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A single bout of physical activity has shown positive effects on cognitive control and affect in young adults. However, individuals at risk for attention-deficit hyperactivity disorder (ADHD) demonstrate cognitive control deficits and emotional dysregulation that negatively impact their quality of life, revealing impairments occupationally, socially, academically, and psychologically. Additionally, the effects of a bout of physical activity on subsequent cognition and affect are unclear in young adults within their real-world environments. Therefore, the purpose of this dissertation was to extend previous research regarding the effect of structured physical activity by observing the effects of a bout of physical activity in a real-world environment. Specifically, this dissertation assessed cognitive control performance and affect prior to and following physical activity and inactivity in individuals who are at risk and not at risk for ADHD in a real-world environment. Young adults throughout the Southeast United States were recruited for this dissertation (*n* = 94), and all participants completed one bout of both physical activity and inactivity over seven days in their real-world environment. Immediately before and after each bout, participants used a mobile device to complete a cognitive control task and affect measures. Cognitive control results revealed a significant decrease in reaction time following physical activity compared to before physical activity and after inactivity for individuals at risk and not at risk for ADHD. All participants reported improved affect after physical activity compared to before physical activity and after inactivity. Together, these data are the first to demonstrate cognitive and affective improvements following physical activity in real-world environments for individuals at risk and not at risk for ADHD.

COGNITIVE CONTROL AND AFFECT BEFORE AND AFTER PHYSICAL ACTIVITY IN A REAL-WORLD ENVIRONMENT FOR YOUNG ADULTS AT RISK AND NOT AT RISK FOR ADHD

by

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APPROVAL PAGE

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CHAPTER I: INTRODUCTION

Individuals with attention-deficit hyperactivity disorder (ADHD; American Psychiatric Association, 2013) exhibit both cognitive and emotional deficits, specifically related to cognitive control and affect. Physical activity accomplished in real-world environments can help alleviate these mental health deficits in young adults at risk for ADHD (Cook et al., 2015). Specifically, health organizations recommend physical activity for individuals at risk for ADHD, because physical activity minimizes ADHD symptoms (LaCount & Hartung, 2018). Additionally, laboratory-based research demonstrates that an acute bout of physical activity significantly improves cognitive control and affect in young adults at risk and diagnosed with ADHD (Fritz & O'Connor, 2016; Gapin et al., 2015; Mehren et al., 2019). However, real-world application is difficult given that inactivity is common among adults in the United States, with 47% of adults, including individuals with ADHD, not engaging in the recommended amount of physical activity (Center for Disease Control and Prevention, 2018; Cook et al., 2015; Physical Activity Guidelines Advisory Committee, 2018; World Health Organization, 2016). Physical inactivity demonstrates a negative correlation to overall physical health (i.e., coronary heart disease, type II diabetes, hypertension, and obesity; Booth et al., 2012), and may similarly correlate to poor cognitive states associated with ADHD, like cognitive control and affective deficits (Cook et al., 2015). Furthermore, studies assessing the behavioral effects of physical activity on the young adult population, and specifically individuals at risk for ADHD, have historically been laboratory-based, excluding the consideration of intraindividual changes in the person's own, real-world environment (Gawrilow et al., 2013). Therefore, the present dissertation assessed cognitive control performance and affect prior to and following physical activity and inactivity in individuals who are at risk and not at risk for ADHD in a real-world environment.

Young adults with ADHD have both cognitive control and affect instabilities. For example, they present developmentally inappropriate levels of inattention and hyperactivity/impulsivity. Symptoms of inattention include careless mistakes, difficulty sustaining attention to a task, being easily distracted, avoidance of tasks requiring mental effort, and forgetfulness. Hyperactivity/impulsivity symptoms consist of fidgeting, difficulty waiting, difficulty being quiet, and frequent interruption, all resulting in cognitive impairments (American Psychiatric Association [APA], 2000). Individuals with ADHD show deficits in frontal lobe function (Bush et al., 2005), which influence cognitive control (i.e., attending to low-level automatic action schema to execute well-learned processes and provide action or inhibition; Norman & Shallice, 1986). Additionally, individuals with ADHD express a range of difficulty regulating their emotions (Barkley, 2010; Shaw et al., 2014) and express higher levels of negative affect as compared to positive affect (De Pauw & Mervielde, 2011). That is, core affect is a subjective response that varies in valence (i.e., ranging from unpleasant to pleasant) and activation (i.e., feelings that range from relaxation or boredom to excitement or anxiety; Russell, 2003). Overall, deficits in cognitive control and affect are displayed in young adults with ADHD, and physical activity has been a proposed method in reducing cognitive control and affect (i.e., inattention and emotional regulation) deficits.

Physical activity has been proposed as an alternative method in reducing ADHD inattention symptoms associated with inhibitory control performance (i.e., a sub-component of cognitive control, which focuses on relevant demands and regulated responses to irrelevant distractions; Donchin & Coles, 1988) and affective valence and activation. Regarding inhibitory control, a recent meta-analysis reveals that adults who are at risk and diagnosed with ADHD improve in attention (e.g., mental alertness) and inhibition following acute physical activity (Den

Heijer et al., 2017). Regarding affect, a review of research evaluating ADHD symptoms suggests improved negative affect (i.e., less jittery, distressed, or nervous) following acute physical activity for individuals diagnosed with ADHD (Archer & Kostrzewa, 2012). Furthermore, empirical evidence has demonstrated that following an acute bout of physical activity, affect became more positive and less negative for adult men at risk for ADHD (Fritz & O'Connor, 2016). Together, these findings provide evidence to support the hypothesis that acute physical activity facilitates inhibitory control performance and affect for individuals who are at risk for ADHD and those who have been diagnosed with ADHD.

When examining the effects of physical activity on young adults with ADHD, researchers use different diagnostic measures. Of particular concern is that most physical activity studies defined ADHD status by using self-report histories (i.e., as opposed to self-report at the time of the study) and physician reviews (Chang et al., 2011; Fritz & O'Connor, 2016; Gapin et al., 2010, 2015; Gawrilow et al., 2013; Mahon et al., 2013; Medina et al., 2010; Milkós et al. 2020; Piepmeier et al., 2015). That is, these measures use self-report of previous diagnoses or a single rating scale that encompasses only one aspect of ADHD, thus lacking diagnostic rigor. This classification system may increase the likelihood of incorrectly identifying ADHD or non-ADHD in participants, impacting the outcomes of the investigation. This is important in a real-world environment because research suggests that ADHD symptomology may differ in a real-world environment compared to a controlled-laboratory setting, suggesting differences in cognitive control performance and emotional dysregulation would be observed in the varied environments (Weizenbaum et al., 2020). There are more effective and clinically-based appropriate methods to diagnose ADHD, and the methods previously mentioned, regarding physical activity studies, are a less than rigorous way to diagnosis ADHD (Anastopoulos et al., 2016, 2021). ADHD is diagnosed when the symptoms: are frequent, are present in two or more settings, are present before the age of 12, interfere with daily functioning, and cannot be explained by another condition. Additionally, multiple methods of assessing classifications must occur through parents or guardians, teachers, and clinicians through rating scales, observations, and interviews (APA, 2013). If any one of the five classification items assessed by multiple informants is absent, the ADHD diagnosis cannot be made. However, even if a combination of the diagnostic classification items are used, this method is more rigorous compared to the previously mentioned studies. Therefore, by assessing ADHD symptom frequency in childhood and as an adult (i.e., in the past 6-months), continuity of symptoms from childhood to adulthood is demonstrated, and individuals may be classified as 'at risk' for ADHD. At-risk does not signify the individual might potentially develop ADHD in the future. At risk for ADHD indicates the individual is reporting childhood and current symptoms that suggest a clinical ADHD diagnosis could be made.

Previous studies have investigated physical activity, inhibitory control, and affect in individuals at risk for ADHD (Gawrilow et al., 2013; Hogan et al., 2013). However, none to present knowledge have combined all components and investigated inhibitory control and affect in individuals at risk for ADHD in one's own real-world environment. While laboratory-based assessments are very informative and lay the foundation for translational research, they lack the ability to fully capture information from the real-world environment, thus failing to obtain a personalized cognitive control and affect assessment. Therefore, literature highlights the importance of using new mobile technology to examine cognitive control and affective factors in a real-world environment (Shiffman et al., 2008; Weizenbaum et al., 2020). Researchers assume that all cognitive factors reflect internal process that are always constant and stable

(Weizenbaum et al., 2020). This is not an appropriate assumption due to intraindividual variability (i.e., short-term within person changes; Fiske &Rice, 1955; Nesselroade, 2004). Short-term cognitive control and affect changes following physical activity cannot be constant and stable, thus not capturing intraindividual variability limits laboratory-based assessments (Weizenbaum et al., 2020. The laboratory setting is controlled with a predetermined background and typically with minimal noise, and participants are unable to engage in their typical routine. However, the real-world environment consists of various settings, where conditions lack control, and the individual's cognitive control and emotional response to their environment is not restricted (Gunes et al., 2008). Likewise, cognitive control and affect are influenced by noise (i.e., physical factors and social environment), which can be manipulated in a laboratory setting, thus not eliciting a typical, real-world response for the individual (Bronfenfrenner, 1997; Ladouce et al., 2017). The present investigation contributed to the new focus of mobile cognition as it sought to examine cognitive control prior to and following physical activity and inactivity, taking into consideration both internal (i.e., affect) and external (i.e., time of day) factors (Weizenbaum et al., 2020). This is especially important for at-risk individuals as researchers continue to learn how the individual's environment influences observations for future clinical application (Halperin & Healey, 2010). Overall, these factors provided evidence to support the efficacy of assessing inhibitory control and affect following physical activity in a real-world environment for individuals at risk for ADHD, which this dissertation aimed to explore.

Rationale and Dissertation Purpose

Based upon the evidence previously stated, literature expansion is necessary to capture the impact of a real-world environment on cognitive control and affect following a single bout of physical activity for individuals at risk for ADHD. The overall purpose of this dissertation was to assess inhibitory control and affect before and after physical activity in a real-world environment with individuals who are at risk and not at risk for ADHD. While promising results have been documented in a laboratory setting, additional real-world factors may reveal different results between physical activity and subsequent cognitive control and affect, which warrant the exploration of these associations in real-world environments. The findings from this experiment are crucial to the advancements in the acute physical activity literature, especially in special populations at risk for cognitive control and affect deficits. Among individuals at risk for ADHD, physical activity may impact their daily functioning (e.g., experience fewer symptoms on a daily basis by decreasing social, academic, and occupational impairments that are associated with inhibitory control and affect). A decrease in symptoms may help benefit people's everyday life with greater attention, fewer distractions, and improved affective states, as this can be a feasible therapeutic modality for individuals at risk for ADHD. Combined, these implications have provided a rationale for investigating inhibitory control and affect in individuals at risk for ADHD prior to and following acute physical activity performed in a real-world environment. The current research is necessary to understand the acute effects of physical activity among individuals who are at risk for ADHD, which could lead to improved quality of life for those individuals.

Aims and Hypotheses

Aim 1: To determine the difference in inhibitory control performance and affect in individuals at risk and not at risk for ADHD in a real-world environment.

Hypothesis:

Prior to the treatment (i.e., physical activity or inactivity), between group differences (i.e., at risk for ADHD and with no risk for ADHD) were predicted to emerge with shorter reaction time for those with no risk for ADHD compared to individuals at risk for ADHD.

Aim 2: To determine the effects of acute physical activity performed in a real-world environment on inhibitory control performance in individuals at risk and with no risk for ADHD.

Hypotheses:

It was hypothesized that after the physical activity treatment within group differences would be observed compared to inactivity for individuals with no risk for ADHD and those at risk for ADHD such that both groups would elicit shorter reaction times. Lastly, since those at risk for ADHD were predicted to perform worse at baseline compared to individuals not at risk, based on previous evidence, those at risk for ADHD were hypothesized to demonstrate a larger magnitude of performance benefits after physical activity compared to individuals without risk for ADHD.

Aim 3: To determine the difference in affective valence and activation in individuals at risk and not at risk for ADHD in a real-world environment.

Hypothesis:

Prior to the treatment, between group differences were hypothesized to occur for affective valence and activation such that individuals at risk for ADHD would elicit lower affective valence and activation scores.

Aim 4: To determine the effects of acute physical activity performed in real-world environments on affect (i.e., valence and activation) in those at risk and with no risk for ADHD.

Hypotheses:

Following treatment, within group differences were hypothesized to emerge. An acute bout of physical activity was predicted to increase affective valence and activation for individuals at risk and with no risk for ADHD. Lastly, since those at risk for ADHD were predicted to report poor affective valence and activation prior to treatment compared to individuals not at risk, those at risk for ADHD were hypothesized to demonstrate a larger magnitude of affective valence and activation after physical activity compared to individuals without risk for ADHD.

CHAPTER II: REVIEW OF LITERATURE

Physical Activity, Cognitive Control, and Affect

Cognitive Control

Individuals use cognitive control to concentrate and pay attention in order to execute a goal-directed behavior (Diamond, 2013). More specifically, cognitive control is composed of top-down cognitive processes, which are functionally distinct, resource limited, and under conscious awareness (Rodgers & Monsell, 1995) to execute well-learned procedures and provide action or inhibition (Norman & Shallice, 1986). Additionally, cognitive control, also referred to as executive function (Diamond et al., 2013) and executive control (Norman & Shallice, 1986), includes planning, scheduling, working memory, task switching, and inhibition (Shallice, 1994). To date, the majority of acute physical activity studies have evaluated inhibition [inhibitory control, including selective attention] among all cognitive control components (Diamond et al., 2013). Inhibitory control is the ability to focus on relevant demands and regulate responses to irrelevant distractions (Donchin & Coles, 1988). Furthermore, inhibitory control is sensitive to selective, focused, and sustained attention (Diamond, 2013). Donchin and Coles (1988) suggest inhibitory control tasks are beneficial because of one's ability to focus on relevant information and regulate responses to irrelevant information using perceptual processing (e.g., interpreting and selecting information based on existing knowledge).

Physical Activity and Cognitive Control

Early reviews, examining both chronic and acute effects, suggest physical activity is beneficial for cognitive function (Anthony et al., 1991; Etnier et al., 1997; Powell et al., 1975; Tomporowski & Ellis, 1986). Additionally, the current empirical literature suggests the transient improvement in cognitive function, specifically cognitive control, following a single bout of activity (Alves et al., 2014; Drollette et al., 2014; Kamijo et al., 2007, 2009; Hillman et al., 2003, 2009; Hsieh et al., 2018; Kao et al., 2017, 2018; O'Leary et al., 2011; Pontifex et al., 2015; Tsukamoto et al., 2016).

In addition to an increase in overall cognitive control, empirical evidence reveals improvements in inhibitory control performance (i.e., faster reaction time) following an acute bout of physical activity (Hillman et al., 2009; Kamijo et al., 2007, 2009; Kao et al., 2017, 2018; O'Leary et al., 2011; Pontifex et al., 2015; Tsukamoto et al., 2016). For example, O'Leary et al. (2011) employed an acute 20-minute aerobic protocol in healthy (i.e., individuals not at risk for cognitive impairment) college students, which resulted in faster reaction times due to the ability to resist distracting stimuli on more demanding tasks following physical activity. Kao et al. (2017) examined inhibitory control performance following an acute bout of moderate and high intensity physical activity. Results demonstrated longer inhibitory control reaction times for rest compared to moderate and high intensity. Furthermore, Kamijo et al. (2007) revealed improved inhibitory control reaction times following light, moderate, and hard physical activity in healthy young adults. However, Kamijo et al. (2009) indicated significantly faster reaction times for younger adults compared to older adults following moderate intensity compared to light intensity or rest. Pontifex et al. (2015) investigated inhibitory control performance prior to and following an acute bout of physical activity and rest in healthy college students. Results revealed a main effect of mode indicating shorter reaction time prior to and following physical activity compared to rest. More recently, Kao et al. (2018) indicated improved inhibitory control reaction times in young adults following physical activity compared to rest. Taken together, healthy adults demonstrate acute inhibitory control improvements following physical activity at moderate intensity.

While evidence suggests physical activity has a positive influence on inhibitory control, these findings are confined to a structured laboratory setting thus not exploiting the opportunity for real-world potential or accounting for real-world behavior. The laboratory setting is restrictive where participants are asked by an experimenter to perform certain tasks in a particular controlled manner, thus unable to capture real-world physiological and psychological behaviors (Gunes et al., 2008). Therefore, this dissertation explored cognitive performance following physical activity in a real-world environment, thus capitalizing on real-world outcomes, expanding to other affective domains in accordance with at-risk populations

Other necessary factors (i.e., intensity, timing and type of cognitive task, and timing and modality of physical activity) may be considered when investigating cognitive control and acute physical activity. Meta-analyses reveal an overall positive effect of acute physical activity on cognition across the lifespan in healthy individuals (Chang et al., 2012; Colcombe & Kramer, 2003; Etnier et al., 1997; Lambourne & Tomporowski, 2010). These meta-analyses are foundational for conducting real-world investigations. Chang et al. (2012) performed an extensive and inclusive meta-analysis, and a positive effect (ES = 0.097 SE = 0.012, ES n = 1034, $p < 0.001$) was revealed for the relationship between acute physical activity and cognitive function. Regarding intensity, immediately following physical activity, very light, light, and moderate activity revealed the largest effects (Chang et al., 2012). For a delay after physical activity, results revealed significant impairments (i.e., negative effects) in cognitive function for very light (< 50% Heart Rate max) physical activity. Even though very hard (> 93% Heart Rate max) physical activity resulted in the largest improvements on cognitive performance, light (50-63% Heart Rate max), moderate (64-76% Heart Rate max) and hard (77-93% Heart Rate max) intensity physical activity revealed positive effects (Chang et al., 2012). Therefore, to determine the effects of physical activity on cognitive control in a real-world setting, individuals may perform physical activity at a moderate intensity.

