACSM, 2021). Participants who reported running weekly were asked to provide their average pace and

specify particular aspects of their usual running routine, such as cross country running, running/walking intervals, running during team practice, etc. Those who reported cycling weekly were asked to provide their average speed and indicate if their usual cycling activities consist of variables such as mountain cycling, road cycling, competitive cycling training, etc. Participants who reported walking for exercise weekly were asked to indicate where they most frequently walk, as well as average treadmill speed and grade, if applicable. Individuals who engaged in other forms of aerobic exercise weekly were asked to provide any additional details that they believe may help researchers understand how they perform each type of exercise. This may include perceived effort levels, sub-categories of exercise types, additional weights or equipment used, etc. The Compendium of Physical Activities (Ainsworth et al., 2011) was then utilized to find the associated METs based on the reported information. A pilot test was run to determine the feasibility of assessing METs from these questions. To assess frequency, participants were asked to report how many days per week, on average, they perform each type of aerobic exercise. Duration was measured by asking respondents how many minutes they typically spend performing each type of exercise on these days.

Total aerobic EV was then calculated using the below equation.

EV = frequency (days) x duration (minutes) x intensity (METS)

Individuals who reported performing multiple types of aerobic exercise each week had their EV calculated separately for each activity. The sum of EV for each exercise type represents the total EV for each individual.

Inhibitory Control

Inhibitory Control was assessed by measuring delaying gratification and impulsivity. The short form of the Delaying Gratification Inventory (DGI-10; Hoerger et al., 2011) was used to

assess delaying gratification. The DGI-10 has been shown to be valid and reliable in measuring each of the five aspects of delayed gratification: food, physical pleasure, social interaction, money, and achievement (Hoerger et al., 2011). Individuals were asked to rate how well each item describes them on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The sum of responses was then calculated to determine the score. Higher scores represent an increased ability to self-regulate in order to delay immediate gratification and achieve greater long-term reward (Liang et al., 2023). A 15-item version of the Barratt Impulsivity Scale (BIS-15; Spinella, 2007) was used to assess impulsivity. This questionnaire has been shown to be valid and reliable in assessing impulsivity among both general and psychiatric populations (Spinella, 2007; Meule et al., 2020). Participants were instructed to rate how well each item describes them on a 4-point Likert scale from 1 (rarely/never) to 4 (almost always). Responses were summed up to calculate the score. Higher scores represent higher levels of impulsivity (Patton et al., 1995).

Data Analysis

Data analysis was conducted using IBM SPSS Statistics Version 29 (IBM, New York). A Pearson correlation was run to explore the relationship between aerobic exercise volume and impulsivity. An additional Pearson correlation was conducted to determine the relationship between aerobic exercise volume and delaying gratification. A regression analysis was then conducted for any significant relationships found to determine the predictability of the model.

Additional regression analyses were then run to determine the predicted values of impulsivity and delaying gratification based on each sub-component of exercise volume (frequency, intensity, and duration). Regression analyses were conducted only for variables that showed significant relationships with exercise volume. Data was also collected to assess whether this

population is taking psychotropic medications, experiencing sleep quality issues, meeting guidelines for heavy caffeine or alcohol consumption, or regularly using drugs that may impact inhibitory control to assess whether further analyses should be implemented to control for these variables. However, due to the limited sample size, no further analyses were conducted.

CHAPTER 4

Results

A total of 84 survey responses were collected for the present study. Eight participants were excluded for being outside of the required age range, 15 were removed for not completing the survey, and 20 responses were omitted due to negative ADHD screenings based on ASRS results. Additionally, one response was excluded due to inconsistent survey responses, and one participant was excluded due to being an outlier. Thus, the final sample consisted of 39 individuals (see Table 1).

Table 1. Participant Characteristics (N=39)

Characteristic	M ± SD
Age (years)	24.33 ± 3.06
Exercise Volume (MET-min/wk)	1446.62 ± 1715.41
Frequency (sessions/wk)	5.87 ± 4.26
Intensity (Weighted Average METs)	5.18 ± 2.31
Time (minutes/wk)	252.32 ± 293.69
BIS-15	37.69 ± 4.80
DGI-10	34.59 ± 5.77

Note. BIS-15 = Barratt Impulsivity Scale, DGI-10 = Delaying Gratification Index.

