EXAMINING PHYSICAL ACTIVITY MODE AND INTENSITY ON COGNITIVE FUNCTIONING IN YOUNG ADULTS

by

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The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, a thesis/dissertation entitled:

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Abstract

The effect of physical activity (PA) on cognition has long been recognized. However, despite a well-documented PA-cognition association in older adults and children, the effect of PA on cognitive functioning in young adults remains unclear. Further complicating the PA-cognition association is that as research in this field has expanded, different methodologies, interventions, and cognitive assessments have led to a diversity of findings and inconsistent results. Diversity in the protocol of PA-cognition studies has made direct comparison of results challenging because of the numerous known variables that moderate the PA-cognition relationship. Additionally, the intermediate period between the near and long-term timescales, particularly in this population, is an under-investigated area of research. Unfortunately, this unattended timeframe may prove vital in understanding why results are not systematically convergent. In this study we examine the PA-cognition relationship in young adults over seven-days while accounting for other covariates known to moderate the PA-cognition association. The aim of this work is to address how some of the variance in findings is related to PA mode and intensity, and to consider how interplay between age, sex, physical fitness, and sleep alter those relationships. In addition, we examine two broad aspects of cognitive function, attention and working memory, in order to compare directly the effect of PA on cognitive performance. Statistical analysis showed that PA plays an important role in a subset of cognitive processes, with a pronounced PA-cognition relationship at these intermediate periods. Additionally, we demonstrate that PA modes and intensities differentially effected cognitive processes, such that particular combinations of mode and intensity benefitted cognition processes selectively. Further, we have confirmed the importance of sex as an influential predictor of cognitive performance. Despite assessing theoretically similar cognitive processes, it is evident from the differential findings that the neurophysiological effects of PA may achieve neurocognitive gains selectively. Generally, these results suggest that PA is predictive of cognitive performance on attentional tasks, but little evidence supports gains in working memory in young adults at intermediate timescales.

Lay Summary

The effect of physical activity (PA) on cognition has long been recognized. In this study we examine the relationship between PA and attentional and working memory processes in young adults over seven-days. The aim of this work is to address how cognition is related to PA mode and intensity, and to consider how interplay between age, sex, physical fitness, and sleep alter those relationships. Analysis shows that PA is important for a subset of cognitive processes. Additionally, we demonstrate that particular combinations of mode and intensity benefit cognition processes. Further, we confirm the importance of sex as a predictor of cognitive performance. Because we observe differential effects of PA mode and intensity on cognitive performance, the neurophysiological effects of PA may achieve neurocognitive gains selectively. Generally, our results suggest that PA is predictive of cognitive performance on attentional tasks, but not of working memory, for young adults at intermediate timescales.

Preface

The presented work is original and unpublished. G. K. Gooderham wrote the manuscript with editorial and intellectual contributions provided by Todd Handy. The experiment was designed by the author and data collection was assisted by Jasmeen Dosanjh, Kim Jihyeon, and Sam Wong. Data analysis was conducted by G. K. Gooderham.

The experiment was approved by UBC Behavioural Research Ethics Board.
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List of Abbreviations

ANT	Attention Network Test
BDNF	Brain Derived Neurotrophic Factor
BMI	Body Mass Index
HIAT	High Intensity Aerobic Training
HIFT	High Intensity Flexibility Training
HIRT	High Intensity Resistance Training
IGF-1	Insulin-like Growth Factor 1
LIAT	Low Intensity Aerobic Training
LIFT	Low Intensity Flexibility Training
LIRT	Low Intensity Resistance Training
MET	Metabolic Equivalent of Task
MIAT	Moderate Intensity Aerobic Training
MIFT	Moderate Intensity Flexibility Training
MIRT	Moderate Intensity Resistance Training
PA	Physical Activity
RT	Reaction Time
SART	Sustained Attention to Response Task

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To Colleen,

With you I can be my best.

Chapter 1: Introduction

The effect of physical activity (PA) on cognition has long been recognized. As the global population becomes increasingly sedentary, concern has arisen for the deleterious consequences inactivity has on health. Estimates indicate that only 15% of the Canadian population meets Health Canada's recommendation of at least 150 minutes of PA per week (Colley et al., 2011). While this statistic is alarming for health practitioners who must combat the heightened risk of mortality in an increasingly unfit population, the effects of an inactive lifestyle have been closely linked with psychological function. Research has illustrated the important ways in which near (Chang, Labban, Gapin, & Etnier, 2012) and long-term PA (Smith et al., 2010) can have beneficial effects on cognitive performance. Additionally, children (Sibley & Etnier, 2003) and older adults (Northey, Cherbuin, Pumpa, Smee, & Rattray, 2018) are profoundly benefited by increased PA at both near and long-term timescales. However, it is less clear whether a lack of PA at intervening timeframes negatively impacts cognition. In this study we seek to explore the PA-cognition relationship in young adults at intermediate timescales.

Physical activity has been demonstrated as an effective method for improving cognitive performance in a number of ways. Behaviourally, PA acts on numerous cognitive domains (Cox et al., 2016) including executive control (Colcombe & Kramer, 2003), attentional alerting (Huertas, Zahonero, Sanabria, & Lupiáñez, 2011), and memory (Loprinzi, Frith, Edwards, Sng, & Ashpole, 2018). Neuroimaging studies have shown that improved cognitive performance resulting from PA is linked to neurophysiological changes in hippocampal volume (Kirk I. Erickson et al., 2011), gray and white matter volume (Colcombe et al., 2006), and functional connectivity between brain regions (Voelcker-Rehage & Niemann, 2013). Aerobic training results in improved functional connectivity between the frontal, posterior, and temporal components of the default mode network and the executive network of older adults, with causal links between increased connectivity in regions expected to be responsible for particular cognitive functions and better performance on those tasks (Voss et al., 2010). Additionally, researchers have identified the ways in which physical activity is a potent agent for inducing neurogenesis, neurotransmission, synaptogenesis, and angiogenesis (Berchicci, Lucci, & Di Russo, 2013; Vivar, Potter, & van Praag, 2012). PA has profound positive effects on neuroplasticity and thus brain health and cognitive performance (Colcombe et al., 2004; Hötting & Röder, 2013).