Moreover, meta-analytic evidence suggests cognitive control tasks, timing of task, and timing of activity are important for determining the effect of acute physical activity on cognitive control. For example, immediately following physical activity resulted in larger positive effects for cognitive control compared to information processing, reaction time, and memory (Chang et al., 2012). Overall, results suggest cognitive control tasks reveal significant positive effects following physical activity. Furthermore, cognitive task timing, in conjunction with physical activity bout time, indicate the greatest effects of cognitive performance occur 1-15 minutes after an acute bout of physical activity (Chang et al., 2012). Accordingly, researchers should implement protocols over 11 minutes to ensure maximal effects of physical activity on cognitive control performance. Collectively, these findings suggest optimal cognitive control performance following an acute bout of physical activity lasting longer than 20 minutes. Therefore, this dissertation addressed these matters by investigating the effects of cognitive control performance following an acute 20-minute bout of physical activity.

Physical activity modality is an important factor in exploring the relationship between cognitive control and physical activity. An additional meta-analysis examined physical activity modality effects on cognitive performance specifically in young adults (Lambourne & Tomporowski, 2010). Results revealed improved cognitive performance following different physical activity modalities (i.e., cycling and running protocols), with individuals sustaining cognitive functioning following acute bouts of aerobic physical activity (Lambourne & Tomporowski, 2010).

To summarize, the results of the meta-analyses emphasize the importance of conducting a study examining effects of moderate physical activity on cognitive control. Therefore, an assumption is that moderate physical activity intensity and modality, outside of a laboratory setting, will allow the individual the possibility to improve psychological states (i.e., affect) but also enhance their cognitive performance. In relation to Aim 2, empirical and meta-analytic evidence prompted the examination of cognitive control following acute physical activity at prescribed range (i.e., RPE range 12-15) of moderate intensity and extend the literature to an individual's real-world environment.

Physical Activity and Affect

In addition to understanding the relationship between cognitive control and physical activity, the examination is warranted for the relationship between affect and physical activity. Russel (1980) proposes core affect (i.e., affect) is comprised of two bipolar and orthogonal dimensions known as valence and activation. More specifically, affect is a subjective response that can vary in both valence (i.e., how good or bad they feel) and activation (i.e., low vs. high arousal). Consequently, valence targets affect by capturing pleasant and unpleasant (i.e., good, bad) affect (Hardy & Rejeski, 1989). Additionally, activation focuses on an individual's arousal levels: high arousal (i.e., excitement, anger, anxiety) and low arousal (i.e., relaxation, boredom, calmness) (Svebak & Murgatroyd, 1985). Measuring these two components will capture an individual's affective state. Therefore, to assess core affect, valence and activation need to be measured. This method has been used as an assessment for affect within the physical activity literature (Backhouse et al., 2007; Ekkekakis, 2003; Ekkekakis et al., 2005, 2008).

There is an extensive literature to suggest that bouts of physical activity improve affect following the bout of physical activity (Ekkekakis et al., 2008; Focht et al., 2002; Nabetani &

Tokunaga, 2001; Niven et al., 2018; Reed et al., 1998). For example, Ekkekakis et al. (2008) employed an acute bout of aerobic physical activity and revealed an increase in both valence and activation following physical activity. More recently, Niven et al. (2018) measured affective valence and activation prior to and following physical activity. While there were no significant valence differences, affective activation declined 5, 10, and 15 minutes after physical activity, revealing lower activation states immediately following physical activity compared to during activity (Niven et al., 2018). However, Thum et al. (2017) examined affect prior to and following an acute bout of physical activity and reported more positive valence following moderate intensity physical activity compared to high intensity interval activity. As such, these findings could be due to varying moderators (i.e., intensity, timing of assessment, and environment). Nevertheless, affect improves, although in various respects, following physical activity.

Although some evidence suggests that specific intensities of physical activity may enhance affect more than others (e.g., Berger & Motl, 2006; Ekkekakis & Petruzello, 1999), there is a general consensus that physical activity regardless of the intensity has the potential to improve affect (Reed & Ones, 2006). In fact, when individuals self-select the intensity of physical activity, that self-selected intensity is likely to improve affect (Ekkekakis et al., 2007; Focht & Hausenblas, 2001; Klaperski et al., 2019; Rendi et al., 2019). All of which suggests that an individual may choose a preferred intensity and still obtain affective benefits.

The majority of the literature explores the physical activity-affect relationship by controlled work-load versus participant-controlled workloads (i.e., self-selected). Focht and Hausenblas (2001) examined individual’s affect response prior to, and following, physical activity in a fitness facility, where individuals were instructed to complete 20 minutes of physical activity at their preferred intensity on a cardio device of their choice (i.e., rowing machine, cycling, or stair master). This data suggests that when given the opportunity to self-select their physical activity intensity and mode, individuals exhibit increases in positive affect following physical activity, albeit there was no control group with the inability to self-select (Focht & Hausenblas). Rendi et al. (2008) found similar results when participants completed a cycling and running protocol in their own fitness center. Positive affect increased and negative affect decreased following both physical activity conditions as compared to measures prior to activity, thus supporting physical activity being performed in one's real-world environment and obtaining assessments before and after treatment. Furthermore, examining affective responses to self-selected physical activity intensity and mode in one's own environment could be advantageous to understand the overall affect assessment the real-world environment verses a controlled laboratory environment for healthy and at-risk individuals. Therefore, this dissertation aimed to explore that relationship. Such influence has potential health implications leading to physical activity adherence for all individuals. This research has the potential to provide further physical activity recommendations (i.e., performing self-selected physical activity for improved affect) thus continuing their physical activity participation.

Furthermore, timing of affect assessment is worth exploring to understand the extent to which physical activity promotes a change in affect. Reed and Ones (2006) analyzed post-assessment times (i.e., 0-2, 5-10, 15-30, and 40-1440 minutes) and suggest positive affect peaks 0-2 minutes following physical activity then declines, thus highlighting the importance of capturing affect immediately following activity. However, previous empirical studies observed positive affect remained elevated until 20-30 minutes (Bixby et al., 2001; Focht & Hausenblas, 2001; Steptoe & Bolton, 1988; Van Landuyt et al., 2000) upon the cessation of physical activity. On the contrary, Backhouse et al. (2007) employed a walking/running laboratory protocol assessing affective valence and activation prior to and 15-minutes following physical activity. There were no significant results for valence or activation from before to after physical activity. However, a potential limitation of this investigation is the timing of affect assessments following physical activity. Therefore, in accordance with Reed and Ones the the optimal time to assess affect is prior to and immediately following physical activity. The extent to which these findings can be generalized to populations other than healthy individuals is still unclear. In order to further comprehend the dynamic nature of affect, current physical activity literature must be consistent by measuring affect prior to and following physical activity. Moreover, Backhouse and colleagues suggest affective responses are subject to potential physical environment influences, thus furthering the exploration of affect in an individual's real-world environment.

Therefore, in reference to Aim 3 and 4, obtaining affect measures before and after activity was implemented to assess valence and activation and understand affect in an individual's real-world environment. Ekkekakis et al. (2007) conducted a between-subjects experiment and examined older adult's affective valence and activation prior to and following an acute bout of outdoor walking compared to an acute bout of rest. Results demonstrated higher levels of perceived activation for the participants following outdoor walking as compared to rest. Conversely, Klaperski et al. (2019) investigated mood prior to and following an acute bout of physical activity outdoors (e.g., running, football) compared to indoors (e.g., swimming, volleyball). Results indicated acute bouts of physical activity led to mood reductions (i.e., reductions of restlessness, feeling bad, and feeling tired) regardless of location. When given the opportunity to be physically active in their own environment, individuals could present more positive affect before treatment compared to entering an unfamiliar laboratory setting (Rendi et al., 2008). The participant's affective response in their real-world environment could attenuate the effect, which is a limitation of the dissertation. While research suggests a positive relationship between affect and physical activity in real-world settings, core affect is typically not assessed (Liao et al., 2015). Therefore, by capturing affective valence and activation, prior to and following physical activity, investigators gain a greater understanding of the ways in which the general population responds when participating in physical activity in their real-world environment.

Taken together, meta-analytic results indicate improved affect following physical activity (Reed & Ones, 2006). Specifically, affective valence and activation demonstrate positive effects following physical activity performed in a real-world environment (Ekkekakis et al., 2007; Focht & Hausenblas, 2001; Klaperski et al., 2019; Rendi et al., 2008). This enables the individuals to select mode and location (i.e., indoors or outdoors). Aim 4 sought to investigate the relationship between affect and physical activity in real-world settings for an at-risk population, as previous research highlights the need for more opportunities to assess and understand affect responses for continued health promotion and quality of life benefits.

Physical Activity, Cognitive Control, Affect, and ADHD

ADHD and Cognitive Control

ADHD is a neurodevelopmental disorder characterized by inattention and/or hyperactivity/impulsivity (APA, 2013). Symptoms first appear in early childhood (i.e., under 12 years of age) and are chronic in nature. Consequently, impairments are revealed academically, psychologically, socially, and occupationally (Weyandt et al., 2016). In 2016, 6.1 million children were diagnosed with ADHD (Center for Disease Control and Prevention, 2018), in addition to a 5% prevalence rate for college students with ADHD (DePaul & Weyandt, 2009). While ADHD is well-understood in the child population, the trajectory into emerging adulthood is not as easily understood, and efficacy testing of interventions are still in the early stages. For example, a recent randomized control trial (Anastopoulos et al., 2021) was conducted to examine cognitive behavioral therapy for college students with ADHD, with cognitive control as a primary outcome. Results revealed significant improvements in cognitive control after two semesters of cognitive behavioral therapy, including ADHD knowledge, behavioral strategies, and adaptive thinking. While the results are promising and take a step in the correct direction of translating research to real-world, authors note that more interventions are needed to determine the effectiveness in different settings (Anastopoulos et al., 2021).

ADHD develops throughout childhood and into emerging adulthood. The economic cost of ADHD in the United States ranges from $38-$72 billion dollars annually (Doshi et al., 2012; Sciberras, 2020). Furthermore, 9.4% of children have been diagnosed with ADHD in the United States and 69% are on medication (Danielson, 2018), with 30% of those on medication experiencing negative outcomes and unable to tolerate the frequent side effects (Conner et al., 2006; Vysniauske et al., 2016; Wigal et al., 2013). Long term evaluation suggests that children who progress into adulthood with ADHD are less likely to receive a formal education and more likely to be unemployed (Kuriyan et al., 2013). These individuals could potentially have a genetic predisposition (Barkley, 2015) but ADHD individuals could also be impacted by other factors such as living environment (Keyes at al., 2008) and the non-medical use of prescription drugs (Cassidy et al., 2015) as a consequence of ADHD and resulting cognitive and emotional deficits (Anastopoulos et al., 2016; Hechtman et al., 2016). Thus, young adults are one of the most understudied age groups with ADHD (Weyandt & DuPaul, 2012). Therefore, exploring the developmental progression of ADHD from childhood into adulthood is pertinent to further understand the cognitive control deficits and how physical activity may help.

Specifically, individuals with ADHD experience inhibitory control deficits compared to healthy controls in laboratory-based settings. To date, multiple investigations examined young adult patients with ADHD compared to healthy controls and observed performance impairments in cognitive control tasks. For example, Weyandt et al. (2016) examined cognitive control in a large sample of first-year college students using the Behavior Rating Inventory of Executive Function (BRIEF). Results revealed that cognitive control performance in individuals with ADHD was significantly worse than those without ADHD. Additionally, McLoughlin et al. (2010) revealed detriments in inhibitory control for adults with ADHD as compared to controls. On the contrary, in an earlier study, Weyandt et al. (1998) investigated cognitive control performance of adults with ADHD relative to a learning disabilities group and a control group on neuropsychological tasks. No significant differences were revealed between the groups, which could be due to the small sample size (i.e., $n = 21$ ADHD, $n = 24$ control). When examining self-reported cognitive control (e.g., BRIEF) alongside objective task measurements performed in a laboratory, at-risk individuals' ADHD symptoms were more strongly correlated with self-report inhibitory control scores compared to inhibitory control performance in the laboratory (Jarrett et al., 2017). Weyandt at al. (2002) conducted a similar study to test attentional performance of adults with and without ADHD. Results demonstrated that the ADHD group performed less favorably in attentional performance compared to control. Taken together, results suggest that laboratory-based protocols exhibit inhibitory control deficits for adults at risk for and diagnosed with ADHD.

Considerable evidence suggests that college students, specifically, with ADHD are likely to demonstrate better cognitive abilities, improved academic success, and better compensatory skills than other populations with ADHD (Frazier et al., 2007). However, college students at risk for or diagnosed with ADHD might also experience different levels of stress which might exacerbate symptoms of ADHD (Frazier et al., 2007). Zang et al. (2019) indicated that pharmacological treatment is the preferred treatment method for ADHD, but a substantial minority of adults are nonresponsive to medication (Faraone, 2006). Additionally, behavioral interventions (e.g., behavioral classroom management) can be difficult to implement, costly, and have a low adherence rate (Vysniauske et al., 2016). Therefore, Anastopoulos et al. (2021) suggest young adults seek alternative methods to medication. Accordingly, in relation to Aim 2, researchers sought to utilize acute physical activity as an alternative means for regulating cognitive control in young adults at risk for ADHD.

Physical Activity, Cognitive Control, and ADHD

In relation to Aim 2, the link between physical activity and cognitive control was evaluated to understand the relationship involving individuals at risk for ADHD. The current literature suggests that acute physical activity has positive effects on cognitive control outcomes in both children and adults with and at risk for ADHD (Den Heijer et al., 2017). The majority of the research focuses on children's cognitive control performance with few studies examining young adults. For example, in an acute physical activity study, Medina et al. (2010) investigated cognitive control performance through a continuous performance task (CPT) (i.e., highly sensitive to those with ADHD) in 7-15-year-old boys after high intensity interval running on the treadmill. Results revealed significant improvements for impulsivity response time, suggesting sustained attention after physical activity among boys with ADHD whose diagnosis was confirmed by a physician (Medina et al., 2010).

On the contrary, Mahon et al. (2013) recruited children with ADHD, confirmed by a physician, and without ADHD to perform a CPT before and after 20 minutes of high intensity interval training (i.e., 10 total minutes being physically active) on a cycle ergometer. Following physical activity, results indicated worse task performance for errors of omission (i.e., not responding when a response is needed) for children with and without ADHD. Additionally, slower reaction time was demonstrated for children with ADHD, suggesting evidence against high intensity interval physical activity. Mahon et al. did not specifically examine high intensity continuous physical activity, which could elicit differing effects on cognitive performance as compared to interval physical activity. These inconsistencies in the literature could be due to varying moderators (i.e., diagnostic criteria, protocol characteristics, and physical activity mode: running or cycling). Specifically, the mode of physical activity an individual participates in and the type of task they complete following physical activity may be impactful to cognitive control performance.

Most ADHD studies examining physical activity (i.e., running or cycling) and cognition implement tasks targeting one or multiple aspects of cognitive control in a controlled-laboratory setting. Among various studies examining physical activity and cognitive control in children with ADHD, researchers employed a running protocol (Chang et al., 2011; Medina et al., 2010; Pontifex et al., 2013). For example, Chang et al. (2011) had participants with ADHD running at moderate intensity on a treadmill for 30 minutes and assessed inhibitory control in addition to examining task-switching. Results demonstrated that physical activity facilitated performance for the inhibitory control task, and children with ADHD in the physical activity group revealed improvements in specific components (non-preservative errors and categories completed) of task-switching. However, no significant results were found in the control group, suggesting physical activity possessed greater benefits for children with ADHD compared to those without. While this study is a randomized control trial design, the cannot be generalized to the young adult population but more importantly lacks rigor due to the historical self-report measure of ADHD. To further address this limitation in the literature, research should be conducted to examine if these physical activity effects are revealed in adult populations whose symptoms potentially encompass impairments in inhibitory control (McLoughlin et al., 2010) and adhere to a more rigorous diagnostic criteria to confirm ADHD diagnosis.

Additionally, Pontifex et al. (2013) recruited children with ADHD (i.e., confirmed through rating scales and a diagnostic interview) and healthy- matched controls between the ages of 8-10 and implemented a 20-minute continuous physical activity bout on the treadmill at moderate intensity. Pontifex and colleagues revealed improvements in accuracy performance following an acute bout of physical activity for both groups of children. That is, children with ADHD and without ADHD demonstrated significant increases in response accuracy on an inhibitory control task following physical activity compared to the control condition. Recently, Milkós et al. (2020) employed a CPT prior to and following a moderate-to-high intensity interval running protocol. ADHD, confirmed through a diagnostic interview, and non-ADHD participants completed four sets of four runs performed on a treadmill with a one-minute rest between each interval. During both the physical activity and resting conditions, participants watched a 20-minute cartoon video. This experiment resulted in a decrease in inhibitory control performance after the physical activity condition for individuals with ADHD.