A Pearson correlation was conducted to examine the relationship between exercise volume and delayed gratification. Results showed a weak positive relationship that was not significant ($r(37) = .231$, $p = .158$), indicating that aerobic exercise volume was not significantly associated with improvements in delayed gratification. An additional Pearson correlation was

conducted to examine the relationship between exercise volume and impulsivity. Results indicated a significant but weak negative relationship (r (37) = -.33, p = .042), suggesting that increases in aerobic exercise volume were significantly associated with a decrease in impulsivity in this sample (see Figure 1).

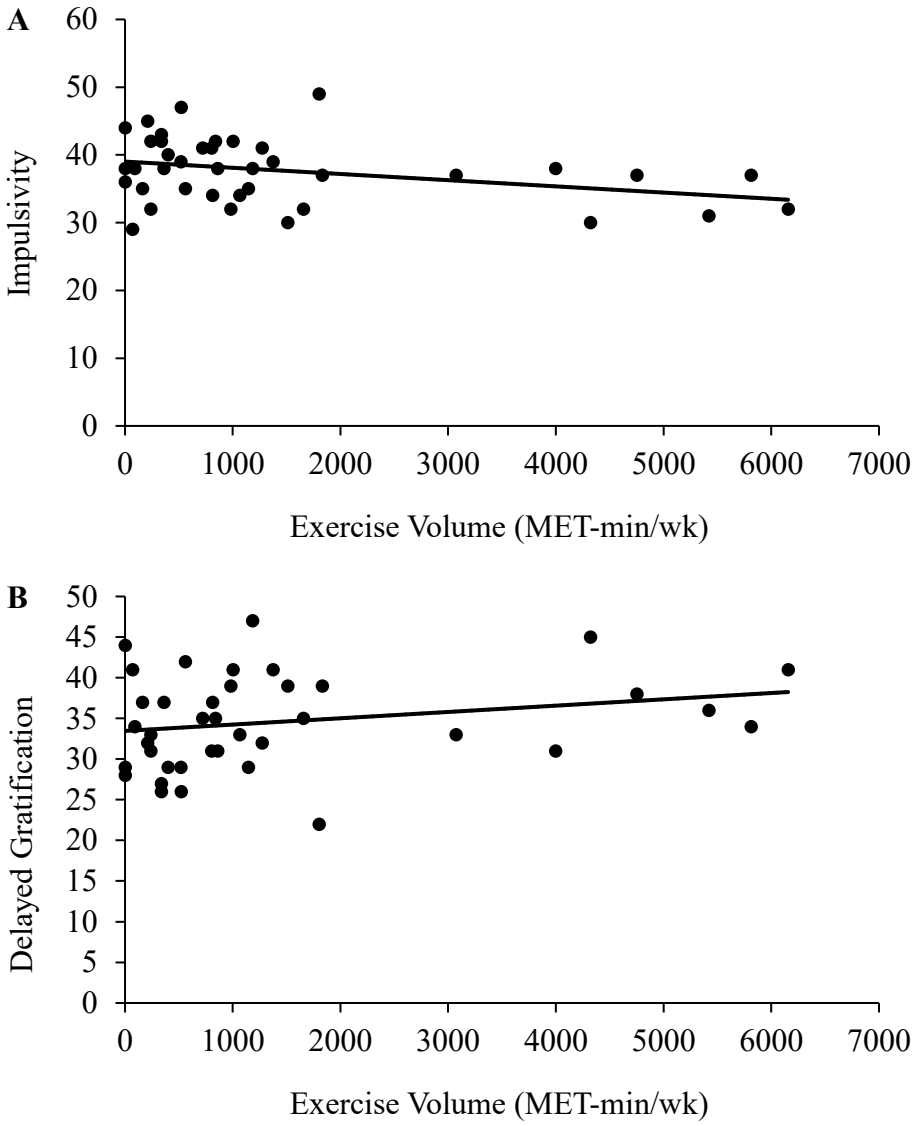

Figure 1. Relationship Between Exercise Volume and (A) Impulsivity and (B) Delayed Gratification. Higher delayed gratification values indicate a greater ability to self-regulate and delay immediate gratification, while high impulsivity values represent higher levels of impulsivity. A: r = -.33, p = .042; B: r = .231, p = .158.

A linear regression was then used to determine whether aerobic exercise volume predicts impulsivity. A regression was conducted exclusively for these variables, as this was the only relationship found to be statistically significant. The model was a significant predictor ($F(1, 37) = 4.43$, $p = .042$), explaining 11% of the variability in impulsivity scores ($R^2 = .11$). Exercise volume was a significant predictor of impulsivity ($B = 0.00$, $SE = 0.00$, $\beta = -0.33$, $t(37) = -2.10$, $p = .042$), suggesting that increased weekly aerobic exercise volume is associated with decreased impulsivity scores.