Nonetheless, some ambiguity still persists regarding the conditions which produce the greatest cognitive gains. Despite a well-documented PA-cognition association, similar experimental paradigms have not always provided convergent evidence of cognitive process specific benefits (Chang et al., 2012; Swagerman et al., 2015). As research in this field has expanded, different methodologies, interventions, and cognitive assessments have been used. The consequence of differences in experimental protocol is that as researchers continue to explore PA as a means of moderating cognition, the diversity of findings has led to inconsistent results (Sáez de Asteasu, Martínez-Velilla, Zambom-Ferraresi, Casas-Herrero, & Izquierdo, 2017). Diversity in the protocol of PA-cognition studies has made direct comparison of results challenging because of the numerous known variables that moderate the PA-cognition relationship. Factors including timescale (Etnier et al., 1997), the mode (Lambourne & Tomporowski, 2010; Sáez de Asteasu et al., 2017), duration (Chang et al., 2012), and intensity (Chang et al., 2012; Ploughman, 2008) of PA interventions, cognitive assessments (Cox et al., 2016; Guiney & Machado, 2013; Smith et al., 2010), and demographic variables such as age

(Cox et al., 2016; Fedewa & Ahn, 2011; Northey et al., 2018), sex (Barha, Davis, Falck, Nagamatsu, & Liu-Ambrose, 2017), and physical fitness (Colcombe et al., 2004) have all been demonstrated to play important roles in modulating the PA-cognition relationship, with interactions between them causing additional complications, meaning that while the literature continues to expand, ambiguity persists.

In this study we examine the PA-cognition relationship in young adults at an intermediate timescale while accounting for other covariates known to moderate the PA-cognition association. The aim of this work is to address how some of the variance in findings is related to PA mode and intensity, and to consider how interplay between additional factors alter those relationships.

1.1 Timescale

The timeframe in which PA has been investigated to act on cognition has been demonstrated to have repercussions on the efficacy of the intervention (Lambourne & Tomporowski, 2010; Swagerman et al., 2015). A common delineation is between the long-term and near-term effects of PA on cognition. Broadly, long-term studies investigate how the cumulative effects of increased PA over weeks or months impact cognitive function while near-term studies examine the consequences of acute or single bouts of PA. Long-term engagement in PA has been demonstrated to have significant positive effects on numerous cognitive processes, including inhibitory control (Colcombe et al., 2004), executive function (Colcombe & Kramer, 2003), and memory (Loprinzi et al., 2018). Similarly, acute bouts of PA have been shown to improve inhibitory control (Verburgh, Königs, Scherder, & Oosterlaan, 2014), executive functioning (Loprinzi & Kane, 2015), and working memory reaction time (RT; McMorris, Sproule, Turner, & Hale, 2011), though the temporal proximity of the cognitive assessment to the PA bout has been shown to be important to the outcome (Lambourne & Tomporowski, 2010). Each timescale has contributed to a growing body of literature recommending PA as a means of enhancing cognitive performance and neurological health. However, the intermediate period between the near and long-term timescales is an under-investigated area of research. Unfortunately, this unattended timeframe may prove vital in understanding the transition of near-term to long-term exercise effects.

Evidence supporting the necessity for examining this intermediate period has emerged in studies of neurotransmitters and neurotrophic factors. Neurogenesis in the hippocampus of rats provided opportunity for voluntary exercise has been demonstrated to be most pronounced three days following the addition of the running wheel to their environment (Fabel & Kempermann, 2008). Others have reported that brain derived neurotrophic factor (BDNF) is elevated two to seven days following aerobic activity (Neeper, Gómez-Pinilla, Choi, & Cotman, 1996) and that no difference in BDNF plasma concentration was found immediately following an exercise program from baseline (Zoladz et al., 2008). Additionally, the blocking of the reuptake of noradrenaline, an important neurotransmitter in the attentional network, was not found until five days following the PA intervention in rats, with no effect witnessed neither immediately after nor two days following the addition of a running wheel to the rat's habitat (Robinson, Buttolph, Green, & Bucci, 2015). Combined neurobiological evidence suggests that the effects of PA exist at periods not captured by the near- and long-term, and that the most significant benefit may not occur until at least the three-day mark. As research more thoroughly describes this relationship, inferences can be made about how near-term effects transition into the cumulative effects demonstrated in long-term studies.

Additionally, evidence has emerged that is supportive of interactions between timescale and PA mode and intensity on altering cognitive function. In a sample of young females working memory performance was impaired during maximal effort aerobic training but, was seen to improve following rest (Bue-Estes et al., 2008). In a meta-analysis of near-term PA on cognitive performance, Chang et al. (2012) found that intensity dictated the efficacy of the exercise intervention, such that higher intensities elicited a delayed constructive response while low intensity training produced positive cognitive effects immediately. Lambourne and Tomporowski (2010) observed that PA during cognitive assessment was typically associated with impaired performance on the task yet superior functioning following the PA intervention. Further, they identify distinct effects of PA mode on performance. Treadmill running impaired concurrent cognitive function but produced benefit following the cessation of the PA when in fact cycling was linked to benefits both during and following the intervention. Therefore, claims that the varying findings are the result of interactions between the cognitive assessment, the duration and intensity of the exercise paradigm (Brisswalter, Collardeau, & René, 2002) have been given additional credence. However, duration and intensity alone do not sufficiently explain the seemingly distinct findings as timescale and PA mode are additional mediating factors. Evidence of this nature supports the necessity to directly assess combinations of PA mode, duration, and intensity.

1.2 Age

Much like how cognitive functioning fluctuates over time, cognitive abilities change over the human lifespan. As the brain continues to mature from infancy through to adolescence, cognitive performance develops until it reaches a state of maximal functional ability in young adulthood (Craik & Bialystok, 2006; Walhovd et al., 2016). The human brain then begins to degrade in the third decade of life, with much of the loss seen in the frontal, parietal, and temporal lobes (Colcombe et al., 2006). However, PA has been shown to accelerate cognitive development and impede cognitive decline, providing neurotrophic and neuroprotective effects (Colcombe et al., 2003, 2006; Ploughman, 2008). In children, aerobic fitness has been linked to both changes in brain structure and function, as well as increased cognitive performance (Chaddock, Pontifex, Hillman, & Kramer, 2011). Further, neural plasticity has been observed following aerobic and resistance training interventions in older adult populations (Colcombe et al., 2004; Kirk I. Erickson et al., 2007; Liu-Ambrose, Nagamatsu, Voss, Khan, & Handy, 2012). Increasing aerobic activity levels in older adults has been associated with changes to brain structures that are consistent with the expected resultant improvement in cognitive performance (Bherer, Erickson, & Liu-Ambrose, 2013) suggesting a direct relationship between improved cognitive functioning and neurological structure.