Alternatively, other studies implemented a cycling protocol (Mahon et al., 2013; Piepmeier et al, 2015). For example, Mahon et al. (2013) recruited children with and without ADHD to perform a CPT before and after 10 total minutes of high intensity interval training on a cycle ergometer. Following physical activity, results indicated poor performance on errors of omission for children with and without ADHD. Moreover, results demonstrated an increase in reaction time for children with ADHD, suggesting high intensity interval physical activity bouts might not be optimal (Mahon et al., 2013). Piepmeier et al. (2015) implemented tasks especially targeting multiple aspects of cognitive control (i.e., inhibitory control, working memory, and task-switching). The participants were asked to complete a 20-minute continuous cycling protocol at moderate intensity. Similar to running, results demonstrated inhibitory control performance was the only aspect of cognitive control that significantly improved performance for children with and without ADHD following acute cycling, albeit ADHD status was measured by self-report. Taken together, following moderate intensity continuous running and cycling protocols, the findings (Chang et al., 2011; Medina et al., 2010; Piepmeier at al., 2015; Pontifex et al., 2013) suggest inhibitory control tasks, as compared to other aspects of cognitive control, demonstrate benefits in individuals at risk for ADHD.

While previous literature lacks diagnostic and protocol consistency and separates the modes of physical activity, implementing both running and cycling protocols in one study presents an opportunity to extend and advance the literature. Additionally, individuals performing aerobic activity in their own environment is different than each participant performing in a laboratory setting. Therefore, implementing both protocols of physical activity help to explain this limitation and expand the observed laboratory effects of acute physical activity on inhibitory control performance in individuals at risk for ADHD and with no risk for ADHD in a real-world environment.

Taken together, these investigations in children present inconsistencies (i.e., diagnostic criteria, physical activity modality, and type of task). Nevertheless, in a systematic review examining the effects of physical activity on cognition in children and adults at risk for ADHD, Den Heijer et al. (2017) suggest that despite these inconsistencies, acute aerobic physical activity can be an effective modality in improving cognitive function, specifically inhibitory control in both children and young adults. Therefore, by implementing an assessment of an ADHD-sensitive task following running and cycling physical activity protocols, additional developments in the literature have been targeted with intent to gain an understanding of the effects physical activity demonstrates among adult populations at risk for ADHD.

Moreover, mixed results have emerged from the available studies mentioned, thus additional work is needed to further develop and expand on the current literature regarding the effects of physical activity on cognitive control in young adults at risk for ADHD. Addressing these expansions in the literature for young adults is pertinent in order to gain a greater understanding of the effects of physical activity on cognitive control. This may aid the young adult population in reducing ADHD symptoms by actively engaging in physical activity. Mehren et al. (2019) report young adults diagnosed with ADHD reveal difficulties in situations in which attentional and interference control are crucial. Further, Gapin et al. (2015) conducted an acute physical activity pilot study examining the effects of cognitive control in 20 college students (i.e., 18-25 years of age). Physician documentation was provided to confirm ADHD diagnosis. Subcomponents of cognitive control were examined (i.e., inhibition, task switching, and working memory) after 30 minutes of moderate intensity physical activity performed on a treadmill. The authors concluded individuals at risk for ADHD had impairments in all tasks, but the inhibition task (i.e., Stroop color-word) was the only measure to reveal a significant difference between those at risk and with no risk for ADHD after physical activity (Gapin et al., 2015). Overall, results suggest acute aerobic physical activity affects inhibitory control in college students at risk for ADHD to a greater extent than other cognitive control components, which supports this dissertation’s aim to focus specifically on inhibitory control.

While inhibitory control performance improves following physical activity in young adults at risk for ADHD, these studies have been performed in a laboratory setting and more evidence is needed to advance the understanding away from a controlled-laboratory setting. Furthermore, acute experimental paradigms have been developed to specifically measure interference control (e.g., inhibitory control tasks: Stroop task, Eriksen flanker task, and a continuous performance task). For example, Mehren et al. (2019) employed a 30-minute moderate physical activity cycling protocol with 40 adults (i.e., 20 with ADHD, 20 without). All individuals classified as ADHD had documentation confirmed by physician. Once physical activity was completed, participants performed a modified version of the Erikson flanker task, and results revealed physical activity significantly improved reaction times in patients with ADHD, but not in patients without ADHD, suggesting improved attention for reaction time performance for those with ADHD. Although this study provides promising evidence for a laboratory setting, where acute physical activity may benefit inhibitory control performance in adults at risk for ADHD, more research is needed to advance the understanding of acute physical activity influences on inhibitory control and affect for young adults at risk for ADHD in their real-world environments.

Physical Activity, Affect, and ADHD

This dissertation aimed to evaluate the influence of physical activity on affect (i.e., valence and activation) in those at risk for ADHD and with no risk for ADHD. While the literature is minimal, understanding the present literature is important to consider the implications of physical activity on affect in young adults at risk for ADHD. For example, Fritz and O’Connor (2016) examined whether an acute bout of moderate intensity cycling would improve mood (i.e., conceptualized as affect) in young adult men at risk for ADHD, as indicated by historical self-report, who were not taking stimulant (i.e., increases neurotransmitter activation) medication. This study also investigated the effects of moderate intensity physical activity on attention. Participants cycled for 20 minutes then completed a CPT, Bakan vigilance test, and a simple reaction time task for psychomotor speed. Additionally, the Profile of Mood States-Brief Form was used to evaluate mood. While no significant cognitive control differences were observed, Fritz and O'Connor revealed significant transient improvements in mood following 20 minutes of moderate intensity cycling, revealing increases in feelings of energy and decreases in feelings of confusion, fatigue, and depression. However, a limitation of this investigation is the use of the Profile of Mood States-Brief Form. Ekkekakis (2013) states this measure has no theoretical argument or empirical evidence to provide a comprehensive realm of mood and should not be implemented just because the measure has been used before in health-behavioral research. To conclude, authors suggest future research should be conducted to examine how cycling protocols outside of the laboratory setting will influence cognitive control and affect (Fritz & O'Connor, 2016).

Cognitive Control, Affect, and ADHD

Cognitive control, affect, and ADHD present similar mechanisms (i.e., amygdala's role in cognitive impairments and increased emotional reactivity), which is why individuals at risk for ADHD are of interest to this dissertation (Villemonteix et al., 2014). Individuals at risk for ADHD not only present inattention and hyperactive/impulsive symptoms, but also exhibit symptoms of emotional dysregulation (i.e., increased presence of mood and anxiety disorders). Evidence suggests ADHD symptoms have a negative impact on emotional regulation (Hechtman et al., 2016). For example, Kessler et al. (2006) reported mood disorders were 38.3% for individuals with ADHD compared to 11.1% of individuals without ADHD, and anxiety disorders were reported as 47.1% of individuals with ADHD compared to 19.5% for individuals without ADHD. More recently, Anastopoulos et al. (2016) reported 28.6% of adults with ADHD exhibited anxiety disorders. Evidence suggests bottom-up (i.e., using sensory signals to assess cognitive processes) emotional dysregulation stems from an increase in emotional reactivity, which is proposed to be linked to the amygdala (i.e., emotional regulation and decision making) (Villemonteix et al., 2014) and affect decrements (Barrett et al., 2007). Additionally, top-down processes (i.e., using cognitive processes to interpret sensory signals) are associated with the prefrontal cortex, which is linked to cognitive control (Villemonteix et al., 2014). Furthermore, Maclean (1955) proposed the concept that the prefrontal cortex is the control center for the amygdala. Therefore, their connectivity is proposed to control cognitive behavior, impulses, and emotional regulation (Domes et al., 2010; Frodl et al., 2010; Rüsch et al., 2007; Welborn et al., 2009), and evidence suggests individuals with ADHD experience abnormal connectivity between their prefrontal cortex and amygdala, thus attributing to ADHD symptoms (Plessen et al., 2006). By examining affect in addition to cognitive control, this dissertation is able to provide further insight on an effective intervention for improving psychological health, including affective responses and cognitive performance for young adults at risk for ADHD. Previous research highlights the need for more opportunities to improve emotional responses in addition to having a positive influence on at-risk individuals' cognitive control performance for continued quality of life benefits with a public health perspective (Gawrilow et al., 2013). Aim 2 and 4 sought to determine if physical activity was an effective treatment for young adults at risk for ADHD, thus ameliorating symptoms regarding cognitive control decrements and emotional dysregulation. Therefore, conducting more research on individuals at risk for ADHD helps further the understanding of the relationship between physical activity, cognitive control, and affect. A refined understanding of this relationship has the potential to improve the quality of life for individuals at risk for ADHD through greater attention and improved affect when using physical activity as a treatment.

Physical Activity, Cognitive Control, Affect, and ADHD

Physical activity is associated with improved cognitive control and affect in individuals not at risk for ADHD, but the literature is limited for those at risk for ADHD. For example, Hogan et al. (2013) employed a cycling protocol with both young and older adults assessing cognitive control and affect prior to and following physical activity. Results were consistent across age and revealed faster reaction times and an increase in high arousal, positive affect (i.e., excited, enthusiastic) following physical activity. However, the physical activity literature is unclear to the extent these findings are consistent with the ADHD population.

Other studies have examined both affect and cognitive control in ADHD within a child population. For example, Gawrilow et al. (2013) conducted a two-part experiment for children at risk (i.e., via self-report) and diagnosed (i.e., confirmed by physician) with ADHD. The first study assessed the association between depressed affect (i.e., operationalized as negative affect) and physical activity levels, while the second study investigated cognitive control following physical activity. Results revealed less depressed affect on days children were more physically active, particularly for individuals with more critical hyperactive (i.e., fidgeting, squirming) symptoms. Additionally, inhibitory control improved following physical activity. While these two experiments were performed individually, evidence combined suggests physical activity is an effective modality to help improve affect and cognitive symptoms in individuals at risk for ADHD. These results were found in children and cannot be generalized to other ages due to developmental cognitive changes from childhood to older adulthood (Erikson et al., 2015).

Therefore, this dissertation sought to employ a protocol for young adults at risk for ADHD by including both affect and cognitive control to further understand how their symptoms are influenced following physical activity.

Literature Expansions

Despite the present evidence in the literature indicating the beneficial effects of physical activity on cognitive control and affect, this dissertation aimed to expand and advance the current literature. First, while previous empirical, laboratory-based research has demonstrated acute physical activity can increase inhibitory control, specifically for those at risk or diagnosed with ADHD (Chang et al., 2011; Den Heijer et al., 2017; Gapin et al., 2010, 2015; Mehren et al., 2019; Milkós et al. 2020; Piepmeier et al., 2015; Pontifex et al., 2013), uncertainty still exists regarding being physically active in one's real-world environment. Physical activity in a real-world environment allowed the individuals to perform a running or cycling protocol completed indoors or outdoors rather than in a laboratory. The allowance of freedom of choice for mode (i.e., running or cycling) and location (i.e., indoors or outdoors) of physical activity was a delimitation to this dissertation. Therefore, the question remained as to whether the same results observed in a laboratory setting would extend to a real-world environment (Gunes et al., 2008; Ladouce et al., 2017). Thus, a more translational approach was evaluating acute physical activity that incorporates moderate intensity on cognitive benefits in the individual's real-world environment.

Secondly, the relationship between individuals at risk for ADHD and their affective responses to physical activity are limited in the existing literature. Individuals with ADHD are characterized as possessing atypical qualities, and the question remained as to whether affect would improve following physical activity in an at-risk individual's real-world environment.

Therefore, this dissertation sought to explore the direct influence of affect before and after an acute bout of moderate intensity physical activity in a real-world environment, thus capitalizing on outcomes from a real-world lens with a public health perspective.

Based upon the evidence previously stated, in order to further advance our knowledge, additional investigations should be employed. Therefore, by examining individuals not at risk for ADHD, this dissertation allowed for a comparison to gain greater insight on the effects of acute physical activity on cognitive control and affect for those at risk for ADHD. Maintaining consistency with the current literature, in addition to building upon previous work, this dissertation aimed to expand laboratory studies by extending the literature and elicit a real-world environment approach for enhancing cognitive control and affect in young adults at risk for ADHD following physical activity.

Purpose

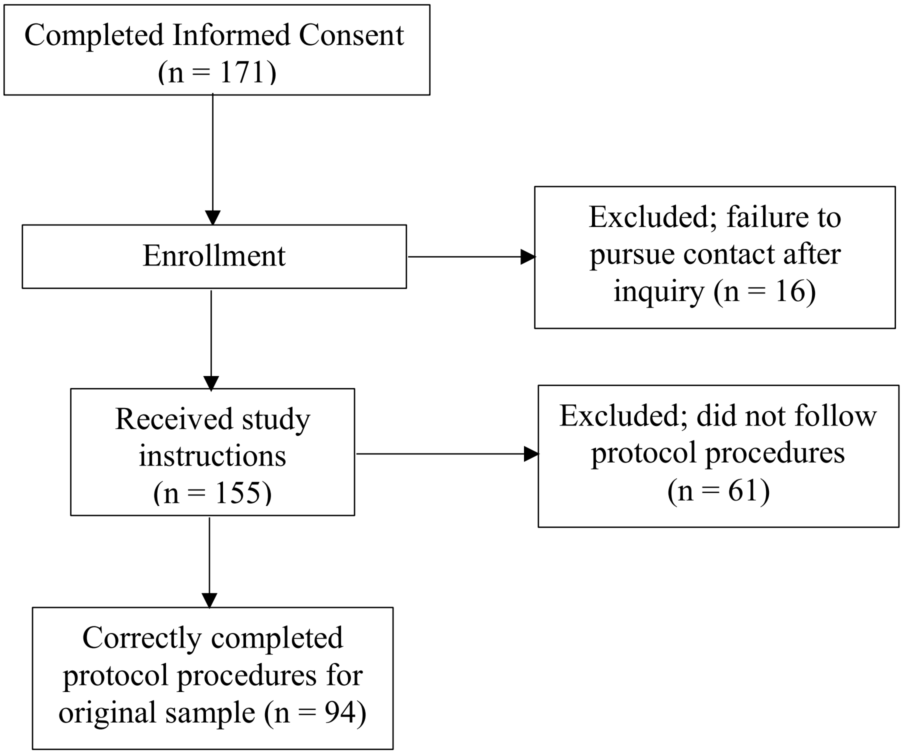
The literature suggests varying acute physical activity influences on cognitive control and affect for individuals who are at risk for ADHD and those who are not at risk. Therefore, the purpose of this dissertation was to evaluate the effects of acute physical activity on cognitive control behavior (i.e., inhibitory control) and affect in individuals at risk and without risk for ADHD in their real-world environment. The underlying hypothesis was acute physical activity would elicit improvements in inhibitory control performance for all individuals, but to a greater extent for those at risk for ADHD. Additionally, affective valence and activation was expected to increase for each group after physical activity as compared to before, but to a greater extent for at-risk individuals.

CHAPTER III: METHODOLOGY

Participants

All participants were recruited from the Southeast United States and provided written consent approved by the Institutional Review Board of the University of North Carolina Greensboro. An *a priori*, ANOVA (repeated measures, mixed within-between interaction) power analysis (alpha = 0.05, power = 0.80) was conducted to detect a small effect size (*f*= 0.21; i.e., mean obtained from interactions in Gapin et al., 2015 & Mehren et al., 2019) in order to determine sample size, which yielded *n* = 96 participants overall, using G*Power 3.1.9.6 for Mac OS X (Faul et al., 2007). Individuals were recruited from undergraduate and graduate classes, Office of Accessibility Resources and Services at the University of North Carolina Greensboro (UNCG), Gove Student Health Center at UNCG (i.e., recruited from the latter two to target individuals who might show symptoms of ADHD), and young adults throughout the Southeast. Individuals who consented to participate (*n* =171) in this dissertation were sent an electronic Physical Activity Readiness Questionnaire (PAR-Q; Thomas et al., 1992) via Qualtrics to complete prior to their start date, ensuring no pre-existing physical or neurological health conditions. Incomplete data were removed prior to analyses due to participant failure to pursue contact after initial inquiry (*n* = 16) and accomplish all protocol procedures correctly (*n* = 61). No participants were excluded due to a pre-existing condition (i.e., heart disease, hypertension, bone, joint, soft tissue problems, or if they have been medically advised not to participate in physical activity), and no individuals dropped out during data collection with a final sample of ninety-four participants (see Figure 1).

Figure 1: Consort Diagram Demonstrating Flow of Participant Enrollment



Demographics

Demographic data was gathered to examine individual factors for descriptive purposes including age, gender, ethnicity, and race. Height and weight were also obtained in imperial units. After collection of data, imperial units were then converted to metrics to calculate BMI (i.e., weight divided by the square of height, kg/m^2). Furthermore, participants were asked to complete the International Physical Activity Questionnaire-Short Form (IPA-Q; Craig et al., 2003) that assessed an individuals' daily physical activity intensity levels which provided a continuous score (expressed in MET-minutes/week) to account for moderate to vigorous physical activity levels. This information was obtained and participants' responses to each questionnaire were confidential.

Screening Measures

For the present investigation, all participants completed two versions of the Behavior Rating Scale (i.e., childhood and past 6-months) to determine if the participants were at risk or not at risk for ADHD, Therefore, the collected evaluation data did not address all five diagnostic criteria and a definitive ADHD diagnosis could not be made. However, for this dissertation, since two criteria were addressed, an individual was classified as 'at risk' for ADHD.