A multiple regression analysis was then conducted to determine whether exercise intensity, frequency, and time, predict impulsivity values. A regression was conducted solely for these subcomponents and impulsivity as a significant relationship between delayed gratification and exercise volume was not found. Mean and standard deviations for the subcomponents included in the multiple regression are displayed in Table 1. The model was not significant, ($F(3, 35) = 1.34$, $p = .276$), explaining 10% of the variability in impulsivity scores ($R^2 = .10$, Adjusted $R^2 = .03$). None of the subcomponents of exercise volume were statistically significant, indicating that frequency ($B = .16$, $SE = .32$, $\beta = .15$, $t(35) = .51$, $p = .610$), intensity ($B = -.07$, $SE = .37$, $\beta = -.03$, $t(35) = -.18$, $p = .861$), and time ($B = -.01$, $SE = 0.00$, $\beta = -.42$, $t(35) = -1.59$ $p = .120$) did not have a significant impact on the model (see Figure 2). These results suggest that these individual subcomponents may not be as impactful as total exercise volume for improving impulsivity.

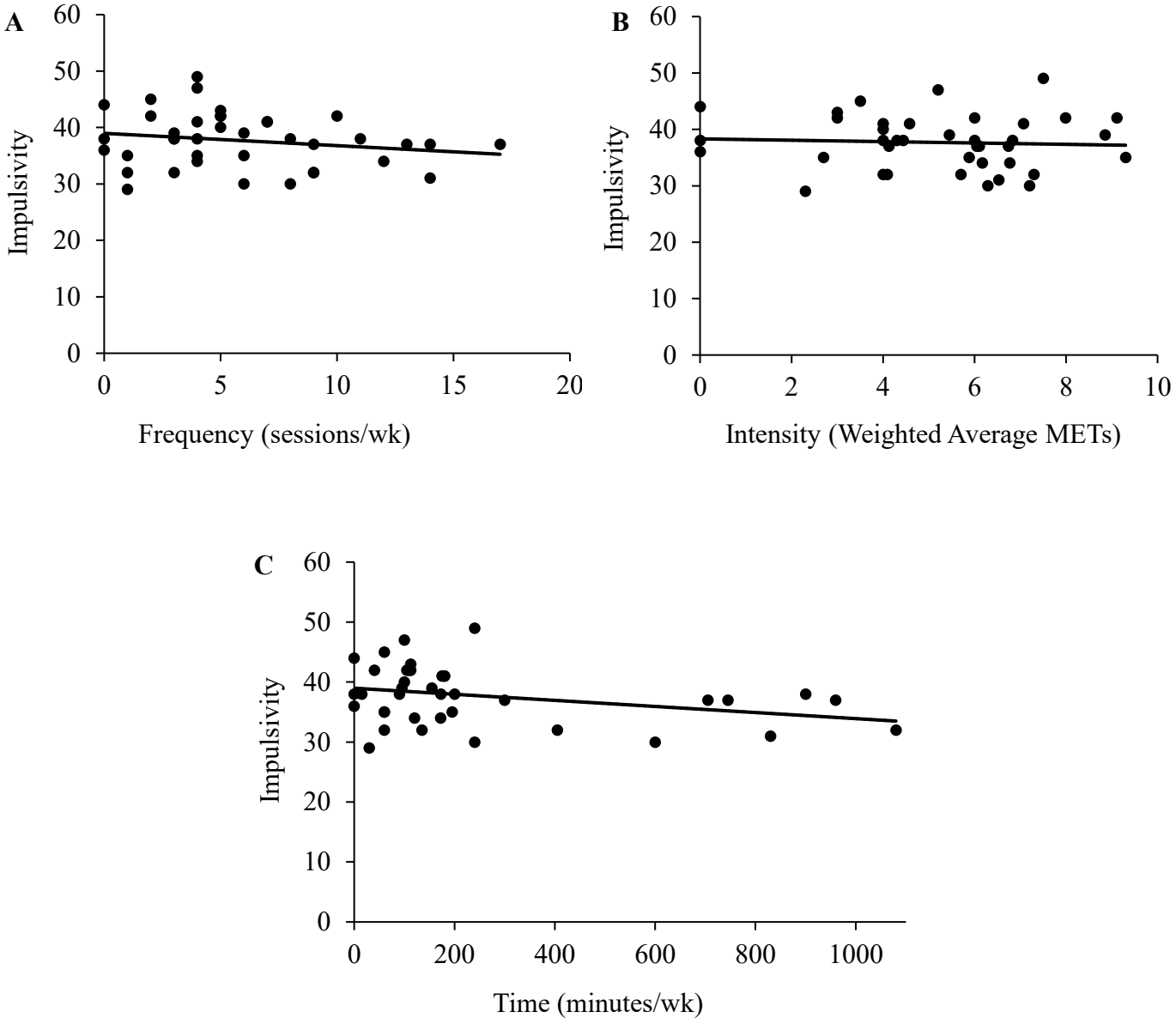

Figure 2. Relationship Between Impulsivity and (A) Frequency, (B) Intensity, and (C) Time.

Overall model: $R^2 = .10$, $F(3, 35) = 1.34$, $p = .276$.

A: $\beta = .15$, $p = .610$; B: $\beta = -.03$, $p = .861$; C: $\beta = -.42$, $p = .120$

CHAPTER 5

Discussion

The purpose of the present study was to investigate the effect of weekly aerobic EV on self-reported IC (i.e., impulsivity and delayed gratification) in young adults who screen positive for ADHD. Additionally, this study aimed to determine which subcomponent of EV has the greatest impact on self-reported IC among young adults who screen positive for ADHD. Results showed a nonsignificant relationship between EV and delayed gratification scores, indicating that EV was not significantly associated with changes in this measure. Additionally, results showed a significant relationship between EV and impulsivity scores, suggesting that EV was significantly associated with improvements in impulsivity. Furthermore, results found that none of the subcomponents— frequency, intensity, or time— were found to significantly predict impulsivity. Instead, the results of this study indicate that total EV may be a greater predictor of impulsivity values among young adults who screen positive for ADHD.

No studies were found that have used self-reported exercise habits and IC ratings to determine the real-world effectiveness of aerobic EV on adults with ADHD. However, the present study can be compared to past studies on this topic, which have primarily used task-based IC measures and experimental designs. Mehren et al. (2019) conducted a study to evaluate the effect of a single bout of cycling on attention and EFs in a group of adults with ADHD. Results showed that the exercise bout significantly improved reaction times among adults with ADHD, but not in the non-ADHD control group. These results suggest that adults with ADHD may experience improvements in IC after a single bout of aerobic exercise. These findings align with those of the present study, which also found improvements in one aspect of IC with increased EV. However, Mehren and colleagues used a flanker task to analyze IC as a single