Physical activity induced changes in brain structure have not been limited to older adult or adolescent populations. Thomas et al. (2016) found that following a six-week aerobic exercise intervention in young to middle aged adults anterior hippocampus volume had increased but, that after a further six-weeks had returned to baseline volume. The authors also note that angiogenesis had not changed but rather myelination had increased (Thomas et al., 2016). Voelcker-Rehage and Niemann (2013) found that coordinative exercise was not related to changes in white matter volume, despite increases in gray matter volume. Comparatively, they found that aerobic exercise may mitigate decline in myelination resulting from aging and that high-fit older adults had larger gray matter volumes, though evidence was not unanimous. In young adults gray matter volume is not associated with aerobic capacity, nor is aerobic capacity related to improved memory performance (Peters et al., 2009). The effect of PA on brain structure appears to be mediated by the age of the population investigated. Because the brain is at its peak during young adulthood PA may have a smaller and more selective effect on brain structure, connectivity, and cognitive functioning.

Despite evidence supporting the neuroplasticity of young adult brains, a comparative lack of studies in this population has resulted in a limited knowledge about the role of PA on cognitive functioning in young adults. A recent meta-analysis on the effect of PA on memory function in healthy young adults by Loprinzi et al. (2018) netted just fourteen studies. Ten of the studies demonstrated an improvement on some aspect of memory performance, though the seven reports assessing working memory were not unanimous in their support of the positive effects of PA. Similarly, Cox et al. (2016) reported only fourteen studies investigating executive function, memory, or processing speed in young adults, and note that while evidence supports PA as an effective means for improving cognitive performance, the limited body of research is inconsistent in its findings. While it is clear that research interest is increasing, both authors conclude that additional research is required in this age range, with specific attention paid to intensity, mode, and cognitive assessment. This study attempts to address these issues by explicitly comparing intensity and mode, as well as their combinations, on executive functioning, attention, and memory. Additionally, we consider the effect of moderating variables on these relationships and how they may be predictive of cognitive performance.

1.3 Other Covariates

While this study examines the effect of PA at an intermediate timescale and in a young adult population that is relatively understudied, numerous other factors have been identified as moderating the PA-cognition relationship. As emphasized previously, demographic factors including sex and physical fitness of the participant population have been found to be critical in the outcome of PA interventions. Further, cognitive assessments themselves are differently affected by PA. Therefore, consideration of these variables, and their impact on the PA-cognition association must be made. Below we will introduce these factors and provide a brief review of how these determinants mediate the PA-cognition interaction. In addition, we discuss the effectiveness of current theories, specifically the inverted U hypothesis (Brisswalter et al., 2002; Kashihara, Maruyama, Murota, & Nakahara, 2009), in explaining the effects of PA on cognitive performance.

Sex has been identified as a significant predictor of the efficacy of PA interventions on cognitive processing (Barha et al., 2017). In fact, researchers have identified biological differences in the response to PA (Baker et al., 2010; Kramer & Erickson, 2007). Females respond to aerobic function with increased plasma BDNF concentrations and better performance on executive function tasks, while men have elevated insulin-like growth factor 1 (IGF-1) levels with no observed executive function benefit (Baker et al., 2010). Estrogen interacts with the effects of increased PA resulting in greater BDNF concentrations in the hippocampus of ovariectomized rats than either intervention alone (Berchtold, Kesslak, Pike, Adlard, & Cotman, 2001), suggesting that estrogen may play a similar role to exercise in promoting neuroplasticity (Kramer & Erickson, 2007). However, Soga et al. (2015) conclude that sex has limited effect on the interaction between PA and executive function, though acknowledge the contradictory findings relative to other reports. Some have suggested that sex may vary the effectiveness of aerobic fitness and adiposity benefits on cognitive functioning (Pindus et al., 2015). Therefore, as with other moderating variables, interactions between sex and other demographic factors may be crucial in the PA-cognition relationship.

The physical fitness of study participants has been of considerable interest in this research domain. Studies have investigated the PA-cognition effect in populations ranging from unfit or untrained individuals to highly trained athletes (Huertas et al., 2011). However, as Zouhal et al. (2008) write, the widely varying fitness of the sample populations may be contributing to the different findings within PA-cognition research. Measures of physical fitness have included physiological measures such as VO_{2max} and Body Mass Index (BMI), and expanded to include both near and long-term questionnaire measures. BMI is a measure of tissue mass and is used as a coarse evaluation of an individual's physical fitness (Hagströmer, Oja, & Sjöström, 2006; Wiedemann, Calvo, Meister, & Spitznagel, 2014) and, compared to $VO_{2max,}$ is a simply calculated value requiring only an individual's height and weight. Despite the simplicity of the measure, BMI still provides a useful measure of a participant's physical activity level (Du et al., 2013) and has been associated with cognitive performance. In a study of lean and obese young adults categorized by BMI, Wiedemann et al. (2014) found that lean young adults outperformed obese young adults on attention and executive function tasks. They also report that as weekly energy expenditure increased, lean individuals RT decreased and obese individuals RT increased, suggesting that the cognitive effects of increased PA levels in young adults may be selective based on physical fitness.

However, effects of fitness on executive control and working memory have not been as easily demonstrated in young adults. High-fit young adults maintain better cognitive control during working memory tasks, whereas low-fit individuals must engage cognitive control processes more heavily (Keita Kamijo, O'Leary, Pontifex, Themanson, & Hillman, 2010), though working memory performance does not seem to be related to chronic aerobic training (Smith et al., 2010). The contrasting effects of fitness versus long-term interventions suggest that aspects of memory function differentially respond to PA. In fact, Stroth et al. (2009) found that in young adults, following a six-week aerobic exercise intervention, participants showed improved visuospatial memory but that no effect was found on selective attention or verbal memory. Therefore, the effects of PA and fitness on memory and attention may be more selective. Similarly, attentional processes are susceptible to intervention characteristics. Aerobic exercise interventions lasting greater than one month were associated with improved attention and processing speed (Smith et al., 2010). However, physical fitness does not affect alerting and orienting components of attentional processing (Pérez, Padilla, Parmentier, & Andrés, 2014). Boucard et al. (2012) found no effect of PA on executive control in young adults whereas Pérez et al. (Pérez et al., 2014) found that inhibitory control was greater in chronically active participants. Both working memory and attentional processes are selectively moderated by how PA and fitness are assessed.