At Risk for ADHD Assessment

All participants were first asked a series of questions regarding ADHD status (i.e., Have you been professionally diagnosed with ADHD?; What medications for ADHD (if any) are you currently taking?; What medications for ADHD (if any) have you been prescribed in the past?; Do you have any other mental health issues for which you have received treatment)? If the participant answered yes to the first question, the individual remained eligible to be classified in either the at risk or not at risk for ADHD category since the investigator did not complete a full exam to ensure participant met all DSM-5 categories (APA, 2013). If the participant was on medication, they were instructed to continue taking medicine as prescribed (Weyandt et al., 2018). Medication information (i.e., stimulant or non-stimulant) was presented as a descriptive outcome. Additionally, two behavior rating scales were given to each participant to assess ADHD in the past 6-months and during childhood, prior to 12 years of age (DuPaul et al., 2013). Each scale consisted of 18 questions alternating between inattention (IA) and hyperactivity-impulsivity (HI) symptoms. Participants answered by indicating 0 (never or rarely), 1 (sometimes), 2 (often), or 3 (very often), where the participant was to respond based on behavior off medication. Counting the number of items indicated by 2 (i.e., often) or 3 (i.e., very often) determined whether the individual was classified as at risk or not for ADHD. If the individual indicated at least four or more 2's and 3's for IA and HI during both childhood and the past 6 months, the individual was classified as 'at risk.' Individuals who indicated fewer than four 2's and 3's for IA and HI, during both childhood and the past 6 months were classified as 'not at risk' for ADHD.

Procedure

Design

A within and between-subjects crossover pretest posttest comparison experimental design was used where each participant was asked to complete one bout of physical activity and one bout of inactivity in their real-world environment. After completion of the informed consent and online documentation, participants were randomized into groups (i.e., to ensure experimental order effects did not occur) and allowed one week to accomplish their physical activity and inactivity bout. Activity bouts were randomized and counterbalanced across participants (Allen, 2017), where half of the participants completed physical activity then inactivity, while the other half completed inactivity then physical activity.

The timeline for data collection in relation to each bout of physical activity and inactivity was prescribed as follows for each participant. Participants first completed a pre-activity inhibitory control task (i.e., continuous performance task, CPT-X) on a mobile device or tablet. Participants then measured their heart rate and provided a Rating of Perceived Exertion (RPE), Feeling Scale (FS), and Felt Arousal Scale (FAS) rating, and completed an activity log. At this time, participants answered a question regarding activity level, since waking then performed the physical activity or inactivity. Upon completion, participants measured their heart rate and provided a RPE, FS, and FAS rating. Participants then executed a post-activity CPT-X. Specifically, heart rate, RPE, FS, and FAS rating and activity logs were provided using one

Qualtrics questionnaire. The activity logs were completed prior to activity bouts and allowed for collecting specific data regarding the participant's activity included the following details: the type of activity (i.e., physical activity or inactivity), location (i.e., indoors or outdoors), presence of others (i.e., in person), entertainment (i.e., music, television, or phone usage), and activity level since waking. Following the activity bouts individuals indicated the amount of time that passed since completing the bout of physical activity or inactivity (i.e., this would be the amount of time between when the participant completed the activity condition and when they completed the questionnaire). Participants were told they may complete the questionnaire on a mobile device, tablet, or computer. Prior to their first day, participants received a detailed instructional document outlining the study procedures.

Bout Intensity

In the physical activity and inactivity bouts, the Borg RPE Scale was used as a subjective manipulation measure for intensity. For the physical activity session, participants were asked to maintain a 12 (above light; Chang et al., 2012) to 15 (very hard; Chang et al., 2012; Mahon et al., 2013; Milkós et al., 2020) on the Borg RPE Scale (Chang et al., 2012) and maintain less than 9 (very light) during inactivity. Meta-analytic results did not reveal positive effects on cognitive performance following very light intensity (Chang et al., 2012). However, previous research reveals improvements in cognitive performance following moderate (Chang et al., 2012; Ludyga et al., 2016) physical activity. Therefore, participants were provided with a description of the RPE scale through the Qualtrics questionnaire, then instructed to indicate their RPE rating directly before and after each bout of physical activity and inactivity. Additionally, participants were instructed to download the Instant Heart Rate Free Application powered by Azumio from *Google Play Store* or *App Store* to obtain their heart rate, as an objective efficacy test (i.e., successfully producing the intended result). Heart rate photoplethysmography, used in smart phones, and electrocardiogram were measured in a medical clinic where measurements resulted in an intraclass correlation of 0.90 (Avram et al., 2019). Additionally, Mitchell et al. (2016) investigated concurrent validity of Instant Heart Rate Free Application on the Android® and iOS® compared to a FT7 Polar® Heart Rate monitor. At rest, the concurrent validity with the Polar® was 0.92 [0.88-0.94] for iOS® and 0.95 [0.92-0.96] for Android®. Following physical activity, concurrent validity with the Polar® was 0.90 [0.86-0.93] for iOS® and 0.94 [0.91-0.96] for Android® (Mitchell et al., 2016). Heart rate was measured by placing the forefinger on the mobile device or tablet's camera lens. According to a 2017 information and technology survey, 97% of college students own a smartphone (Brooks & Pomerantz, 2017). Once the heart rate was provided, individuals were asked to log this information through the Qualtrics questionnaire immediately before and after each bout of physical activity and inactivity, to assure individuals were participating in moderate physical activity and remaining below very light on inactivity bouts.

Physical Activity and Inactivity Parameters

The physical activity and inactivity bout were performed in the individual's real-world environment for 20 minutes. Physical activity consisted of continuous movement (Chang et al., 2012; Hsieh et al., 2018) and participants chose from jogging/running or cycling. These two aerobic activities have been used in the laboratory setting and reveal positive outcomes related to the modalities (Chang et al., 2013; Lambourne & Tomporowski, 2010; Ludyga et al., 2016). The inactivity bout was one of the following: reading, studying, or watching television (Ludyga et al., 2016). Chang et al. (2012) observed significantly larger positive effects when physical activity was performed in the morning (i.e., before noon) compared to afternoon or evening. Therefore, participants were asked to complete both their physical activity and inactivity bout before noon. This variable was controlled to maximize acute physical activity effects considering other variables (i.e., type of physical activity and location) were not being controlled. These predetermined choices that may impact results are delimitations.

Continuous Performance Task-X

A modified version of the Conners' Continuous Performance Task (Conners, 1985), referred to as CPT-X, was utilized in the present dissertation to assess aspects of inhibitory control. The CPT-X task, classified as inhibitory control (Levy et al., 2018), was utilized to examine reaction time. The CPT-X was chosen due to moderate correlations between speed measures compared to other inhibitory control tasks (i.e., Stroop task, Go/No-go task, Stop Signal Task), thus demonstrating construct validity (Fernandez-Marcos et al., 2018). Whereas, low convergent validity was exhibited for response accuracy (Fernandez-Marcos et al., 2018). Reaction time and response accuracy can be used in conjunction to determine the presence of a speed-accuracy trade-off. Furthermore, Sibley et al. (2006) monitored response accuracy errors during the Stroop task. Error estimates were less than 1% following both the physical activity and control session (i.e., response accuracy did not improve or decline), indicating the absence of a speed-accuracy trade-off. Therefore, CPT-X reaction time performance will be considered the outcome variable of interest (Sibley et al., 2006) and response accuracy will be used as a manipulation check. Additionally, CPT-X has frequently been used in both healthy individuals and those with mental health conditions (Buchsbaum & Sostek, 1980; Halperin et al., 1991; Losier et al., 1996). Specifically, CPT-X has been employed in research assessing individuals with ADHD (Medina et al., 2010; Mahon et al., 2013).

Participants were instructed to download Presentation Mobile Application using Presentation® software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com) from *Google Play Store* or *App Store*. Once downloaded, participants input the investigation identification number (i.e., identification number to access the task, and have results sent to the investigator via Presentation® online platform). In previous research, task results have not been hindered by mobile or tablet operating system timing precision (Woods et al., 2017). Regardless of the device (i.e., desktop, mobile, or tablet), latency standard deviations were less than one millisecond for delivery and less than nine milliseconds for touch detection, resulting in reliable responses through Presentation Mobile Application (Woods et al., 2017). The task required participants to use their smart phone or tablet and respond to any letter other than 'X.' The target begins after a 500ms fixation cross with a 700ms interstimulus interval (ISI). Participants were instructed to respond as quickly and accurately as possible with their left or right thumb to any letter other than 'X.' When the participant is shown 'X,' they were instructed not to respond. Once the task was completed, participants selected 'upload' on their screen, which uploaded their time-stamped data to Presentation® online platform.

Each day of testing, participants received eight practice trials prior to completing the task. For the experiment, participants completed two total blocks of 50 trials with mixed target probability. For the purposes of this task, 'X' is defined as the target. Presentation® software randomizes the trials within each block, where block one consisted of 20% target ('X') presentation and the second block consisted of 80% target ('X') presentation to minimize target anticipation, while maintaining an equal number of trials. For each treatment condition, blocks were analyzed together for equal probability. The researcher was the only one with access to the data, which was then processed for analysis.

Affect Measures

Affect measurements consisted of the Feeling Scale (FS) and Felt Arousal Scale (FAS). Both FS and FAS are domain-general (i.e., not domain-specific to physical activity), target core affect, and are based on strong theoretical and experimental principles (Ekkekakis & Petruzzello, 2000, 2002; Ekkekakis et al., 2003). FS and FAS are easy to understand, but used independently (Ekkekakis, 2013). FS is an 11-point scale assessing valence (i.e., pleasant, unpleasant) from very bad (-5) to very good (+5; Hardy & Rejeski, 1989). FAS is a 6-point scale estimating the activation (i.e., arousal) of an individual from low arousal: relaxed, bored, or calm (1) to high arousal: excited, anxious, or angry (6; Svebak & Murgatroyd, 1985). Therefore, FS and FAS were implemented to analyze valence and activation.

Statistical Analysis

In the initial data collection, an error occurred within the Qualtrics questionnaire where affect data was not collected correctly. Due to the error, the participants who already completed the study (n = 40) were asked to complete the study a second time to collect appropriate measures. Of these participants, only twenty-four completed the study a second time following error correction. From these participants, only data from the second time completing the study were used in the final analyses. Additional participants (n = 54) completed the study after error correction for the first time. Therefore, the final analyses included the original sample of participants who completed the inhibitory control task (n = 94), and a sub-sample of participants (n = 78) who completed the affect measures. Analyses were performed separately for both the main and sub-sample data. Analyses for the original sample were conducted to account for the larger sample size, thus increasing statistical power for the cognitive control data.

Statistical analyses were conducted using SPSS (IBM, SPSS, v. 27 Chicago, IL). Significant ($p < 0.05$) results and standard error of mean (±SEM) are reported. Demographic factors (i.e., age, gender, ethnicity, race, physical activity level, BMI, and medication status) are expressed as mean and ±SEM and analyzed by conducting an independent t-test, chi-square test, or Fisher's exact test to determine between group (i.e., at risk and not at risk for ADHD) differences for risk factor. One participant did not provide BMI information. Therefore, the missing value was replaced using the linear trend at point method, and BMI values are based upon $n = 94$.

Before hypothesis testing, a preliminary analysis was conducted to ensure experimental order effects did not occur. This analysis employed an additional between subject factor with two levels (physical activity-inactivity, inactivity-physical activity) to the analyses described below for each dependent measure. Additional preliminary analyses were conducted on the cognitive control measure on whether the participant completed the study once or twice, and presence or absence of affect data to ensure no group differences on the independent variable (i.e., Treatment: Physical Activity or Inactivity).

To measure the intervention's efficacy (i.e., successfully producing the intended result), heart rate and RPE data were analyzed with a 2 (Treatment: physical activity, inactivity) x 2 (Time: before, after) x 2 (Risk Factor: at risk for ADHD, not at risk for ADHD) mixed-design ANOVA with risk factor for ADHD as the between-subjects factor. Heart rate data points were missing from each variable (Physical Activity Before: $n = 87$, Physical Activity After: $n = 92$, Inactivity Before: $n = 91$, and Inactivity After: $n = 92$), but the missing values were replaced using the linear trend at point method (i.e., missing values are replaced with their predicted values). Therefore, heart rate values were replaced and based upon $n = 94$. RPE data was only represented for the sub-sample, and many data points were missing for each variable (Physical Activity Before: 21%, Inactivity Before: 17%, and Inactivity After: 9%). Data were missing because of item nonresponse on the activity log. To determine a valid statistical inference, due to the large number of missing data values, a multiple imputation was performed under the assumption that missing values were at random, using the Monte Carlo Markov chain (MCMC) method with 20 imputations (Graham et al., 2007). Analyses performed on the data were pooled, and results were reported from these values (i.e., univariate combination) after the 20 iterations. Therefore, RPE values were based upon n = 78.

In relation to Aim 2 and Aim 4, a series of mixed-design analysis of variance (ANOVAs) were conducted to examine how physical activity influences inhibitory control and affect for young adults at risk and not at risk for ADHD. For Aim 2 and Aim 4, the null hypotheses are as follows. Within groups, there will be no difference between treatment (i.e., physical activity and inactivity), and there will be no difference between time (i.e., before and after). There will be no interaction effect between risk factor and treatment, risk factor and time, treatment and time, and risk factor, treatment, and time.

For Aim 2 and Aim 4 separate analyses were performed for mean reaction time, FS, and FAS using a 2 (Treatment: physical activity, inactivity) x 2 (Time: before, after) x 2 (Risk Factor: at risk for ADHD, not at risk for ADHD) mixed-design ANOVA with risk factor for ADHD as the between-subjects factor. CPT-X response accuracy was analyzed using a 2 (Treatment: (physical activity, inactivity) x 2 (Time: before, after) x 2 (Risk Factor: at risk for ADHD, not at risk for ADHD) mixed-design ANOVA with risk factor for ADHD as the between-subjects factor to confirm that participants were maintaining response accuracy.

To test the assumptions (i.e., ensuring data does not violate assumptions to alter interpretation of results), the Q-Q plots were performed to detect dependent variable normality for each combination of factors. Additionally, standardized residuals were used to detect outliers, in any combination of the independent variables (i.e., within- and between-subjects) because they can have a negative effect on the analysis, distorting the differences between groups. The Q-Q plots (see Appendices C, D, and E) and standardized residuals indicated that for all individuals the RT, FS, and FAS data consists of normally distributed errors. Mauchly's test for sphericity, which is one of the assumptions that is required for the repeated measures design, was not necessary because each variable had only two levels. Therefore, the Greenhouse-Giesser statistic was used. Additionally, Levene's test of equality for error variance was conducted to ensure error variance was equal across all groups such that for all levels of repeated measures, variances were homogeneous.

Interactions, starting from the highest order, were tested prior to main effects. As interaction effects were significant, simple effects were tested by conducting ancillary univariate ANOVAs using Estimated Marginal Means with treatment and time as variables of interest. Each factor was compared at the level of treatment and time at each level of the other factor. Bonferroni-adjustments were made and reported using mean and ±SEM. For significant main effects and interactions, partial eta squared (η_p^2) (i.e., measuring proportion of the variance explained by the remaining total variance once accounted for variance explained by the other variables in the model) was reported.

CHAPTER IV: RESULTS

Demographics

Demographic information of both the original sample (i.e., contains only cognitive control data) and sub-sample (i.e., contains cognitive control and affect data) is reported in Table 1 and Table 2, respectively. To ensure at risk for ADHD and not at risk for ADHD individuals were not demographically different, an independent samples *t*-test was conducted. Results for Age, MVPA, and BMI revealed no differences in risk factor for the original sample and sub-sample of participants across demographic measures. A chi-square test or Fisher's exact test was conducted for categorical variables. Results for Gender, Ethnicity, and BMI classifications revealed no differences between individuals at risk for ADHD and individuals not at risk for ADHD. However, individuals at risk for ADHD were mostly white compared to those not at risk who were majority white and African American.

Table 1:Means (±SEM), Counts (%), Independent Samples t-test, and Chi- Square Results for Original Sample Demographic Variables

Measure	At Risk for ADHD	Not at Risk for ADHD	*t*	χ^2	*p*
n	27	67			
Gender				.03	.87
Female, *n* (%)	17 (63.00)	41 (61.20)			
Age	21.78 (0.45)	21.88 (0.41)	0.15		.88
Race, *n* (%)					$.00^{a*}$
Asian	2 (7.40)	3 (4.50)			
African American	3 (11.10)	28 (41.80)			
Two-or more races	1 (3.70)	8 (12.00)			
White	21 (77.8)	28 (41.80)			
Ethnicity, *n* (%) (Spanish, Hispanic, or Latino Origin)	1 (3.70)	8 (11.90)		1.51	.22
MVPA min/day	92.57 (13.21)	88.56 (8.14)	-0.26		.79
BMI	26.15 (1.08)	24.68 (0.51)	-1.40		.17
BMI Classifications, *n* (%)					$.08^{b}$
Underweight	1 (3.70)	1 (1.50)			
Normal	11 (40.70)	42 (62.7)			
Overweight	7 (25.9)	16 (23.90)			
Obese	7 (25.9)	6 (9.00)			

Note. ^{a,b} = Fisher's Exact Test

Significant ($p < .05$) effects are indicated with *.