construct, rather than breaking it down into subcomponents such as impulsivity and delayed gratification. Furthermore, these researchers used an experimental design to assess the impact of a single exercise bout, while the present study utilized self-reported data to analyze participants' exercise habits at a single point in time. The differing designs of these studies make direct comparisons difficult. However, both studies found associations between aerobic exercise and at least one aspect of IC.

Additionally, Rassovsky & Alfassi (2019) investigated the impact of aerobic exercise on attention among adults with and without ADHD. Participants had their attention assessed twice; once while in a seated position, and again while walking on a treadmill. Results showed that the ADHD group had faster reaction times during exercise when compared to seated times. Conversely, the non-ADHD control group showed faster reaction times while seated when compared to exercise times. These findings indicate that aerobic exercise may elicit improvements in IC among adults with ADHD. These results can be compared to those of the current study, which found that EV was significantly associated with improvements in impulsivity, an aspect of IC. However, these researchers assessed IC as a single measure, rather than analyzing different subcomponents, as was done in the present study. The current study also utilized self-report measures, while Rassovsky & Alfassi implemented an experimental design. Though the study designs differ, both studies suggest that there is an association between exercise and improved IC in adults with ADHD.

Furthermore, Gapin et al. (2015) examined the impact of acute aerobic exercise on EFs in college students with and without ADHD. Participants had each domain of EF measured before and after a bout of aerobic exercise. The exercise bout improved all aspects of EFs in the non-ADHD group. However, exercise improved only inhibitory performance among the ADHD

group. Results of this study imply that acute exercise may improve the IC aspect of EFs among college-aged adults with ADHD. These results agree with those of the present study, which also found improvements in one aspect of IC with greater EV. Similar to the previous studies, Gapin et al. used an experimental design rather than the self-reported measures collected in the present study. Furthermore, Gapin and colleagues analyzed IC as a single construct instead of assessing individual components. This study also used pre- and post-measurements to allow researchers to measure changes over time, while the present study analyzed exercise habits at one moment in time. Despite these differences, both studies found that exercise was associated with improvements in at least one aspect of IC among the present population.