Finally, sleep habits have been demonstrated to moderate cognitive performance (Astill, Van der Heijden, Van IJzendoorn, & Van Someren, 2012; Killgore, 2010; Lim & Dinges, 2010). Acute sleep deprivation has been found to impair RT and accuracy on complex attention tasks as well as measures of working memory (Lim & Dinges, 2010). However, the relationship between sleep, PA and cognitive functioning is less clear. In a study on how acute lifestyle behaviours impact exam performance, young adults were found to achieve better grades when reporting higher sleep quality and more aerobic PA (Ho, Kozik, Gooderham, & Handy, 2017). Sleep quantity and quality therefore are potent means by which cognitive performance is modulated.

1.4 Explanatory Theories

One overarching framework for understanding how PA impacts cognitive function is the inverted U hypothesis, which dictates that cognitive performance is a function of PA intensity, such that moderate intensity provides the greatest benefit while low and high intensities diminish the positive effects of PA. The hypothesis has been commonly cited as the mechanism by which PA moderates cognitive performance (Brisswalter et al., 2002; Kashihara et al., 2009; Lambourne & Tomporowski, 2010). As intensity increases, so does the exertion necessary to complete that same physical task. Using laboratory methods, exertion is relatively easily measured using heartrate or VO_{2max}. However, in field settings exertion can be difficult to measure as the tools required to accurately extract that data can be expensive, cumbersome, or inaccurate. Without the ability to directly quantify measures of exertion, scales have been devised to provide researchers and clinicians the means of assessing perceived exertion. The Borg Rating of Perceived Exertion Scale was designed to capture the perceived exertion levels (Borg, 1982), and others since have utilized the scale to produce quantitative scales of exertion as measured by ability to maintain the activity for a period of time (Norton, Norton, & Sadgrove, 2010). Perceived exertion is an important and useful means for extracting information pertaining to the intensity of PA without the need for direct measurement. For the purposes of this study, exertion and intensity were used synonymously.

The hypothesis can be extended to govern the relationship between cognition and duration, stating that optimal performance will be elicited at moderate intensities and intermediate durations. Short bouts of exercise interspersed throughout periods of long sitting have been shown to improve mood, decrease levels of fatigue, and increase self-reported levels of energy (Bergouignan et al., 2016). The same study however, did not report improved performance on a Flanker task from six 5-minute bouts of moderate intensity aerobic training, nor from a single 30-minute session. However, others have found evidence that a single 30-minute bout of aerobic activity in children is related to greater on-task attention (Kubesch et al., 2009), suggesting that even short doses of PA may provide cognitive benefit.

Finally, the inverted U hypothesis can be implemented in describing the association between cognitive performance and the temporal proximity of the cognitive assessment. In fact, acute aerobic exercise to maximal effort has been shown to have negative consequences for immediate working memory performance in young adult women, but improved working memory following recovery (Bue-Estes et al., 2008). However, in attentional tasks concurrent bouts of moderate and vigorous intensity aerobic training reduced alerting effects but did not moderate performance on orienting or executive control tasks (Huertas et al., 2011). It is therefore expected that changes in intensity, duration, and temporal proximity of PA have differential effects on select cognitive processes.

This study investigates the role of age, sex, physical fitness, sleep, and PA mode, duration, and intensity in the young adult population. In addition, we examine two broad aspects of cognitive function, attention and working memory, in order to compare directly the effect of PA on cognitive performance. It is anticipated that aerobic training will have beneficial effects on attention and working memory tasks. We expect that resistance training will be predictive of better performance on attentional tasks, while not related to working memory. In addition, flexibility training will not be related to performance on any measured aspect of cognitive performance. In accordance with the inverted U hypothesis, we hypothesize that moderate intensity training will be predictive of better scores on both the attentional and working memory tasks. However, high and low intensities will be related to better performance selectively.

Finally, we predict that supporting variables, specifically age and sex, will be associated with differential performance on outcome measures.

Chapter 2: Methods and Measures

2.1 Participants

One hundred and three participants were recruited using the University of British Columbia Department of Psychology's Human Subject Pool (85 female, 13 male, 5 undeclared; Mean age = 20.05; SD = 1.94) with remuneration provided in course credit. Six participants did not complete the Sustained Attention to Response Task (SART) or Sternberg Task and therefore they were withheld from analysis involving those measures (80 female, 12 male, 5 undeclared; Mean age = 20.01; SD = 1.94). Ethical approval was provided by the University of British Columbia Behavioural Research Ethics Board and all participants provided written informed consent.

2.2 Apparatus

Cognitive tasks were displayed on 19" LCD monitors at a resolution of 1280x1024 running the Windows 7 operating system. The open-source Cognitive Battery 3.2 (Ho, 2015/2018) software package was employed for data collection. Questionnaires completed on the day of cognitive testing utilized the same computers. Daily questionnaires were completed on participants personal computers. Qualtrics Survey Software ("Qualtrics," 2018) was used for questionnaire distribution and display.

2.3 Procedure

Participants were enrolled in the eight-day study. On Day 1, participants completed a demographic questionnaire and were given detailed instructions on how to complete the Daily

Exercise Questionnaire (DEQ; see below). Research assistants guided participants through a mock version of the DEQ, provided examples for each type of activity and intensity, and ensured participants were comfortable in answering the given questions. In the event that participants had a question during the course of the study, contact information for the researchers was provided. Participants were instructed to complete the questionnaire prior to going to bed each evening. In the event that they forgot to complete the questionnaire for the day they were instructed to complete it as soon as possible. On Days 1-7, the questionnaire was distributed at 20:30 each evening using Qualtrics Survey Software's Mailing List feature. Email addresses were confirmed by research assistants during the Day 1 session. Participants returned to the laboratory on Day 8 to complete the cognitive battery and physical activity questionnaires. The cognitive assessments, described below, were presented in random order and all tasks were completed in full prior to the beginning of the following task. After completing the cognitive assessments participants completed the DEQ, the International Physical Activity Questionnaire (IPAQ), the SIT-Q, and the Perceived Stress Scale. Participants were then debriefed by a Research Assistant.