Table 2: Means (±SEM), Counts (%), Independent Samples t-test, and Chi- Square Results for Sub-Sample Demographic Variables

Measure	At Risk for ADHD	Not at Risk for ADHD	*t*	χ^2	*p*
n	25	53			
Gender				.03	.86
Female, *n* (%)	16 (64.00)	35 (66.00)			
Age	21.60 (0.49)	22.00 (0.50)	0.51		.61
Race, *n* (%)					.02[a]*
Asian	1 (4.00)	2 (3.80)			
African American	3 (12.00)	20 (37.70)			
Two-or more races	1 (4.00)	7 (13.20)			
White	20 (80.00)	24 (45.30)			
Ethnicity, *n* (%) (Spanish, Hispanic, or Latino Origin)	1 (4.00)	5 (9.40)			.66[b]
MVPA min/day	90.03 (14.11)	91.60 (9.60)	0.08		.94
BMI	25.98 (1.15)	24.41 (0.57)	-1.37		.18
BMI Classifications, *n* (%)					.67[c]
Underweight	1 (4.00)	1 (1.90)			
Normal	11 (44.00)	36 (67.90)			
Overweight	7 (28.00)	11 (20.80)			
Obese	6 (24.00)	4 (7.50)			

Note. [a,b,c] = Fisher's Exact Test

Significant ($p < .05$) effects are indicated with *.

ADHD Assessment

ADHD measure counts for original sample and sub-sample participants are reported in Table 3. Behavior Rating Scale for Childhood and Past 6 Months are reported for the original sample (see Appendix A) and sub-sample (see Appendix B).

Table 3: ADHD Measure Counts

Measure	Original Sample	Sub-Sample
	n (%)	*n* (%)
Currently on medication for a psychiatric disorder?		
Anxiety	1 (1.10)	1 (1.30)
Depression	3 (3.2)	2 (2.60)
Both	4 (4.30)	4 (5.10)
No	86 (91.50)	71 (91.00)
How long have you been taking this medication?		
Less than 1 week		
1 to 2 weeks	2 (25.00)	12 (15.40)
3 to 4 weeks		
Greater than 4 weeks	80 (85.1)	66 (84.60)
Yes	14 (14.90)	12 (15.40)
No	80 (85.10)	66 (84.60)
If so, what medications currently on?		
Adderall	3 (3.20)	3 (3.90)
Bupropion	1 (1.10)	1 (1.30)
Concerta	1 (1.10)	1 (1.30)
Ritalin	1 (1.10)	1 (1.30)
Strattera	1 (1.10)	
Vyvanse	2 (2.20)	1 (1.30)
None currently	6 (5.40)	5 (6.40)
What ADHD medications have been prescribed in the past?		
Adderall	6	5
Amphetamine Salts	1	1
Concerta	1	1
Daytrana	1	
Quillivant XR	1	1
Ritalin	2	1
Strattera	1	

Vyvanse	3	3
Diagnosed by a medical profession with a mental health condition?		
Anxiety	3 (3.70)	3 (4.40)
Autism Spectrum Disorder	1 (1.20)	1 (1.50)
Depression	2 (2.50)	2 (2.90)
Post-Traumatic Stress Disorder	1 (1.20)	1 (1.50)
Never Been Diagnosed	74 (91.4)	61 (89.70)

Note. Frequencies are not listed for 'What ADHD medications have been prescribed in the past?' Individuals had to fill in the blank and could have indicated more than one medication. Therefore, frequencies would not have equaled the number of participants currently on medication.

Activity Log

Activity log measures of both the original sample and sub-sample were reported in Table 4 and Table 5, respectively. After conducting independent samples *t*-test, these data show that individuals not at risk for ADHD are not significantly different from individuals at risk for ADHD for both the original sample and sub-sample. Independent samples *t*-tests were conducted to ensure activity log variables did not present differences among individuals at risk for ADHD compared to individuals not at risk for ADHD. Heart rate and RPE were not included in the independent samples *t*-test analysis, as they were analyzed later as intervention efficacy variables.

Table 4: Original Sample Means (±SEM), Counts (%), and Independent Samples t-test Results for Activity Log

Measure	At Risk for ADHD	Not at Risk for ADHD	*t*	*p*
	n = 27	*n* = 67		
Physical Activity				
Time from cessation of activity to end of Qualtrics questionnaire (min)	8.15 (1.67)	8.96 (1.12)	0.39	.70
Heart rate				
Before	72.26 (2.16)	68.12 (1.37)		
After	126.07 (4.94)	127.54 (3.14)		
Type, *n* (%)			0.31	.76
Cycling	6 (22.20)	13 (19.40)		
Running	21 (77.70)	54 (80.60)		
Location, *n* (%)			0.16	.87
Indoors	13 (48.10)	31 (46.30)		
Outdoors	14 (51.90)	36 (53.70)		
Activity in the presence of others	4 (14.80)	19 (28.40)	1.38	.17
Entertainment, *n* (%)			-1.02	.31
Music	22 (81.50)	57 (85.10)		
Using phone	1 (3.70)	4 (6.00)		
Watching television	2 (7.40)	1 (1.50)		
No response	2 (7.40)	5 (7.50)		
Inactivity				
Time from cessation of activity to end of Qualtrics questionnaire (min)	13.33 (5.79)	10.16 (1.94)	-0.67	.51
Heart rate				
Before	71.85 (2.66)	69.80 (1.69)		
After	73.26 (3.09)	70.95 (1.96)		
Type, *n* (%)			-1.02	.31
Reading	2 (7.40)	6 (9.00)		

Reading, Studying	2 (7.40)			
Studying	4 (14.8)	16 (23.90)		
Studying, Watching television		1 (1.50)		
Watching television	19 (70.40)	44 (65.70)		
Location, *n* (%)			0.63	.53
Indoors	27 (100.00)	66 (98.50)		
Outdoors		1 (1.50)		
Activity in the presence of others	10 (37.00)	24 (35.80)	-0.11	.91

Note. Entertainment includes only physical activity. No significant ($p < .05$) effects associated with activity log.

Table 5: Sub-Sample Means (±SEM), Counts (%), and Independent Samples t-test Results for Activity Log

Measure	At Risk for ADHD	Not at Risk for ADHD	*t*	*p*
	n = 25	*n* = 53		
Physical Activity				
Time from cessation of activity to end of Qualtrics questionnaire (min)	7.40 (1.56)	9.62 (1.40)	0.99	.33
Heart rate				
Before	71.82 (2.28)	67.94 (1.57)		
After	127.60 (4.70)	127.17 (3.23)		
RPE				
Before	9.09 (0.62)	8.81 (0.38)		
After	12.24 (0.63)	13.23 (0.43)		
Activity Level Since Waking, *n* (%)			0.89	.38
Low	20 (80.00)	42 (79.20)		
Moderate	3 (12.00)	10 (18.90)		
High		1 (1.90)		
No response	2 (8.00)			
Type, *n* (%)			0.73	.47
Cycling	6 (24.00)	9 (17.00)		
Running	19 (76.00)	44 (83.00)		
Location, *n* (%)			1.02	.31
Indoors	13 (52.00)	21 (39.60)		
Outdoors	12 (48.00)	32 (60.40)		
Activity in the presence of others	4 (46.00)	13 (24.50)	0.84	.40
Entertainment, *n* (%)			-1.29	.20
Music	20 (80.00)	44 (83.00)		
Using phone	1 (4.00)	4 (7.50)		
Watching television	2 (8.00)			
No response	2 (8.00)	5 (9.40)		

Inactivity				
Time from cessation of activity to end of Qualtrics questionnaire (min)	11.20 (5.70)	10.94 (2.41)	-0.05	.96
Heart rate				
Before	71.72 (2.92)	69.62 (2.01)		
After	73.64 (3.40)	71.05 (2.34)		
RPE				
Before	7.23 (0.50)	7.83 (0.34)		
After	7.22 (0.48)	8.00 (0.33)		
Activity Level Since Waking, *n* (%)			0.14	.89
Low	21 (84.00)	43 (81.10)		
Moderate	4 (16.00)	9 (17.00)		
High				
No response	2 (8.00)	1 (1.90)		
Type, *n* (%)			-1.08	.28
Reading	2 (8.00)	5 (9.40)		
Reading, Studying	2 (8.00)			
Studying	4 (16.00)	15 (28.30)		
Studying, Watching television		1 (1.90)		
Watching television	17 (68.00)	32 (60.40)		
Location, *n* (%)			0.68	.50
Indoors	25 (100.00)	52 (98.10)		
Outdoors		1 (1.90)		
Activity in the presence of others	9 (16.00)	18 (34.00)	-0.17	.86

Note. Entertainment includes only physical activity. No significant ($p < .05$) effects associated with activity log.

Preliminary Analyses

Preliminary analyses were conducted on the cognitive control mean reaction time measure to ensure no group differences prior to or following on the independent variable (i.e., Treatment: Physical Activity or Inactivity). Preliminary analyses (see Table 6) were performed on: A) If the participant completed the study once or twice; B) Presence or absence of affect data; and C) Session order, to determine if these effects influence outcomes associated with the physical activity treatment. Results did not reveal any significant interactions with Treatment x Participant Completion: (*p's* $\geq .25$); Treatment x Presence of Affect Data: (*p's* $\geq .19$); Treatment x Session Order: (*p's* $\geq .62$), across CPT-X measures. Therefore, subsequent analyses were collapsed across participant completion, presence of affect data, and session order. Preliminary analyses that were conducted on the cognitive control measure determined no group differences associated with the physical activity and inactivity treatment. Therefore, the following analyses are performed on the original model that include cognitive control and affect.

Table 6: Summary of Statistical Analyses for Preliminary Analyses

Effect	F	df1/df2	p	η_p^2
Participant Completion				
Treatment	0.99	1,94	.32	.01
Treatment x Participant Completion	1.36	1,94	.25	.02
Time	3.63	1,94	.06	.04
Time x Participant Completion	0.58	1,94	.45	.01
Treatment x Time	4.59	1,94	.04	.05
Treatment x Time x Participant Completion	1.37	1,94	.25	.02
Presence of Affect Data				
Treatment	0.17	1,94	.66	.00
Treatment x Presence of Affect Data	1.75	1,94	.19	.02
Time	2.95	1,94	.09	.03
Time x Presence of Affect Data	0.02	1,94	.88	.00
Treatment x Time	1.44	1,94	.23	.02
Treatment x Time x Presence of Affect Data	0.06	1,94	.81	.00
Session Order				
Treatment	0.31	1,94	.58	.00
Treatment x Session Order	0.24	1,94	.62	.00
Time	5.91	1,94	.02	.06
Time x Session Order	0.40	1,94	.53	.00
Treatment x Time	3.29	1,94	.07	.03
Treatment x Time x Session Order	0.01	1,94	.92	.00

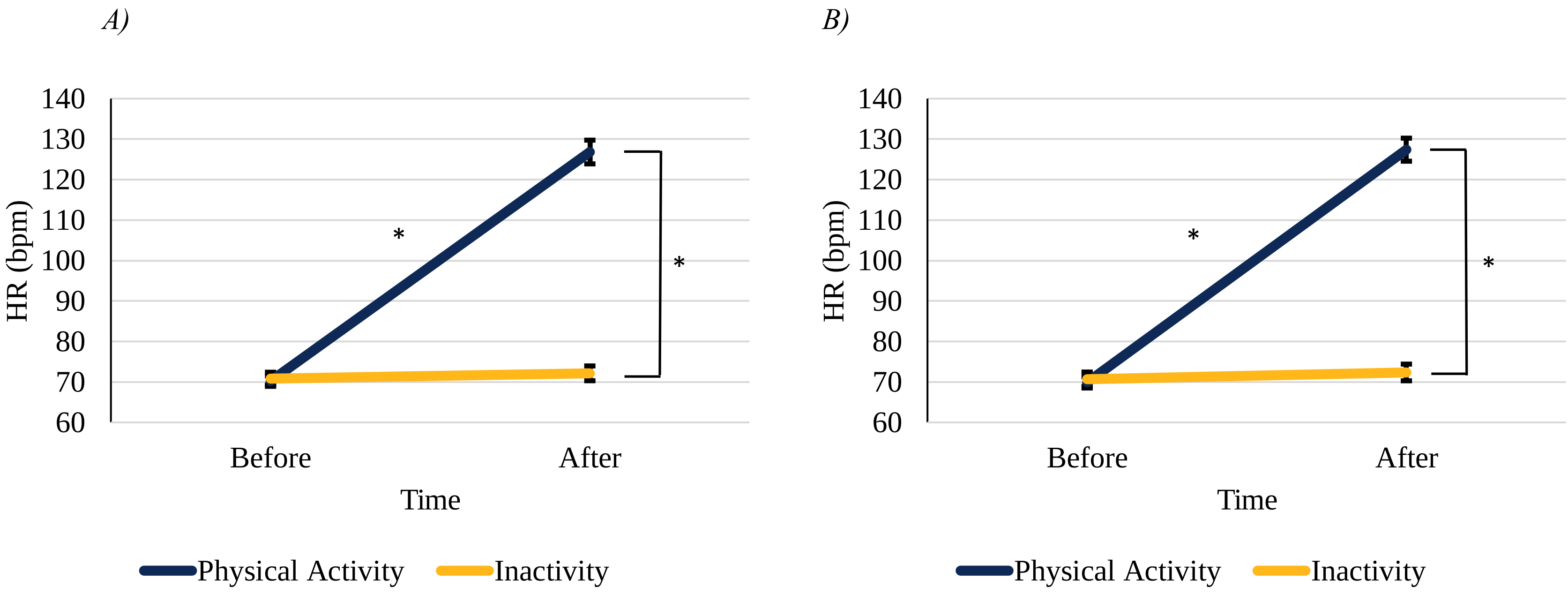
Note. No significant ($p < .05$) effects associated with preliminary analyses.

Intervention Efficacy

Heart rate data for the original sample indicated main effects of Treatment, (*p* < .05), and Time, (*p* < .05), which were superseded by a Treatment x Time interaction, (*p* < .05, see Figure 2a). Simple effect tests revealed, after treatment, heart rate for physical activity was 126.81 (±2.93 BPM) and 72.11 (±1.83 BPM) for inactivity, a statistically significant mean difference of 54.70 BPM, 95% Confidence Interval [CI; 48.28, 61.13], *p* = .00. Before treatment, heart rate for physical activity was 70.19 (±1.28 BPM) and 70.82 (±1.58 BPM) for inactivity, a mean difference of 0.63 BPM, 95% CI [-2.27, 3.53], *p* = .67, which was not statistically significant. Therefore, heart rate was greater after physical activity as compared to before physical activity (i.e., after 20 minutes of moderate intensity physical activity) and after inactivity. The between-subjects factor (i.e., risk factor) revealed no main effects or interactions (*p's* ≥ .38).

Sub-sample heart rate data for each Treatment indicated main effects of Treatment, (*p* < .05), and Time (*p* < .05), which were superseded by a Treatment x Time interaction, (*p* < .05, see Figure 2b). Simple effect tests revealed, after treatment, heart rate for physical activity was 127.39 (±2.85 BPM) and 72.34 (±2.06 BPM) for inactivity, a statistically significant mean difference of 55.04 BPM, 95% CI [48.60, 61.49], *p* = .00. Before treatment, heart rate for physical activity was 69.88 (±1.38 BPM) and 70.67 (±1.77 BPM) for inactivity, a mean difference of 0.79 BPM, 95% CI [-2.42, 4.01], *p* = .62, which was not statistically significant. Therefore, heart rate was greater after physical activity as compared to before physical activity and after inactivity. Risk factor revealed no main effects or interactions (*p's* ≥ .54).

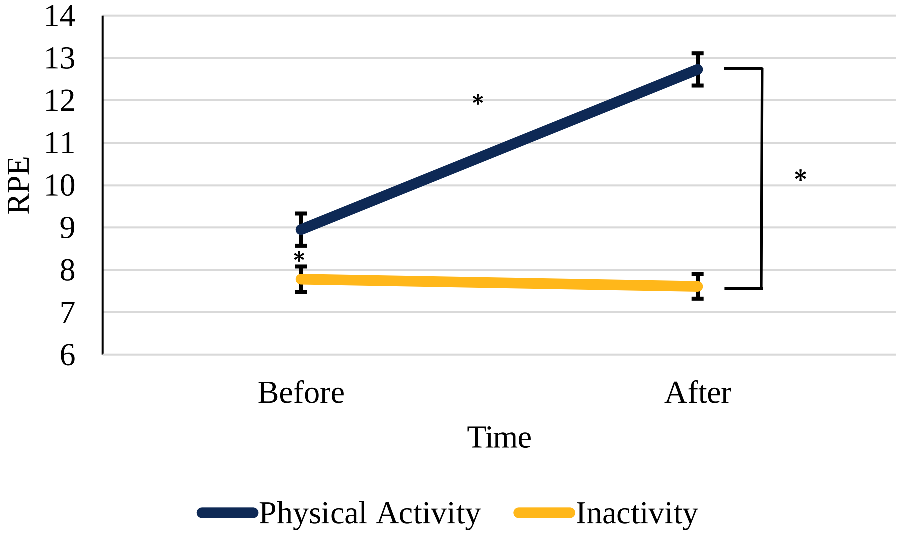
Figure 2: Heart Rate for (A) Treatment by Time Original Sample and (B) Treatment by Time Sub-Sample



Note. Significant (*p* < .05) effects are indicated with *.

RPE sub-sample results (see Figure 3) indicated main effects of Treatment, ($p < .05$), and Time, ($p < .05$), which were superseded by a Treatment x Time interaction, ($p < .05$). Simple effect tests revealed that after treatment, RPE for physical activity was 12.73 (±0.38) and 7.60 (±0.29) for inactivity, a statistically significant mean difference of 5.13, 95% CI [4.21, 6.06], $p = .00$. Before treatment, RPE for physical activity was 8.71 (±0.31) and 7.77 (±0.28) for inactivity, a statistically significant mean difference of 0.94, 95% CI [0.37, 1.50], $p = .00$. Therefore, RPE was greater after physical activity as compared to before physical activity (i.e., after 20 minutes of moderate intensity physical activity), before inactivity, and after inactivity. Risk factor revealed no main effects or interactions (*p's* ≥ .16).