There are a few potential mechanisms that may be responsible for the improvement in impulsivity levels seen with increased EV. Wigal et al. (2012) found that EF improvements associated with exercise may be caused by a similar mechanism to that of stimulant medications for ADHD, which increase dopamine and norepinephrine in the prefrontal cortex (Rubia et al., 2014). Research has shown that aerobic exercise stimulates the release of several catecholamines, including dopamine, serotonin, epinephrine, and norepinephrine (Anish, 2005). Therefore, exercise may allow catecholamine levels to be regulated in individuals with ADHD, which may improve EFs such as attention and impulse control (Wigal et al., 2013). Similarly, Chang et al. (2012) found that the improvements in EFs associated with exercise may occur due to an increase in dopamine release. These researchers also suggest that exercise activates the dorsolateral prefrontal cortex, which is an area of the brain that often can be functionally and structurally different in those with ADHD. This study also suggests that exercise can improve impulse control, thus helping individuals better direct their attention (Chang et al., 2012). This indicates that the release of catecholamines, specifically dopamine, and the activation of the

dorsolateral prefrontal cortex may serve as two potential mechanisms for IC improvements through exercise.

Conversely, the lack of a significant association between EV and delayed gratification scores suggests that other factors may be involved in this aspect of IC. While impulsivity entails immediate attention and decision making, delayed gratification involves longer-term decision making and cognitive processes (Hoerger et al., 2011). Thus, while impulsivity may be improved by the release of catecholamines and prefrontal cortex activation associated with acute exercise (Chang et al., 2012), a more structured, long-term intervention might be necessary to observe improvements in delayed gratification. Future research should examine the impact of aerobic exercise on delayed gratification among this population by utilizing an experimental design where improvements are monitored over time. Additionally, studies could examine the impact of specific factors such as frequency, intensity, and time on delayed gratification in adults with ADHD.

Furthermore, while total EV was shown to be a significant predictor of impulsivity scores, its subcomponents— frequency, intensity, and time— were not. It is possible that the interaction between these subcomponents is what drives the improvement in impulsivity. Thus, it may be more important that individuals are consistent with weekly aerobic exercise, rather than aiming for specific intensity, time, and frequency goals. Further research is needed to examine the interaction between these variables and their combined impact on impulsivity among this population.

The present study has a few limitations. First, this study may have been limited by the sample size. A greater sample may have improved statistical power and produced findings with greater reliability. Additionally, variables such as sleep quality, psychotropic medication status, caffeine

intake, and alcohol and drug intake were not accounted for. Given that these behaviors are prevalent among those with ADHD (Cusick et al., 2020; Lee et al., 2021; Martinex-Raga et al., 2013), excluding these participants would have significantly limited our sample size. Another possible limitation has to do with the self-reported nature of the data. Participants' reports of their weekly exercise habits may not have been entirely accurate, potentially due to response bias or difficulties recalling aspects of their exercise habits. An additional limitation is that most participants resided in the southeast, which may have resulted in findings that are less representative of a broader ADHD population. Lastly, because this study collected participants' EV and IC data at a single point in time, potential fluctuations in behavior could not be accounted for. Future studies should be conducted using a longitudinal design to analyze changes in EV and IC over a longer period of time.

The findings of the present study can be applied within several research or clinical scenarios involving the treatment of individuals with ADHD. The present study found that increased EV was associated with improvements in impulsivity but not delayed gratification. These results suggest that increasing one's weekly aerobic EV may be an effective non-pharmacological intervention to improve impulsivity levels. Researchers, clinicians, and fitness professionals can apply these findings by recommending that patients with ADHD increase their total aerobic EV to potentially decrease impulsivity. However, the nonsignificant relationship between EV and delayed gratification suggests that alternate treatments or interventions may be necessary to improve this aspect of IC. Further research should examine the impact of different training interventions on delayed gratification among individuals with ADHD. A longitudinal study design may be particularly beneficial in determining the effect of long-term exercise habits on delayed gratification measures. Additionally, the results of the present study found that

frequency, intensity, and time did not significantly impact impulsivity scores, suggesting that increasing total aerobic EV may be more beneficial in improving impulsivity among this population. Clinicians and researchers can apply these results by advocating for increased overall aerobic EV, focusing on promoting individuals' enjoyment of their exercise habits to maintain consistency. Fitness professionals can also utilize these findings by designing training programs that help individuals with ADHD increase their total EV, rather than primarily emphasizing the specific subcomponents.