2.4 Cognitive Measures

2.4.1 Attention Network Test

The Attention Network Test (ANT) is a form of the Eriksen Flanker Task designed to differentiate between three different components of the attentional network (Fan, McCandliss, Sommer, Raz, & Posner, 2002). Posner and Petersen (1990) posit that three major functions underlie attentional functioning: "(*a*) orienting to sensory events; (*b*) detecting signals for focal (conscious) processing, and (*c*) maintaining a vigilant or alert state" (p. 26). The ANT addresses each proposed component of the attentional network through different combinations of stimuli presentation. The ANT uses four cue conditions and six stimuli to assess functional ability of alerting, orienting and executive control. The cue and stimuli conditions are presented in Figure 1 along with an example of the presentation sequence and timing of the task. The stimuli presented are typical of the flanker task, where one central target arrow is flanked on either side by two distractor arrows, with the addition of a neutral condition where the flanking arrows are replaced by lines. The result is a row of five arrows. In the congruent condition the target arrow is either left or rightward facing and the flanking arrows share the same orientation. The incongruent condition differs in that the flanking arrows are oppositely oriented to the target arrow. The cues differ in the information that they provide to the participant in advance of the stimuli onset. In the no-cue condition a fixation cross is provided but no cue is given to warn of the imminent onset of the stimuli. The further three conditions alert the participant of the upcoming presentation of the stimuli. The central-cue replaces the fixation cross with a central asterisk, the double-cue places an asterisk both above and below the central fixation point, and the spatial-cue orients the participant to the location of the stimuli by providing an asterisk at the stimuli location.

A single trial began with the presentation of a fixation cross for 400-1600ms, followed by the display of the cue for 100ms. This was then followed by another fixation cross, displayed for 400ms, after which the stimulus was presented for up to 1700ms or until a response was recorded. Participants indicated the direction of the target arrow using the arrow keys on a keyboard. The RT was recorded in milliseconds as the time between the onset of the flanker stimulus and the response. Participants completed three sets of 96 trials, totaling 288 trials. Prior to testing, participants completed one practice block consisting of 24 trials.

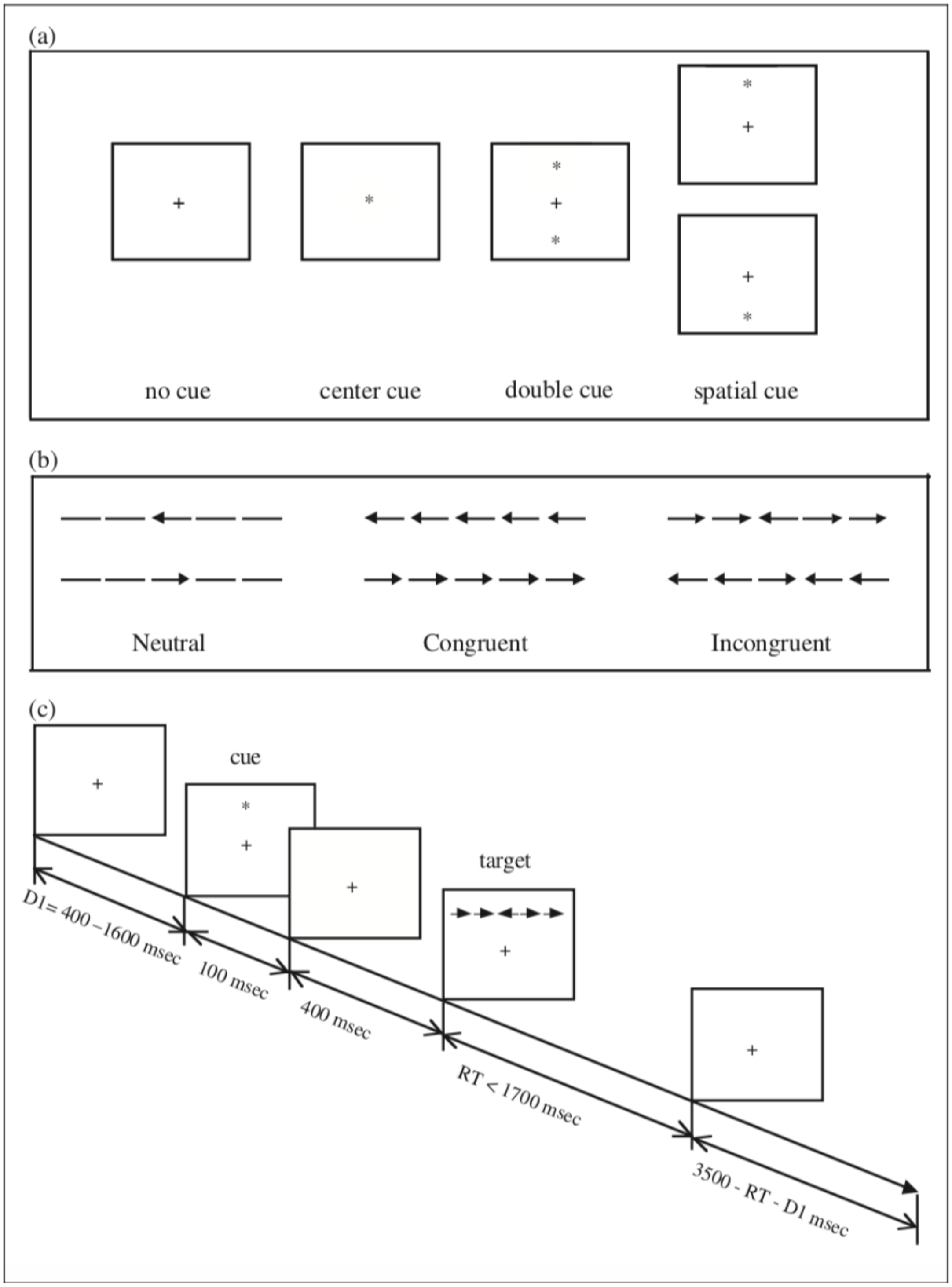

Figure 1. The Attention Network Test. "Experimental procedure. (a) The four cue conditions; (b) the six stimuli used in the present experiment; and (c) an example of the procedure." Reproduced from (Fan et al., 2002, p. 341).