Figure 3: Ratings of Perceived Exertion for Treatment by Time Sub-Sample



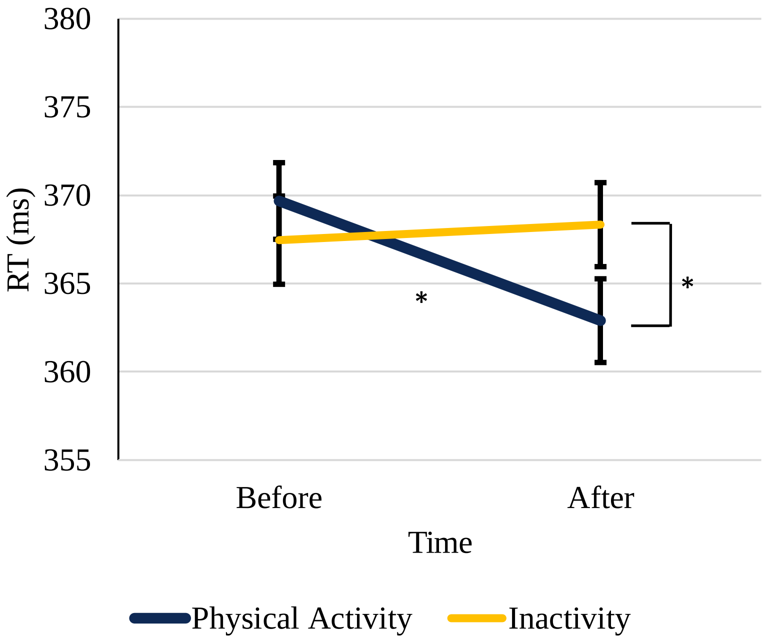
Note. Significant ($p < .05$) effects are indicated with *.

CPT-X Performance

Reaction Time (RT)

For RT scores, the variances for individuals at risk and not at risk for ADHD were not significantly different (*p's* ≥ .12), ensuring variance is constant across groups. In relation to Aim 1 and 2, to determine a difference in inhibitory control performance in individuals at risk and not at risk for ADHD, a mixed-design ANOVA was performed (see Table 7). The omnibus analysis for mean RT revealed a Treatment x Time interaction ($p < .02$). Simple effect tests revealed, after treatment, mean RT score for physical activity was 362.89 (±2.37 ms) and 368.34 (±2.38 ms) for inactivity, a statistically mean difference of 5.45 ms, 95% CI [.49, 10.41], $p = .03$. Before treatment, mean RT score for physical activity was 369.68 (±2.17 ms) and 367.46 (±2.50 ms) for inactivity, a mean difference of 2.23 ms, 95% CI [-2.88, 7.34], $p = .39$, which was not statistically significant (see Figure 4). Therefore, results indicated shorter RT after physical activity compared to after inactivity and before physical activity. Lastly, the between-subjects factor (i.e, risk factor) revealed no main effects or interactions (*p's* ≥ .06).

Figure 4: CPT-X Reaction Time Results for Treatment by Risk Factor

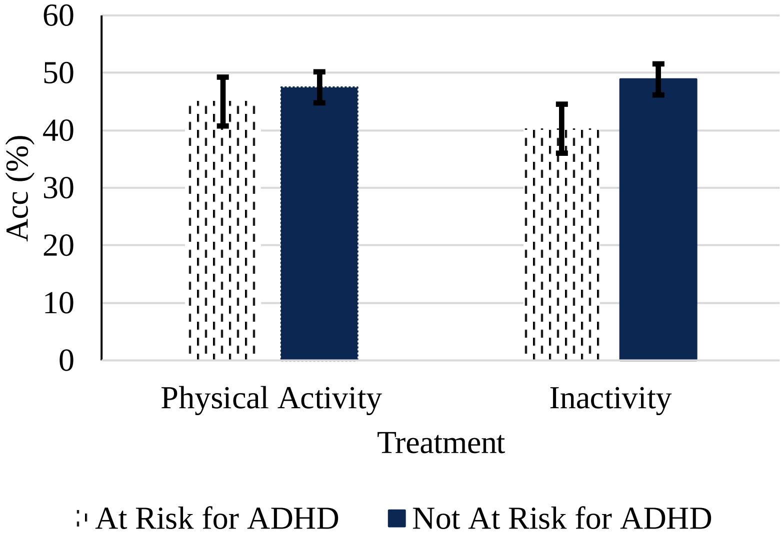


Note. Significant (*p* < .05) effects are indicated with *.

Response Accuracy

To test for a difference in response accuracy (i.e., accurate responses to non-targets) in individuals at risk and not at risk for ADHD, a mixed-design ANOVA was performed (see Table 7). Results revealed a Treatment x Risk Factor interaction, (*p* < .04). Simple effect tests demonstrated for individuals at risk for ADHD, response accuracy mean for physical activity was 45.02 (±4.25%) and 40.30 (±4.26%) for inactivity, a mean difference of 4.72%, 95% CI [-.18, 9.62], *p* = .06. For individuals not at risk for ADHD, response accuracy mean for physical activity was 47.49 (2.70%) and 48.87 (±2.70%) for inactivity, a mean difference of 1.37%, 95% CI [-1.74, 4.48], *p* = .39. After testing for simple effects, while there is a trend for greater response accuracy before and after physical activity compared to inactivity for individuals at risk for ADHD, no significant differences were present for response accuracy (see Figure 5).

Figure 5: CPT-X Response Accuracy Results for Treatment by Risk Factor



Note. Significant (*p* < .05) effects are indicated with *.

Table 7: Summary of Statistical Analyses for CPT-X Measures.

Effect	F	df1/df2	p	η_p^2
Reaction Time				
Treatment	0.64	1,94	.42	.01
Treatment x Risk Factor	0.46	1,94	.50	.01
Time	2.80	1,94	.10	.03
Time x Risk Factor	1.54	1,94	.22	.02
Treatment x Time*	6.16	1,94	.02*	.06
Treatment x Time x Risk Factor	3.63	1,94	.06	.04
Response Accuracy				
Treatment	1.31	1,94	.26	.01
Treatment x Risk Factor*	4.33	1,94	.04*	.05
Time	2.94	1,94	.09	.03
Time x Risk Factor	1.36	1,94	.25	.02
Treatment x Time	0.23	1,94	.62	.00
Treatment x Time x Risk Factor	2.81	1,94	.09	.03

Note. Significant ($p < .05$) effects are indicated with *.

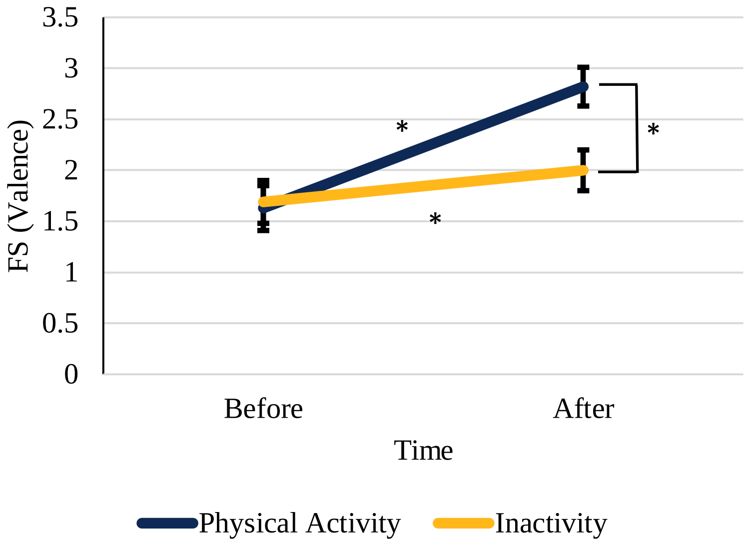
Affect Measures

Feeling Scale

For FS scores, the variances for individuals at risk and not at risk for ADHD were not significantly different (*p's* ≥ .17), ensuring variance is constant across groups. To evaluate Aim 3 and 4, which was to determine a difference in affective valence in individuals at risk and not at risk for ADHD, a mixed-design ANOVA was performed (see Table 8). The omnibus analysis for FS (valence) revealed a main effect of Time, ($p < .05$), which was superseded by a Treatment x Time interaction, ($p < .05$).

Simple effect tests demonstrated after treatment, affective valence for physical activity was 2.82 (±0.19) and 2.00 (±0.20) for inactivity, a statistically significant mean difference of 0.82, 95% CI [0.38, 1.25], $p = .00$. Before treatment, affective valence for physical activity was 1.63 (±0.22) and 1.69 (±0.21) for inactivity, a mean difference of 0.05, 95% CI [-0.45, 0.56], $p = .84$ (see Figure 6). Therefore, after physical activity participants indicated more positive valence compared to after inactivity. Lastly, results including the risk factor revealed no main effects or interactions (*p's* ≥ 0.40).

Figure 6: Affective Valence for Treatment by Time



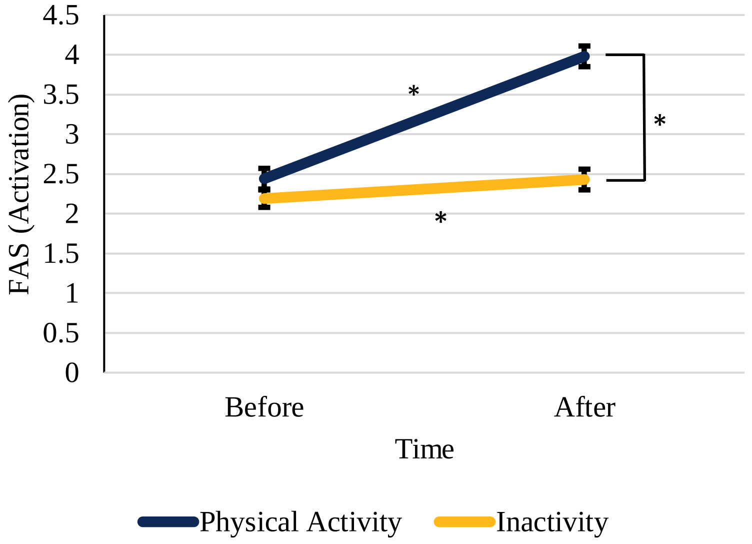
Note. Significant (*p* < .05) effects are indicated with *.

Felt Arousal Scale

For FAS scores, the variances for individuals at risk and not at risk for ADHD were not significantly different (*p's* ≥ .40), ensuring variance is constant across groups. To evaluate Aim 3 and 4, which was to determine a difference in affective activation in individuals at risk and not at risk for ADHD, a mixed-design ANOVA was performed (see Table 8). The omnibus analysis for FAS (activation) revealed main effects of Treatment, (*p* < .05), and Time, (*p* < .05), which were superseded by a Treatment x Time interaction, (*p* < .05).

Simple effect tests demonstrated after treatment, affective activation for physical activity was 3.98 (±0.13) and 2.43 (±0.13) for inactivity, a statistically significant mean difference of 1.55, 95% CI [1.26, 1.84], *p* = .00. Before treatment, affective valence for physical activity was 2.44 (±0.13) and 2.19 (±0.11) for inactivity, a mean difference of 0.24, 95% CI [-0.04, 0.53], *p* = .10 (see Figure 7). Therefore, after physical activity participants reported greater activation compared to after inactivity. Lastly, risk factor revealed no main effects or interactions (*p's* ≥ .70).

Figure 7: Affective Activation for Treatment by Time



Note. Significant (*p* < .05) effects are indicated with *.

Table 8: Summary of Statistical Analyses for Affect Measures.

Effect	F	df1/df2	*p*	η_p^2
Feeling Scale				
Treatment	3.18	1,78	.08	.04
Treatment x Risk Factor	0.08	1,78	.77	.00
Time*	72.46	1,78	.00*	.49
Time x Risk Factor	0.01	1,78	.93	.00
Treatment x Time*	18.39	1,78	.00*	.20
Treatment x Time x Risk Factor	0.71	1,78	.40	.01
Felt Arousal Scale				
Treatment*	62.00	1,78	.00*	.45
Treatment x Risk Factor	0.00	1,78	.99	.00
Time*	116.68	1,78	.00*	.61
Time x Risk Factor	0.02	1,78	.89	.00
Treatment x Time*	54.93	1,78	.00*	.42
Treatment x Time x Risk Factor	0.15	1,78	.70	.00

Note. Significant ($p < .05$) effects are indicated with *.

CHAPTER V: DISCUSSION

The present study evaluated inhibitory control and affect prior to and following physical activity and inactivity in individuals who are at risk for ADHD and not at risk for ADHD in a real-world environment. This investigation was developed on the premise of implementing a protocol to assess these factors in a real-world environment with individuals who are at risk and not at risk for ADHD. Overall, young adults at risk and not at risk for ADHD demonstrated faster RT after physical activity compared to after inactivity. Additionally, individuals at risk and not at risk for ADHD indicated more positive valence and greater activation following physical activity in their own real-world environment. While the present data is partially contrary to the a priori hypotheses, the translational approach of this current investigation has addressed the limitations of previous literature and added to the current literature.

Physical Activity, Cognitive Control, and ADHD

The present cognitive control results revealed improvements in RT following physical activity as compared to inactivity and demonstrated RT was shorter following physical activity as compared to before. Moreover, in contrast to the first hypothesis, prior to treatment between group differences did not occur as predicted. Furthermore, the present results are partially contrary to the second hypothesis in that all young adults demonstrated faster RT after physical activity compared to inactivity, but young adults at risk for ADHD did not demonstrate larger magnitude of performance benefits after physical activity compared to individuals not at risk for ADHD. The current data complements the existing literature revealing cognitive control benefits following physical activity (Ludyga et al., 2016; Moreau & Chou, 2019). Present results are consistent with recent findings, revealing significant improvements in inhibitory control, specifically RT, for young adults following acute physical activity (Den Heijer et al., 2017;

Gapin et al., 2015; Ludyga et al., 2017; Piepmeier et al., 2015). Taken together, these data suggest that RT improves following physical activity compared to inactivity for young adults who are at risk and not at risk for ADHD in a real-world environment.

Reaction time and response accuracy are measures that support inhibitory control. While RT was the primary outcome of interest, response accuracy was also analyzed to ensure a speed/accuracy trade-off did not occur. The present findings did not reveal any significant differences in response accuracy for individuals at risk and not at risk for ADHD. While RT and response accuracy are complimentary aspects of inhibitory control, inhibitory control is affected by physical activity differently between individuals at risk and not at risk for ADHD. Of importance, while response accuracy maintained follow physical activity, RT improved, thus overall efficiency was demonstrated after physical activity compared after inactivity. Overall, current findings along with existing literature suggest that acute physical activity does elicit inhibitory control RT improvements and benefits young adults who are at risk and not at risk for ADHD in their real-world environment.

Physical Activity, Affect, and ADHD

The present affect results demonstrated, regardless of risk factor, all participants reported more positive valence and greater activation after physical activity compared to before physical activity and after inactivity. In contrast to the third and forth a priori hypotheses (i.e., predicting between group differences prior to treatment and that those at risk for ADHD would demonstrate a larger magnitude of affective valence and activation benefits after physical activity compared to individuals with no risk for ADHD), these data suggest that while physical activity enhances valence and activation, benefits are not specific to individuals at risk for ADHD (i.e., effects are present in individuals at risk and not at risk for ADHD). Within group differences were also hypothesized to emerge, where an acute bout of physical activity was predicted to increase affective valence and activation for individuals at risk and not at risk for ADHD. The findings of within group differences are consistent with the previous findings that suggest an improvement in valence and activation following physical activity compared to inactivity (Ekkekakis et al., 2008; Focht et al., 2002; Nabetani & Tokunaga, 2001; Niven et al., 2018; Reed et al., 1998). Additionally, findings from the present study align with previous literature (i.e., allowing for the self-selection of activity) suggesting increased affect following physical activity in one's own real-world environment (McAuley et al., 1996; Rendi et al., 2008).

By capturing affective valence and activation, prior to and following physical activity, this study has provided a greater understanding of the way in which at risk and not at risk for ADHD young adults respond when participating in physical activity in their real-world environment. Although the present investigation does not capture affect over multiple days and time periods throughout the day, this study was able to capture real time data on a person's own mobile device, resembling Ecological Momentary Assessment (EMA; Stone & Shiffman, 1994). The use of EMA, or studies of similar design, allows for data collection moment-to-moment for each individual, thus enhancing ecological validity due to its nature in assessing constructs (i.e., affect) as they are occurring in each individual (Weizenbaum et al., 2020). Kanning et al. (2015) suggests the use of event contingent prompting schedule method immediately following physical activity to gain momentary valid data, capturing affect in the individual's real-world environment. Therefore, a strength of the present study is the methodological use of event contingent prompting schedule (i.e., individual initiates the survey before and after activity) to further understand affect immediately following physical activity.