The present study suggests that aerobic exercise may improve impulsivity levels, but not delayed gratification, among young adults who screen positive for ADHD. Additionally, results of this study indicate that total aerobic EV may be more important than frequency, intensity, or time when aiming to decrease impulsivity. Future studies should utilize structured interventions over a longer period of time to determine whether aerobic exercise can improve delayed gratification among this population. Furthermore, future research should examine the combined impact of frequency, intensity, and time to explore potential mechanisms behind the improvement in impulsivity with the combination of these variables.

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Appendix A

Participant Questionnaire

Study Title: The Effect of Aerobic Exercise Volume on Inhibitory Control in Young Adults with ADHD
Protocol Number: IRB-FY2024-266
Approval Date: 9/30/2024
Principal Investigator: Caroline Mull
Institution: Middle Tennessee State University

You are being asked to participate in a research project. The following information is provided to inform you about the research project and your participation in it.

1. Purpose of the study: The purpose of this study is to investigate the effect of weekly aerobic exercise volume on self-reported inhibitory control in young adults who screen positive for ADHD. Additionally, this study aims to determine which subcomponent of exercise volume (frequency, intensity, or duration) will have the greatest impact on self-reported inhibitory control among this population.
2. Description of procedures to be followed and approximate duration of the study: Read each survey question carefully and select the appropriate answer choice. Survey completion will take approximately 5-10 minutes.
3. Compensation for participation: No compensation will be provided for participation.

Here are your rights as a participant:
a) Your participation in this research is voluntary.
b) You may skip any item that you don't want to answer, and you may stop the research at any time. Note that if you leave an item blank, you will be warned that you missed one, just in case it was an accident. You can still click that you don't want to answer. Some items may be required in order to accurately present the study.
c) There are no risks associated with your participation besides possible discomfort with some of the questions.
d) There are no real benefits to you from participating besides possibly learning something about the research.
e) You will NOT be asked to provide any identifiable personal information.
f) All efforts, within reason, will be made to keep the personal information in your research record private, but total privacy cannot be promised. Your information may be shared with people at MTSU (such as the MTSU Institutional Review Board) or other agencies (such as the

Federal Government Office for Human Research Protection) if you or someone else is in danger or if we are required to do so by law.

Contact Information: If you should have any questions about this research study please contact:
Principal Investigator: Caroline Mull
Contact Information: cgm4b@mtmail.mtsu.edu
Faculty Advisor: Dr. Vaughn Barry Contact Information: vaughn.barry@mtsu.edu
For additional information about giving consent or your rights as a participant in this study, please contact the Middle Tennessee State University (MTSU) Office of Compliance at 615-494-8918 or via email at irb_information@mtsu.edu. (http://www.mtsu.edu/irb)
If you're ready to get started, please make your choice below before clicking the arrow button. Thanks again for volunteering your time to this project!

I have read the information above. I am at least 18 years old. I believe I understand the purpose, risks, and benefits of the research, and I know what I will be expected to do as a study participant.

- ○ I consent to participate
- ○ I decline to participate

How old are you?

_____

End of Block: Age

Start of Block: Block 8

Have you experienced a significant trauma in the past 6 months?

- ○ Yes
- ○ No
- ○ Unsure

End of Block: Block 8

Start of Block: ASRS

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

	Never	Rarely	Sometimes	Often	Very Often
How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?	○	○	○	○	○
How often do you have difficulty getting things in order when you have to do a task that requires organization?	○	○	○	○	○
How often do you have problems remembering appointments or obligations?	○	○	○	○	○

When you have a task that requires a lot of thought, how often do you avoid or delay getting started?	○	○	○	○	○
How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?	○	○	○	○	○
How often do you feel overly active and compelled to do things, like you were driven by a motor?	○	○	○	○	○

End of Block: ASRS

Start of Block: Block 7

What type(s) of aerobic exercise do you typically engage in each week? (i.e., cardio-type exercise using large muscle groups in a repetitive and rhythmic manner)

- [ ] Running
- [ ] Cycling
- [ ] Walking
- [ ] Dancing
- [ ] Stair climber
- [ ] Elliptical
- [ ] Yoga
- [ ] Other (enter here) _____
- [ ] None

Page Break

End of Block: Block 7

Start of Block: Running

On average, how many days per week do you run?

1 2 3 4 5 6 7

On average, how many minutes do you spend running on these days?

_____

At the intensity you typically run, how difficult would it be to carry on a conversation?