2.4.2 Sustained Attention to Response Task

The Sustained Attention to Response Task assesses a participant's ability to sustain attention and monitor errors (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). In this testing paradigm, participants are presented with a series of numbers and are instructed to withhold a key press to a rare target item while making key presses for all other targets. The numbers 1-9 inclusive were presented in random order, with the number 3 designated as the withholding target. In total, participants responded to 225 trials, with each digit presented 25 times. Each digit was presented for 250ms and was followed by a 900ms masking image. Participants were instructed to respond as quickly and accurately as possible. One 10 trial practice session was provided to train participants and familiarize them with the testing procedure.

2.4.3 Backwards Digit-Span

The Backwards Digit-Span task is a test of "directed-attention abilities because participants must move items in and out of their attentional focus (Cowan, 2001), which is a major component of short-term memory (Jonides et al., 2008)" (Berman, Jonides, & Kaplan, 2008, p. 1208). Beginning with a three-digit sequence, participants were presented with a number sequence and instructed to enter the sequence in reverse order. As the task progressed, the sequence progressively increased in length until a nine-digit sequence was given with each sequence length repeated twice, resulting in fourteen trials. A response was coded as correct if the sequence was accurately recounted and was independent of sequence length. Each digit was presented for 1000ms with 100ms between digits. Participants were given as much time as required to provide a response.

2.4.4 Sternberg Task

The Sternberg Task is an assessment of working memory and assesses the ability of an individual to recall the contents of short term memory. Sternberg (1966), demonstrated that serial search was required to extract the contents of working memory, and that as the quantity of information increased, retrieval slowed. In this task a participant is shown either a two or six-digit number sequence then asked whether a probe digit was present in the sequence. Each digit in the sequence was presented for 1200ms with 250ms between digits. Participants were provided up to 2250ms upon onset of the probe to record their response.

2.5 Physical Activity Measures

2.5.1 Daily Exercise Questionnaire

The DEQ was comprised of nine questions assessing high, moderate, and low intensity across aerobic, resistance, and flexibility training modes. Participants responded by self-reporting the duration of PA for each combination of intensity and mode. In addition to the instruction provided on Day 1, definitions of intensity were stated in the questionnaire such that low intensity equated to a Rating of Perceived Exertion of 8-10, moderate 11-13, and high 14-20 (Borg, 1982; Norton et al., 2010). Finally, sleep quality and quantity were reported for the previous night on a Likert scale and duration item respectively.

2.5.2 International Physical Activity Questionnaire

The self-administered, long-form International Physical Activity Questionnaire (IPAQ) was completed by participants on the final day of the study. The IPAQ measures self-reported physical activity over the previous seven days and has high reliability and validity (Craig et al., 2003; Dinger, Behrens, & Han, 2006; Hagströmer et al., 2006), and is robust to differences in age, sex, and language (Wanner et al., 2016). Further, the IPAQ has been used as a measure of physical activity in numerous studies comparing the efficacy of physical activity on cognitive performance, including task switching (Kamijo & Takeda, 2010), spatial priming (Kamijo & Takeda, 2009), RT (Kamijo et al., 2009), response monitoring (Kamijo & Takeda, 2013), response inhibition (Wiedemann et al., 2014), and academic achievement (Marques, Santos, Hillman, & Sardinha, 2017; Pellicer-Chenoll et al., 2015; Zhang et al., 2015).

The IPAQ measures physical activity over the previous seven days across several domains of daily living, including job-related PA, transportation PA, housework, house maintenance, and caring for family PA, and recreation, sport, and leisure time PA. Participants report the daily totals of each activity and the number of days per week that they engage in that activity. Those values are then multiplied to produce a weekly total. Activities are categorized by type and intensity before being multiplied by Metabolic Equivalent of Task (MET) values corresponding to the exertion required to complete the task (Ainsworth et al., 2000). METs are calculated as 1.0 (4.184 kJ)$\bullet$kg$^{-1}\bullet$h^{-1}, and are used to assess the metabolic expenditure required to complete a task at a particular intensity, enabling for the comparison of energy consumption across PA modes, durations, and intensities (Ainsworth et al., 2000). The scoring protocol provides for the calculation of total vigorous, moderate, and walking METs along with total sitting time (The IPAQ Group, 2005).

The IPAQ was used as a validation measure of the DEQ and to provide a secondary measure of physical activity. A univariate regression was used to assess the degree to which high, moderate, and low intensity activity, assessed by the DEQ, correlated with vigorous, moderate, and walking METs measured with the IPAQ. High intensity training was significantly correlated with total vigorous METs, $r(101) = .24$, $p = .01$, moderate intensity training was not significantly correlated with moderate METs, $r(101) = .16$, $p = .10$, and low intensity training was significantly correlated with walking METs, $r(101) = .43$, $p < .001$. It is possible that a more analogous measure of walking METs is found with average low intensity aerobic training which was also found to be significant, $r(101) = .45$, $p <. 001$.

Chapter 3: Results

3.1 Regression Models

The goal of data analyses was to investigate the effect of PA duration on cognitive functioning while controlling for covariates. PA duration was categorized according to mode and intensity, allowing for the comparison of aerobic, resistance, and flexibility training, and high, moderate, and low intensities. Three regression models based on PA mode and intensity were tested on each cognitive variable. Model 1 examined average daily aerobic, resistance, and flexibility training. Model 2 tested average daily high, moderate, and low intensity training levels. Model 3 used average daily levels of high, moderate, and low intensity aerobic training, high, moderate, and low intensity resistance training, and high, moderate, and low intensity flexibility training. All models included six covariates: age, sex, BMI, total sitting time, and average sleep duration and quality for the period of the study. All models were predicted at an alpha of .05.

Wild Robust Regression was selected as the primary inferential test due to anticipated violations in normality, homoscedasticity, and multicollinearity. The Wild Robust Regression "implements a wild bootstrap under the robust regression framework using Huber's loss function and M-estimation" (Biesanz, 2018, p. 16, 2017/2018). Confidence intervals were calculated with casewise resampling and are provided as Biased Corrected and Accelerated (BC_a) at 95%. As a result of the implementation of different statistical methods to calculate *p* values and 95% CI's, discrepancies between inferences occurred (e.g. Sex in Model 3 ANT Executive Control).

3.2 Attention Network Test

The Attention Network Test assesses executive control, alerting, and orienting, by calculating the difference between the mean RT of two paired conditions (congruent vs. incongruent flankers, double-cue vs. no-cue, spatial-cue vs. central-cue respectively). Larger scores are indicative of a greater difference in mean RTs between the low (congruent flankers, double-cue, and spatial-cue) and high demand (incongruent flankers, no-cue, central-cue) conditions while a small value indicates greater similarity in RT between the conditions.