Consistent with findings from a previous EMA review (Liao et al., 2015), the present results demonstrated on average individuals improved affective valence and activation following physical activity in a real-world environment. However, empirical studies reveal inconsistencies with the present findings. Hevel et al. and Kanning et al. did not find any associations with healthy older adults and affect after physical activity. Whereas Mata et al. examined young adults with and without depression, who demonstrated improved affect after physical activity. Moreover, each study examined physical activity and affect across differing time periods (i.e., 3-10 days) in addition to implementing different affect measures (i.e., Short Mood Scale; Circumplex Model; PANAS). Therefore, the discrepancies of results in the present study might be due to age (Hevel et al., 2021; Kanning et al., 2015), mental health condition (Hevel et al., 2021; Kanning et al., 2015; Mata et al., 2012), bouts of physical activity (Mata et al., 2012), and affect measures (Hevel et al., 2021; Kanning et al., 2015). Taken together, current findings along with existing literature suggest that acute physical activity does elicit valence and activation improvements for individuals in their real-world environment.

While there was no significant difference between individuals at risk and not at risk for ADHD for valence or activation, individuals at risk improved following physical activity but not to a larger magnitude than individuals not at risk for ADHD. This suggests an acute bout of physical activity may help benefit people's everyday life with improved affective states and has potential to be used as a feasible therapeutic modality to lesson symptom severity for individuals at risk for ADHD.

Mechanisms

To date, multiple mechanisms have been hypothesized to be linked to acute physical activity, inhibitory control, and affect. Specifically, norepinephrine (NE) is found in the locus coeruleus (LC), and the LC-NE system is important for regulation of sensory signal transmission, where an increase in LC-NE results in a higher level of information processing (Nieuwenhuis, 2005). Distracted behaviors elicit high levels of baseline (i.e., tonic) activity and absence of LC phasic changes (i.e., brief, rapid increases in firing rate), while responses are followed by a period of inactivity caused by inhibition of NE. Therefore, the system is overall less responsive to external events (Nieuwenhuis et al., 2005). As processing relevant information occurs, responsiveness is important for all individuals. Furthermore, an individual's arousal state (i.e., overarousal) may be associated with increased tonic LC activity and reduced phasic response (Nieuwenhuis et al., 2005), and data suggests LC phasic stimulation improved attention (i.e., inhibitory control) in the pre-frontal cortex for individuals (Berridge & Waterhouse, 2003). Consequently, researchers suggest increases in NE influence cognitive control after an acute bout of aerobic physical activity (Gligoroska & Manchevska, 2012; McMorris et al., 2015). These inhibitory control changes in the pre-frontal cortex, resulting from the influence of NE following physical activity, appear similar to the changes in RT following physical activity for individuals found in the present study. However, the documented increases in NE, as described above, might reflect only one measure to support inhibitory control, as these studies have not distinguished between RT and response accuracy. Therefore, the present results suggest physical activity has selective effects on inhibitory control, specifically shorter RT following physical activity for individuals at risk and not at risk for ADHD with no significant differences for response accuracy. Therefore, the changes observed in inhibitory control RT for young adults at risk and not at risk for ADHD, might reflect an increase in NE, thus supporting the relationship between NE, inhibitory control, and physical activity.

Moreover, a moderate increase in physical activity intensity is suggested to increase activity in dorsolateral pre-frontal cortex, thus influencing NE production (Gapin et al., 2011; Fulk et al., 2004), supporting the implementation of moderate intensity exercise. NE could be the mechanism reflecting a positive, curvilinear relationship, where an increase in physical activity intensity reveals an increase in cognitive control performance, suggesting increases in NE could be beneficial for behavioral (i.e., RT) measures for individuals who are at risk and not at risk for ADHD. McMorris and Hale (2015) suggest moderate levels of NE are present during moderate intensity physical activity, which activates the pre-frontal cortex. NE increases lead to improved perception (i.e., being aware of and attending to relevant information) by increasing the signal to noise ratio, thus a plausible explanation for the improvements in RT following physical activity compared to inactivity for young adults.

Improvements in affective valence and activation following physical activity might be influenced by cognitive factors (Ekkekakis et al., 2003), considering cognitive control and affect for individuals at risk and not at risk for ADHD are regulated by the amygdala's role in cognitive impairments and increased emotional reactivity (Villemonteix et al., 2014). Physiological stress (i.e., a disruption in homeostasis, such as performing physical activity) could lead to stimulation of the amygdala, thus controlling cognitive behavior and emotional regulation (Domes et al., 2009; Frodl et al., 2010; Rüsch et al., 2007; Welborn et al., 2009). The stimulation of the amygdala could be the cause of the cognitive control and affective valence and activation improvements in the present results. As the amygdala experiences a shift in psychological stress, according to the Inverted-U for arousal (Yerkes & Dodson, 1908), optimal amygdala activity reflects core affect improvements following moderate intensity physical activity. Taken together, it is plausible that the observed effects of acute moderate intensity physical activity on cognitive control and affect are the result of the activity increase of the LC-NE system and regulation of the amygdala.

While the LC-NE system and regulation of the amygdala may be the cause of the observed effects of an acute bout of physical activity on cognitive control and affect, these proposed mechanisms are limited to investigate in a controlled-laboratory setting. Hence, self-efficacy may have influenced cognitive control and affect in a real-world environment. Self-efficacy refers to an individual's belief that he/she can execute the desired behavior to produce the intended results (Bandura, 1977). Self-efficacy is a proposed determinant of cognitive appraisals to a perceived challenging situation. Therefore, an increase in cognitive control and affect following physical activity could be mediated by self-efficacy. However, according to the dual-mode model, individuals participating in moderate intensity physical activity demonstrate a more pleasant and more activated uniform response after physical activity, not driven by cognitive factors. Therefore, self-efficacy would not be a key mechanism until individuals begin performing vigorous physical activity, due to increased heterogeneity in an individual's cognitive response, driven by cognitive factors (Ekkekakis et al., 2003). On the contrary, self-efficacy could be an antecedent to physical activity with the increased affect as the consequence (Dunton et al., 2017). Allowing an individual to be physically active in his/her own environment might elicit higher efficacy thus leading to an increased focus and improved cognitive control (Clore & Palmer, 2009). Additionally, as an individual believes he/she is capable of engaging in an acute bout of moderate intensity physical activity, an increase in self-efficacy prior to physical activity elicits an increase in affect following physical activity (Bigelow, 2020). This effect is also evident in EMA studies revealing that increases in self-efficacy were associated with a momentary increase in physical activity (Pickering et al., 2016). Therefore, it is plausible that self-efficacy, as an antecedent to physical activity, may influence cognitive control and affect in an individual's real-world environment following an acute bout of physical activity.

Limitations and Future Directions

Despite the findings of the present investigation and expansions to the current literature, the presence of specific limitations is worth noting. First, while the overall sample size (*n* = 94) was adequate, based on the power analysis, the differences in risk factor group size may have increased the likelihood of a Type II error, specifically for individuals at risk for ADHD. The results could have elicited risk factor main effects and interactions, but due to the unequal risk factor group size, these differences were not seen. Second, individuals classified as 'at risk' for the present study did not undergo a full diagnosis; instead, they were categorized based on their results from the Childhood and Adult Past 6-months Behavior Rating Scale. This system of categorization, while rigorous, may have resulted in misclassifications and potentially included individuals who were not at risk or did not include young adults who were at risk. Including only people with clinical diagnoses may have revealed between group differences. Future investigations should seek to include a large number of participants in both groups, where the ADHD group has been clinically diagnosed. Third, as individuals were instructed to continue taking prescribed medications, pharmacological usage for individuals at risk for ADHD could have attenuated the effect demonstrated after physical activity. Forth, this investigation did not consider affect during physical activity. By observing the affective changes that occur before, during, and after physical activity, additional information can further describe the affective response (Ekkekakis et al., 2008). Previous laboratory-based studies suggest that during an acute bout moderate intensity physical activity affective valence decreases or remains stable and affective activation increases. However, upon the cessation of physical activity, valence increases and activated decreases, thus affect is still positive but less activated (i.e., positive deactivated; Ekkekakis et al., 2008; Niven et al., 2018; Thum et al., 2017). Therefore, if the present investigation assessed affect during physical activity, then the findings could potentially be stronger. Despite the limitations, this study demonstrated that individuals at risk for ADHD improved their cognitive control performance and affect improved for all individuals following physical activity.

A strength of this study is the ability to capture individuals' cognitive control and affect in their own real-world environment, and study instructions should be presented to individuals in a manner that increases adherence of participation after initial contact. Future studies implementing this research design should consider verbal (i.e., face-to-face or virtual video) communication in addition to written (i.e., e-mail) communication with the individual to explain the study instructions. By increasing the overall adherence rate of participation, the efficacy of the study increases, thus being able to further understand and optimize cognitive control and affect in a real-world environment for young adults at risk and not at risk for ADHD. Further developments in optimizing cognitive control and affect outcomes possess potential to increase personal and workplace productivity and performing tasks effectively and efficiently.

Therefore, the present results justify further exploration to understand the effects physical activity has on individuals who are diagnosed with ADHD. These implications can be used to develop an intervention implementing the same protocol but using individuals diagnosed with ADHD (i.e., as opposed to at risk for ADHD) compared to a healthy, control group. Alternatively, assessing only individuals with diagnosed ADHD, a pilot intervention may be conducted to examine before and after effects of physical activity and inactivity on cognitive control and affect. Physical activity performed in the real-world environment has the potential to be a treatment plan for individuals with ADHD. However, a physical activity intervention would involve long-term adherence to a physical activity regimen. This is problematic for ADHD individuals given their inherent tendency not to initiate or sustain attention to a task or avoid tasks requiring mental effort (Vysniauske et al., 2016). Therefore, implementing the determinants of the Self-Determination Theory (i.e., autonomy, perceived competence, and social relatedness) would allow the young adult to satisfy their needs in efforts to adhere to a physical activity program (Deci &Ryan, 1985). If a young adult in a social context was given autonomy over one aspect of the program (i.e., type of physical activity performed) his/her perceived competence might increase, thus leading to an increase in motivation to adhere and continue the physical activity program. This pilot intervention might provide a means for a future randomized control trial. Efficacious treatment developments are crucial for individuals diagnosed with ADHD, thus allowing the opportunity for individuals to optimize personal and occupational productivity and quality of life.

Conclusion

In conclusion, these data suggest young adults at risk and not at risk for ADHD yield inhibitory control RT improvements, and young adults, regardless of risk factor demonstrate affective valence and activation increases following an acute bout of physical activity in real-world environments. Existing laboratory-based literature has suggested the beneficial effects of acute physical activity on cognitive control and affect, and young adults at risk for ADHD have been characterized as possessing atypical qualities (i.e., procrastination, poor time management, difficulty starting and finishing tasks, lacks patience, and easily bored; Katragadda & Schubiner, 2007). However, less is known regarding how these effects extend to a real-world environment. Thus, this study sought to explore the influence of inhibitory control and affect for young adults at risk for ADHD prior to and following an acute bout of moderate intensity physical activity in a real-world environment, thus capitalizing on outcomes from a real-world perspective.

The findings from this investigation expand the current understanding regarding acute effects of physical activity on inhibitory control and affect in individuals at risk and not at risk for ADHD. These results are important for future research addressing public health concerns from a psychological and physiological perspective targeting one's real-world environment. This investigation expands the current literature and indicates young adults at risk and not at risk for ADHD demonstrate faster inhibitory control RT after physical activity compared to after inactivity. Additionally, people indicate more positive valence and greater activation following physical activity in their own environment. The benefits of cognitive control and affect following physical activity exist for all individuals, but it is especially important to note the improvements for people at risk for ADHD. In summary, individuals at risk for ADHD demonstrated improved inhibitory control RT and increases in core affect following physical activity, which has the potential to lessen their symptoms and lead to improved quality of life.

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APPENDIX A: ORIGINAL SAMPLE COUNTS (%) CHILDHOOD AND ADULT (PAST 6 MONTHS) BEHAVIOR RATING SCALE OFF MEDICATION

Measure	Childhood				Adult			
	0	1	2	3	0	1	2	3
Fail to give close attention to details or make careless mistakes in my work	51 (54.80)	31 (33.30)	6 (6.40)	5 (5.30)	60 (64.50)	23 (24.70)	7 (7.50)	3 (3.20)
Fidget with my hands or feet or squirm in my seat	25 (26.60)	25 (26.60)	23 (24.50)	21 (22.30)	28 (30.10)	30 (32.30)	16 (17.00)	19 (20.20)
Have difficulty sustaining my attention in tasks or fun activities	47 (50.0)	24 (25.50)	15 (16.00)	8 (8.50)	52 (55.90)	28 (30.10)	10 (10.80)	3 (3.20)
Leave my seat in situations in which remaining seated is expected	66 (70.20)	20 (21.30)	4 (4.30)	4 (4.30)	70 (75.30)	14 (15.10)	7 (7.50)	2 (2.20)
Don’t listen when spoken to directly	67 (71.30)	19 (20.20)	5 (5.30)	3 (3.20)	66 (71.00)	17 (18.30)	6 (6.50)	4 (4.30)
Feel restless	40 (42.60)	28 (29.80)	12 (12.80)	14 (14.90)	36 (38.70)	31 (33.30)	12 (12.80)	14 (14.90)
Don’t follow through on instructions and fail to finish work	70 (74.50)	15 (16.00)	6 (6.40)	3 (3.20)	70 (75.30)	17 (18.30)	4 (4.30)	2 (2.20)
Have difficulty engaging in leisure activities or doing fun things quietly	69 (73.40)	16 (17.00)	6 (6.40)	3 (3.20)	65 (69.10)	18 (19.10)	8 (8.50)	2 (2.20)
Have difficulty organizing tasks and activities	59 (62.80)	25 (26.60)	7 (7.40)	3 (3.20)	62 (69.90)	20 (21.50)	7 (7.50)	4 (4.30)
Feel “on the go” or “driven by a motor”	36 (38.30)	28 (29.80)	11 (11.70)	19 (20.20)	38 (40.90)	25 (26.80)	11 (11.80)	19 (20.40)
Avoid, dislike, or feel reluctant to engage in work that requires sustained mental effort	51 (54.30)	25 (26.60)	9 (9.60)	9 (9.60)	48 (51.60)	24 (25.80)	15 (16.10)	6 (6.50)
Talk excessively	41 (43.60)	30 (31.90)	10 (10.60)	13 (13.08)	41 (44.10)	30 (32.30)	13 (14.00)	9 (9.70)
Lose things necessary for tasks and activities	63 (67.00)	21 (22.30)	4 (4.30)	6 (6.40)	56 (60.20)	25 (26.90)	8 (8.60)	4 (4.30)
Blurt out answers before questions have been completed	59 (62.80)	21 (22.30)	8 (8.50)	6 (6.40)	63 (67.70)	22 (23.70)	6 (6.50)	2 (2.20)
Easily distracted	27 (28.70)	35 (37.20)	15 (16.00)	17 (18.10)	35 (37.60)	28 (29.80)	12 (12.90)	18 (19.40)
Have difficulty awaiting my turn	63 (67.00)	15 (16.00)	10 (10.60)	6 (6.40)	67 (72.00)	15 (16.10)	8 (8.60)	3 (3.20)
Forgetful in daily activities	58 (61.70)	21 (22.30)	11 (11.70)	4 (4.30)	49 (53.80)	26 (28.60)	10 (11.00)	6 (6.60)
Interrupt or intrude on others	54 (57.40)	30 (31.90)	5 (5.30)	5 (5.30)	60 (64.50)	23 (24.70)	8 (8.60)	2 (2.20)

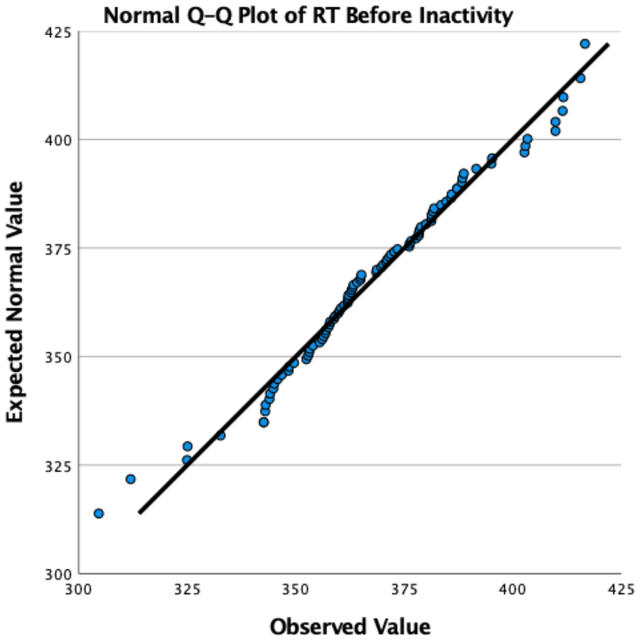
Note: 0 = Never or rarely; 1= Sometimes; 2 = Often; 3 = Very Often.