- I could easily carry on a conversation
- I could carry on a conversation, but it would be somewhat difficult
- Difficult, I could likely only sustain a few words

On average, what is your pace while running? (in min/mile)

_____

Does your USUAL running consist of any of the following?

- ☐ Cross country running
- ☐ Running during team practice
- ☐ Running up stairs
- ☐ Jogging in place
- ☐ Combination of jogging/walking
- ☐ Pushing a wheelchair/baby carrier
- ☐ None of the above

Please enter any additional details that may help researchers understand how you perform this type of exercise, such as intensity or effort levels, sub-categories of this exercise type (e.g., different types of yoga, running, or dancing), additional weights or equipment used, or any other important factors.

_____

End of Block: Running

Start of Block: Cycling

On average, how many days per week do you cycle?

1 2 3 4 5 6 7

On average, how many minutes do you spend cycling on these days?

_____

At the intensity you typically cycle, how difficult would it be to carry on a conversation?

- ○ I could easily carry on a conversation
- ○ I could carry on a conversation, but it would be somewhat difficult
- ○ Difficult, I could likely only sustain a few words

Do you know your average cycling speed? (in mph)

- ○ Yes (enter here) _____
- ○ No

Does your USUAL cycling consist of any of the following?

- ☐ Mountain cycling
- ☐ Training for competitive cycling/racing
- ☐ Road cycling
- ☐ Cycling leisurely/for pleasure
- ☐ BMX
- ☐ None of the above

Please enter any additional details that may help researchers understand how you perform this type of exercise, such as intensity or effort levels, sub-categories of this exercise type (e.g., different types of yoga or dancing), additional weights or equipment used, or any other important factors.

_____

End of Block: Cycling

Start of Block: Walking

On average, how many days per week do you walk for exercise?

1 2 3 4 5 6 7

On average, how many minutes do you spend walking on these days?

_____

At the intensity you typically walk, how difficult would it be to carry on a conversation?

- ○ I could easily carry on a conversation
- ○ I could carry on a conversation, but it would be somewhat difficult
- ○ Difficult, I could likely only sustain a few words

Where do you MOST frequently walk?

- ○ On a treadmill
- ○ Outside on a paved path
- ○ On an indoor track
- ○ Other (enter here) _____

What is your average speed when walking on a treadmill? (in mph)

_____

What is your average grade (or incline) when walking on a treadmill?

_____

Please enter any additional details that may help researchers understand how you perform this type of exercise, such as intensity or effort levels, sub-categories of this exercise type (e.g., different types of yoga or dancing), additional weights or equipment used, or any other important factors.

_____

End of Block: Walking

Start of Block: Dancing

On average, how many days per week do you dance for exercise?

1 2 3 4 5 6 7

On average, how many minutes do you spend dancing on these days?

_____

At the intensity you typically dance, how difficult would it be to carry on a conversation?

- ○ I could easily carry on a conversation
- ○ I could carry on a conversation, but it would be somewhat difficult
- ○ Difficult, I could likely only sustain a few words

Please enter any additional details that may help researchers understand how you perform this type of exercise, such as intensity or effort levels, sub-categories of this exercise type (e.g., different types of yoga or dancing), additional weights or equipment used, or any other important factors.

_____

End of Block: Dancing

Start of Block: Elliptical

On average, how many days per week do you exercise on the elliptical?

1 2 3 4 5 6 7

On average, how many minutes do you spend exercising on the elliptical on these days?

_____

At the intensity you typically exercise on the elliptical, how difficult would it be to carry on a conversation?

- ○ I could easily carry on a conversation
- ○ I could carry on a conversation, but it would be somewhat difficult
- ○ Difficult, I could likely only sustain a few words

End of Block: Elliptical

Start of Block: Stair climber

On average, how many days per week do you exercise on the stair climber?

1 2 3 4 5 6 7

On average, how many minutes do you spend exercising on the stair climber on these days?

_____

At the intensity you typically exercise on the stair climber, how difficult would it be to carry on a conversation?

- ○ I could easily carry on a conversation
- ○ I could carry on a conversation, but it would be somewhat difficult
- ○ Difficult, I could likely only sustain a few words

End of Block: Stair climber

Start of Block: Yoga

On average, how many days per week do you practice yoga?

1 2 3 4 5 6 7

On average, how many minutes do you spend practicing yoga on these days?

_____

At the intensity you typically practice yoga, how difficult would it be to carry on a conversation?