3.2.1 Executive Control

Contrary to previous research on executive control, we did not observe predictive relationships between PA mode nor PA intensity. However, nonsignificant trends suggest that both aerobic training and low intensity training may improve inhibitory control on executive control tasks. None of the models predicted a significant proportion of variance. In order to establish the validity of the executive control effect in our sample we conducted a paired samples t-test which revealed a significant difference between the congruent and incongruent conditions, $t(102) = -23.05$, $p < .001$. The data suggest that in spite of faster RT in the congruent condition when compared to the incongruent condition, the effect was not predicted by PA.

3.2.2 Alerting

The alerting effect was measured by comparing the mean RT of the double-cue to no-cue conditions. PA mode was a significant predictor of performance on the alerting component of the ANT. Our data show that resistance training was associated with better performance and smaller differences in mean RT between the double-cue and no-cue conditions, $\beta = -.32$, $t(85) = -3.30$, p

= .001, 95% CI [-.67, -.08], while flexibility training was predictive of larger differences between the two conditions $\beta = .42$, $t(85) = 5.05$, $p < .001$, 95% CI [.22, 1.00]. Model 1 also predicted a significant proportion of variance, $R^2_{adj} = 0.14$, $F(9, 85) = 2.64$, $p = .009$, indicating that the model predicts alerting scores. However, training at different intensities was not predictive of alerting scores. Despite support from Model 1 of the beneficial effect of resistance training and the deleterious effect of flexibility training, only moderate intensity resistance training was predictive of alerting effect in the final tested model, $\beta = -.29$, $t(79) = 2.81$, $p = .006$, 95% CI [-.87, .06]. Interestingly, moderate intensity training was not predictive of alerting effects in Model 2, suggesting that intensity is only predictive when coupled with resistance training. Our data demonstrates that without accounting for intensity, flexibility training impairs alerting performance. Neither Model 2 nor Model 3 predicted a significant proportion of variance. A manipulation check demonstrated a significant slowing in RT in the no-cue condition relative to the double-cue condition, $t(102) = -19.13$, $p < .001$.

Table 1. Attention Network Test - Model 1

						BCa 95% CI	
	β	*SE*	*t*(85)	*p*	*Resampling Pairwise β*	*LL*	*UL*
Age	-0.08	0.08	-1.05	.298	-0.03	-0.20	0.22
Sex	0.66	0.14	4.71	<.001	0.70	0.30	1.14
BMI	-0.01	0.06	-0.23	.819	-0.01	-0.16	0.15
Sleep Hours	-0.05	0.09	-0.59	.559	0.02	-0.21	0.30
Sleep Quality	0.09	0.08	1.14	.257	0.15	-0.01	0.36
Weekly Sitting Time	0.00	0.07	0.07	.946	0.04	-0.14	0.24
Aerobic Training	0.11	0.07	1.47	.146	0.07	-0.15	0.26
Resistance Training	-0.32	0.10	-3.30	.001	-0.35	-0.67	-0.08
Flexibility Training	0.42	0.08	5.05	<.001	0.50	0.22	1.00

Note. Sleep Hours, Sleep Quality, Aerobic Training, Resistance Training, and Flexibility Training, reported as average daily value. BMI = Body Mass Index.

Table 2. Attention Network Test Alerting - Model 3

						BCa 95% CI	
	β	*SE*	*t(79)*	*p*	*Resampling Pairwise β*	*LL*	*UL*
Age	-0.08	0.08	-1.01	.314	-0.02	-0.20	0.22
Sex	0.61	0.14	4.36	<.001	0.62	0.15	1.04
BMI	-0.02	0.06	-0.38	.706	-0.02	-0.19	0.17
Average Sleep Hours	-0.06	0.08	-0.80	.427	0.01	-0.22	0.32
Average Sleep Quality	0.09	0.07	1.26	.210	0.17	-0.02	0.37
Weekly Sitting Time	0.01	0.08	0.17	.867	0.06	-0.14	0.30
HIAT	0.10	0.11	0.93	.357	0.16	-0.12	0.49
MIAT	0.10	0.07	1.39	.168	0.09	-0.17	0.30
LIAT	0.00	0.08	0.00	1.000	-0.02	-0.26	0.18
HIRT	-0.05	0.11	-0.42	.676	-0.02	-0.35	0.41
MIRT	-0.29	0.10	-2.81	.006	-0.36	-0.87	0.06
LIRT	-0.06	0.09	-0.65	.517	-0.09	-0.38	0.16
HIFT	0.03	0.19	0.15	.881	0.03	-0.56	0.52
MIFT	0.26	0.17	1.53	.130	0.16	-0.32	0.59
LIFT	0.12	0.14	0.88	.382	0.30	-0.14	0.99

Note. Sleep Hours, Sleep Quality, Aerobic Training, HIAT, MIAT, LIAT, HIRT, MIRT, LIRT, HIFT, MIFT, and LIFT reported as average daily value.

3.2.3 Orienting

Spatial orienting was assessed by comparing the mean RT of the spatial-cue to the central-cue condition. No significant predictors were found in either Model 1, Model 2, or Model 3. To ensure that the null results were not an artifact of RT to the cue conditions a paired samples t-test was conducted. A significant difference in RT was observed between the two conditions, $t(102) = -9.59$, $p < .001$, indicating that despite the presence of an orienting effect, PA was not predictive of the effect. None of the models predicted a significant proportion of variance.

3.3 Sustained Attention to Response Task

Four different aspects of sustained attention and error monitoring were calculated with the SART responses: the proportion of errors, RT following an error, RT following a correct response, and mean RT. Each measure was independently analyzed with the three regression models and are reported below.