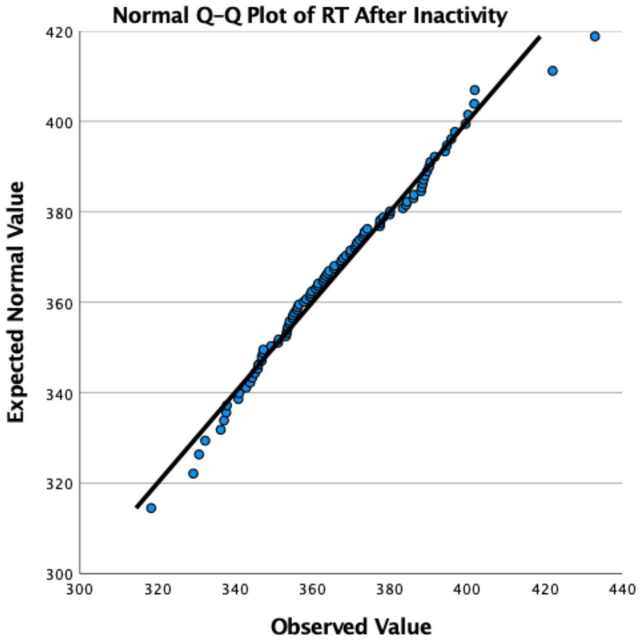
APPENDIX B: SUB-SAMPLE COUNTS (%) CHILDHOOD AND ADULT PAST 6 MONTHS BEHAVIOR RATING SCALE OFF MEDICATION

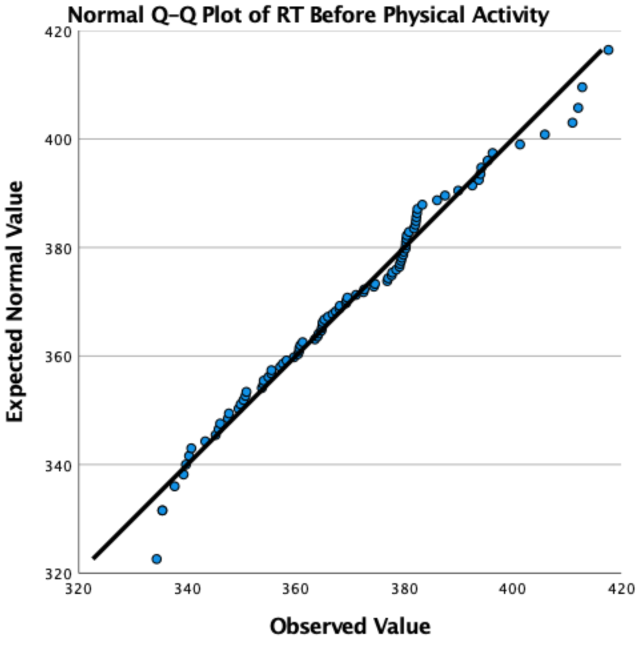
Measure	Childhood				Adult			
	0	1	2	3	0	1	2	3
Fail to give close attention to details or make careless mistakes in my work	39 (50.60)	28 (36.40)	6 (7.80)	4 (5.20)	49 (62.80)	20 (25.60)	7 (9.00)	2 (2.60)
Fidget with my hands or feet or squirm in my seat	18 (23.10)	23 (29.50)	18 (23.10)	19 (24.40)	22 (28.20)	25 (32.10)	13 (16.70)	18 (23.10)
Have difficulty sustaining my attention in tasks or fun activities	38 (48.70)	20 (25.60)	14 (17.90)	6 (7.70)	43 (55.10)	24 (30.80)	9 (11.50)	2 (2.60)
Leave my seat in situations in which remaining seated is expected	54 (69.20)	18 (23.10)	4 (5.10)	2 (2.60)	57 (73.10)	13 (16.70)	7 (9.00)	1 (1.30)
Don’t listen when spoken to directly	56 (71.80)	15 (19.20)	4 (5.10)	3 (3.80)	53 (67.90)	16 (20.50)	6 (7.70)	3 (3.80)
Feel restless	32 (41.00)	21 (26.90)	11 (14.10)	14 (17.90)	30 (38.50)	24 (30.80)	11 (14.10)	13 (16.70)
Don’t follow through on instructions and fail to finish work	58 (74.40)	12 (15.40)	6 (7.70)	2 (2.60)	58 (74.40)	15 (19.20)	4 (5.10)	1 (1.30)
Have difficulty engaging in leisure activities or doing fun things quietly	56 (71.80)	15 (19.20)	5 (6.40)	2 (2.60)	53 (67.90)	17 (21.80)	7 (9.00)	1 (1.30)
Have difficulty organizing tasks and activities	47 (60.30)	22 (28.20)	7 (9.00)	2 (2.60)	51 (65.40)	18 (23.10)	6 (7.70)	1 (1.30)
Feel “on the go” or “driven by a motor”	28 (35.90)	24 (30.80)	10 (12.80)	16 (20.50)	30 (38.50)	22 (28.20)	9 (11.50)	17 (21.80)
Avoid, dislike, or feel reluctant to engage in work that requires sustained mental effort	40 (51.30)	21 (26.90)	9 (11.50)	8 (10.30)	40 (51.30)	18 (23.10)	15 (19.20)	5 (6.40)
Talk excessively	30 (38.50)	26 (33.30)	10 (12.80)	12 (15.40)	31 (39.70)	26 (33.30)	15 (19.20)	5 (6.40)
Lose things necessary for tasks and activities	50 (64.10)	19 (24.40)	4 (5.10)	5 (6.40)	46 (59.00)	21 (26.90)	8 (10.30)	3 (3.80)
Blurt out answers before questions have been completed	47 (60.30)	18 (23.10)	8 (10.30)	5 (6.40)	52 (66.70)	19 (24.40)	6 (7.70)	1 (1.30)
Easily distracted	21 (26.90)	27 (34.60)	15 (19.20)	15 (19.20)	30 (38.50)	20 (25.60)	11 (14.10)	17 (21.80)
Have difficulty awaiting my turn	52 (66.70)	12 (15.40)	10 (12.80)	4 (5.10)	57 (73.10)	11 (14.10)	8 (10.30)	2 (2.60)
Forgetful in daily activities	42 (53.80)	27 (34.60)	5 (6.40)	4 (5.10)	39 (50.90)	24 (31.20)	9 (11.70)	5 (6.50)
Interrupt or intrude on others	49 (62.80)	20 (25.60)	7 (9.00)	2 (2.60)	48 (61.50)	21 (26.90)	8 (10.30)	1 (1.30)

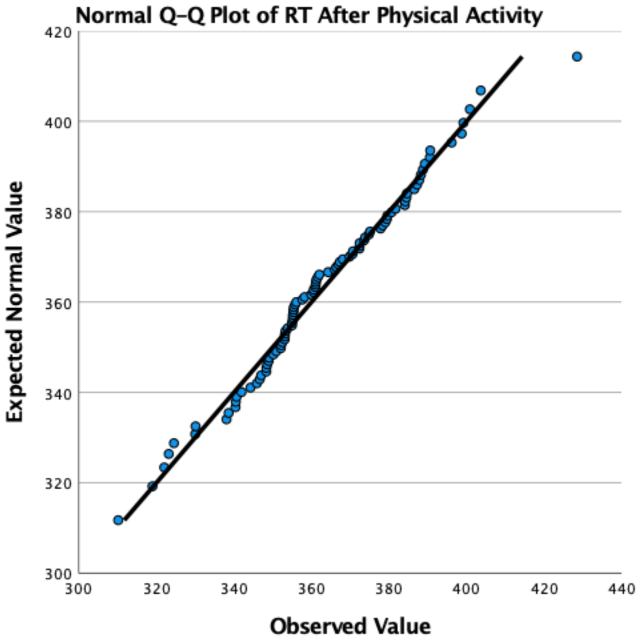
Note: 0 = Never or rarely; 1= Sometimes; 2 = Often; 3 = Very Often.

APPENDIX C: Q-Q PLOTS FOR CPT-X RT

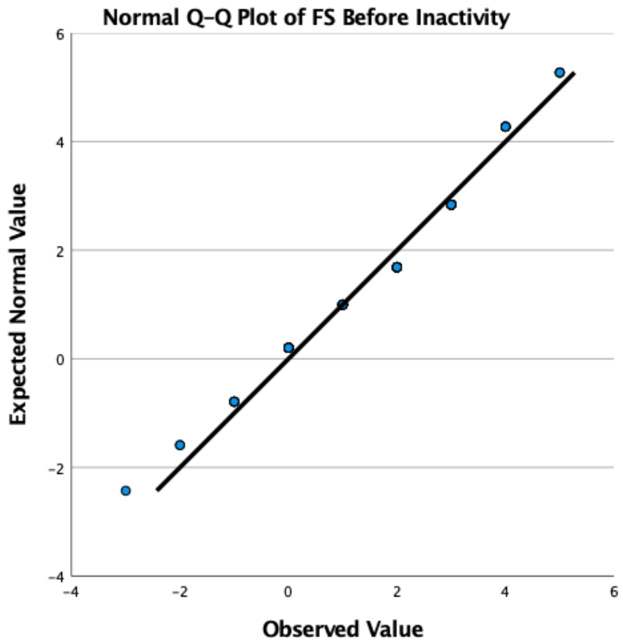


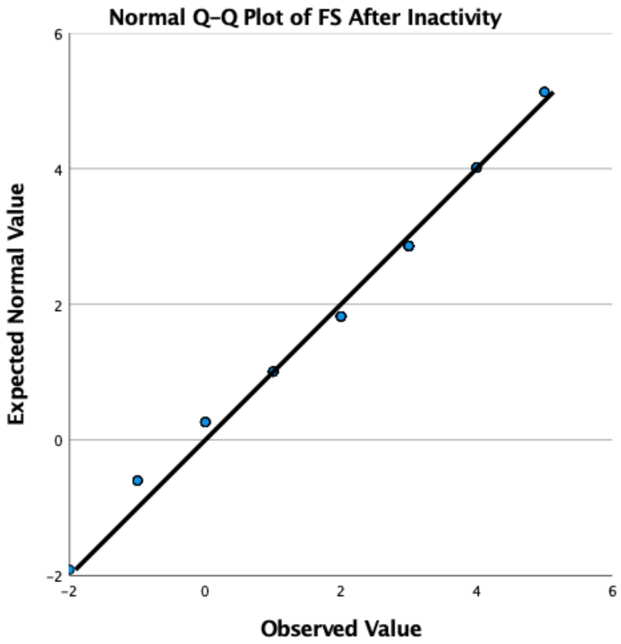


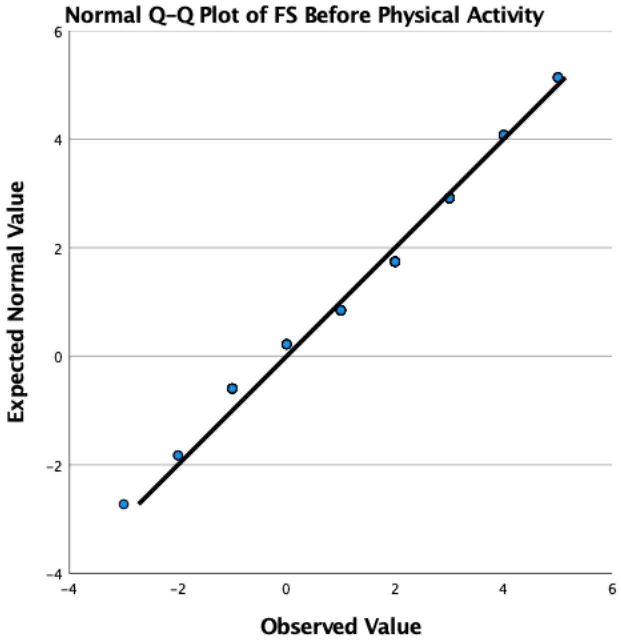


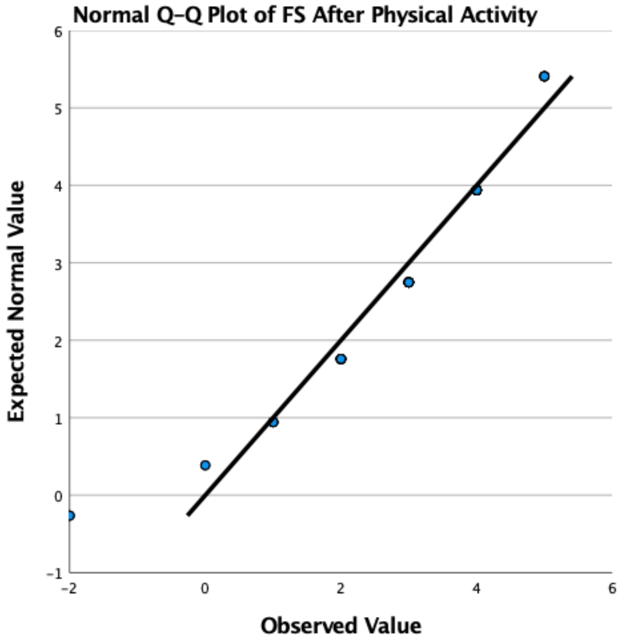


APPENDIX D: Q-Q PLOTS FOR FS

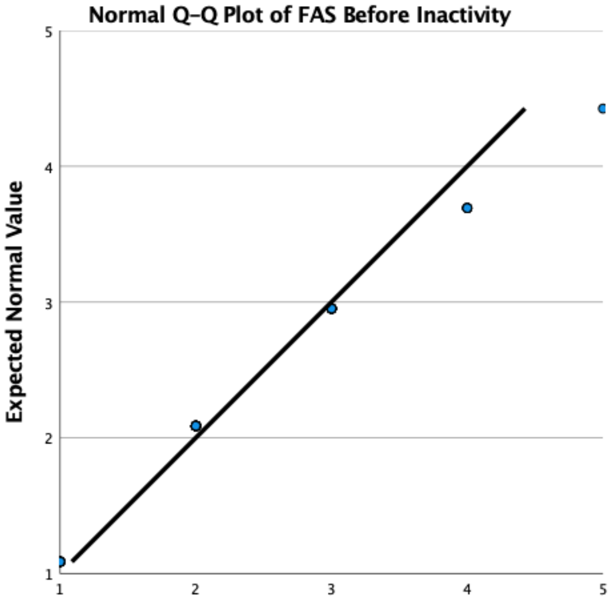


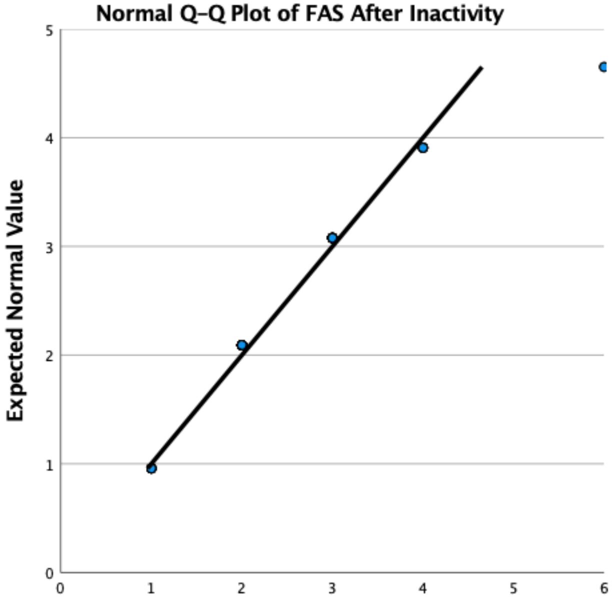


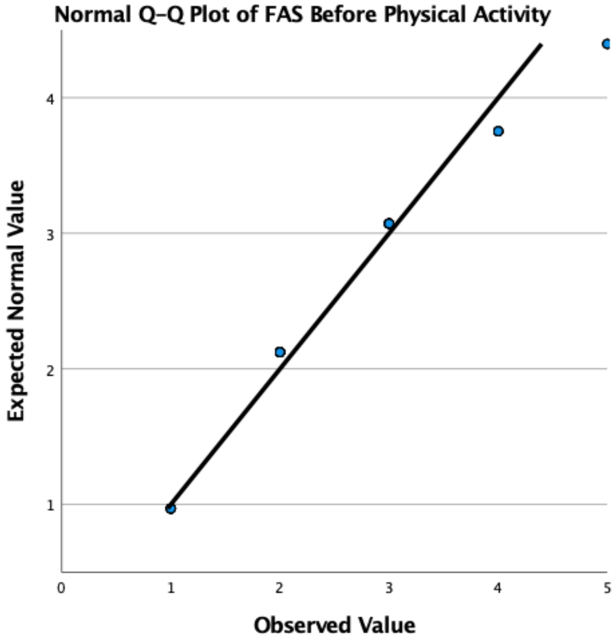




APPENDIX E: Q-Q PLOTS FOR FAS


Normal Q–Q Plot of FAS Before Inactivity


Normal Q–Q Plot of FAS After Inactivity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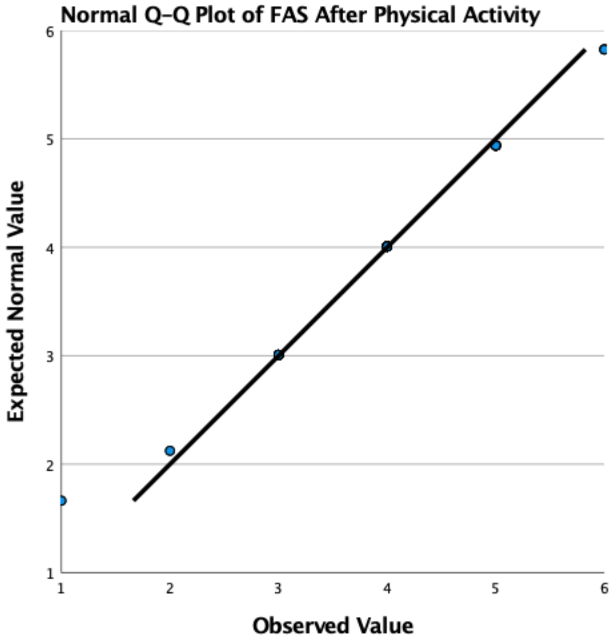
Normal Q–Q Plot of FAS After Physical Activity