- ○ I could easily carry on a conversation
- ○ I could carry on a conversation, but it would be somewhat difficult
- ○ Difficult, I could likely only sustain a few words

Please enter any additional details that may help researchers understand how you perform this type of exercise, such as intensity or effort levels, sub-categories of this exercise type (e.g.,

different types of yoga or dancing), additional weights or equipment used, or any other important factors.

_____

End of Block: Yoga

Start of Block: Other

Please answer the following questions for the type of exercise you indicated as "other."

On average, how many days per week do you perform this type of exercise?

1 2 3 4 5 6 7

On average, how many minutes do you spend performing this type of exercise on these days?

_____

At the intensity you typically perform this type of exercise, how difficult would it be to carry on a conversation?

- ○ I could easily carry on a conversation
- ○ I could carry on a conversation, but it would be somewhat difficult
- ○ Difficult, I could likely only sustain a few words

Please enter any additional details that may help researchers understand how you perform this type of exercise, such as intensity or effort levels, sub-categories of this exercise type (e.g., different types of yoga or dancing), additional weights or equipment used, or any other important factors.

_____

_____

_____

_____

_____

End of Block: Other

Start of Block: DGI-10

Rate how well each statement describes you on average.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I would have a hard time sticking with a special, healthy diet.	○	○	○	○	○
I try to spend my money wisely.	○	○	○	○	○
I have given up physical pleasure or comfort to reach my goals.	○	○	○	○	○
I try to consider how my actions will affect other people in the long-term.	○	○	○	○	○
I cannot be trusted with money.	○	○	○	○	○
I do not consider how my behavior affects other people.	○	○	○	○	○
I cannot motivate myself to accomplish	○	○	○	○	○

long-term goals.					
I have always tried to eat healthy because it pays off in the long run.	○	○	○	○	○
When faced with a physically demanding chore, I always tried to put off doing it.	○	○	○	○	○
I have always felt like my hard work would pay off in the end.	○	○	○	○	○

End of Block: DGI-10

Start of Block: BIS-15

Rate how well each statement describes you on average.

	Rarely/Never	Occasionally	Often	Almost always/Always
I act on impulse	○	○	○	○
I act on the spur of the moment.	○	○	○	○
I do things without thinking.	○	○	○	○
I say things without thinking.	○	○	○	○
I buy things on impulse.	○	○	○	○
I plan for job security.	○	○	○	○
I plan for the future.	○	○	○	○
I save regularly.	○	○	○	○
I plan tasks carefully.	○	○	○	○
I am a careful thinker.	○	○	○	○
I am restless at lectures or talks.	○	○	○	○
I squirm at plays or lectures.	○	○	○	○
I concentrate easily.	○	○	○	○

I don't pay attention.	○	○	○	○
I am easily bored solving thought problems.	○	○	○	○

End of Block: BIS-15

Start of Block: Confounders

How many hours do you typically sleep each night?

1 2 3 4 5 6 7 8 9 10 11 12 13 14

1 

On a scale of 1-10, how would you rate your overall quality of sleep?

Poor Excellent

0 1 2 3 4 5 6 7 8 9 10

How many days per week do you typically consume caffeine?

- ○ Less than once per week
- ○ 1-2 days per week
- ○ 3-4 days per week
- ○ 5-6 days per week
- ○ Every day

On days you consume caffeine, approximately how much caffeine do you consume?

- ○ Less than 100mg
- ○ 100-200mg
- ○ 200-300mg
- ○ 300-400mg
- ○ More than 400mg
- ○ Unsure

End of Block: Confounders

Start of Block: Confounders

Are you currently taking any psychotropic medications? (i.e., antidepressants, anti-anxiety medications, stimulants, antipsychotics, mood stabilizers)

- ○ Yes
- ○ No

On average, how many alcoholic drinks do you have each week? (i.e., 12 oz beer, 5 oz wine, 1.5 oz distilled spirits)

0 2 4 6 8 10 12 14 16 18 20

Excluding alcohol, have you used recreational drugs or substances in the past year? (responses will be kept confidential)

- ○ Yes
- ○ No

Excluding alcohol, how often do you typically use recreational drugs or substances? (responses will be kept confidential)

- ○ Daily
- ○ Weekly
- ○ Monthly
- ○ Once every few months
- ○ Once every year
- ○ Less than once a year
- ○ Never

End of Block: Confounders

Start of Block: Block 16

What country do you currently reside in?

_____

What is your sex?

- Male
- Female
- Intersex
- Prefer not to say

End of Block: Block 16