3.3.1 SART Mean RT

Aerobic training was associated with improved Mean RT scores in Model 1. Participants who reported more aerobic training demonstrated an increased ability to sustain attention and respond to the task stimuli, $\beta = -.12$, $t(79) = -2.40$, $p = .019$, 95% CI [-.32, -.01]. Neither resistance nor flexibility training were linked to Mean RT. In Model 2, high intensity training was predictive of increased Mean RT, $\beta = .24$, $t(79) = 3.01$, $p = .003$, 95% CI [.09, .64], while low intensity training was related to decreased Mean RT values, $\beta = -.13$, $t(79) = -2.80$, $p = .007$, 95% CI [-.30, .06]. As demonstrated in Model 1 and Model 2, sustained attention is modulated by both PA mode and intensity. When directly comparing the aerobic training intensity and SART Mean RT, high intensity aerobic training was predictive of longer RT, $\beta = .18$, $t(73) = 2.49$, $p = .015$, 95% CI [-.04, .49], while low intensity aerobic training was associated with reduced RT, $\beta = -.10$, $t(73) = -2.52$, $p = .014$, 95% CI [-.27, .10]. The model suggests that the observed relationships were not the result of either collapsing mode across intensity nor intensity across mode. Therefore, Mean RT was associated with dose specific responses to high intensity aerobic training and low intensity aerobic training. A significant proportion of variance was not predicted by any of the models.

Table 3. Sustained Attention to Response Task Mean Reaction Time - Model 2

						BCa 95% CI	
	β	*SE*	*t(79)*	*p*	*Resampling Pairwise β*	*LL*	*UL*
Age	-0.09	0.04	-2.41	.018	-0.07	-0.19	0.07
Sex	0.37	0.14	2.67	.009	0.37	-0.13	0.79
BMI	0.00	0.05	0.00	.996	-0.08	-0.46	0.09
Sleep Hours	0.04	0.05	0.80	.424	0.09	-0.17	0.33
Sleep Quality	0.03	0.06	0.50	.618	-0.01	-0.28	0.16
Weekly Sitting Time	-0.09	0.04	-2.18	.032	-0.01	-0.19	0.33
High Intensity Training	0.24	0.08	3.01	.003	0.32	0.09	0.64
Moderate Intensity Training	-0.13	0.09	-1.45	.150	-0.26	-0.69	0.00
Low Intensity Training	-0.13	0.05	-2.80	.007	-0.12	-0.30	0.06

Note. Sleep Hours, Sleep Quality, High Intensity Training, Moderate Intensity Training, and Low Intensity Training, reported as average daily value.

Table 4. Sustained Attention to Response Task Mean Reaction Time - Model 3

						BCa 95% CI	
	β	*SE*	*t(73)*	*p*	*Resampling Pairwise β*	*LL*	*UL*
Age	-0.09	0.04	-2.60	.011	-0.05	-0.18	0.18
Sex	0.32	0.13	2.38	.020	0.26	-0.50	0.72
BMI	-0.01	0.05	-0.14	.886	-0.08	-0.52	0.12
Average Sleep Hours	0.07	0.06	1.18	.241	0.13	-0.18	0.43
Average Sleep Quality	0.01	0.06	0.12	.907	-0.03	-0.31	0.17
Weekly Sitting Time	-0.08	0.05	-1.79	.078	0.02	-0.17	0.40
HIAT	0.18	0.07	2.49	.015	0.21	-0.04	0.49
MIAT	-0.04	0.06	-0.70	.488	-0.07	-0.33	0.13
LIAT	-0.10	0.04	-2.52	.014	-0.09	-0.27	0.10
HIRT	0.17	0.18	0.95	.344	0.01	-0.69	0.52
MIRT	-0.14	0.14	-1.02	.310	-0.12	-0.61	0.47
LIRT	0.02	0.04	0.37	.709	-0.04	-0.31	0.14
HIFT	0.03	0.14	0.23	.817	0.33	-0.24	1.69
MIFT	-0.07	0.10	-0.69	.491	-0.33	-0.98	0.07
LIFT	-0.10	0.08	-1.23	.222	0.01	-0.37	0.50

Note. Sleep Hours, Sleep Quality, Aerobic Training, HIAT, MIAT, LIAT, HIRT, MIRT, LIRT, HIFT, MIFT, and LIFT reported as average daily value.

3.3.2 SART Proportion of Errors

SART proportion of errors was predicted by PA mode. Flexibility training was a significant predictor of the proportion of errors in Model 1, $\beta = .25$, $t(79) = 2.19$, $p = .032$, 95% CI [-.23, .55]. We did not find support for an association between aerobic or resistance training and the proportion of errors in the task. Furthermore, intensity was not found to be predictive of errors committed. However, in Model 3 low intensity aerobic training, $\beta = .17$, $t(73) = 2.13$, $p = .037$, 95% CI [-.02, .40], significantly predicted participant's proportion of errors on the SART. Neither Model 1, Model 2, nor Model 3 were significant predictors of the proportion of variance.

Table 5. Sustained Attention to Response Task Proportion of Errors - Model 3

						BCa 95% CI	
	β	*SE*	*t(73)*	*p*	*Resampling Pairwise β*	*LL*	*UL*
Age	-0.01	0.11	-0.09	.927	-0.04	-0.30	0.19
Sex	-0.50	0.25	-2.04	.044	-0.51	-1.05	0.27
BMI	-0.08	0.11	-0.67	.507	-0.05	-0.27	0.24
Average Sleep Hours	-0.12	0.10	-1.16	.252	-0.11	-0.36	0.14
Average Sleep Quality	-0.12	0.11	-1.06	.294	-0.11	-0.33	0.14
Weekly Sitting Time	0.06	0.11	0.57	.572	0.01	-0.23	0.24
HIAT	-0.07	0.17	-0.44	.663	-0.08	-0.45	0.29
MIAT	-0.14	0.11	-1.20	.235	-0.15	-0.40	0.13
LIAT	0.17	0.08	2.13	.037	0.19	-0.02	0.40
HIRT	-0.13	0.22	-0.60	.550	-0.16	-0.67	0.39
MIRT	0.10	0.18	0.55	.581	0.14	-0.39	0.69
LIRT	-0.13	0.10	-1.34	.184	-0.12	-0.41	0.14
HIFT	0.13	0.22	0.61	.544	0.22	-0.32	0.89
MIFT	0.18	0.21	0.82	.415	0.15	-0.44	0.61
LIFT	0.02	0.16	0.13	.899	-0.07	-0.57	0.34

Note. Sleep Hours, Sleep Quality, Aerobic Training, HIAT, MIAT, LIAT, HIRT, MIRT, LIRT, HIFT, MIFT, and LIFT reported as average daily value.

3.3.3 SART RT Following an Error

Our data show that neither PA mode nor intensity relate to RT following an error (see Appendices for complete models and results). In addition, none of the models predicted a significant proportion of variance.

3.3.4 SART RT Following a Correct Response

PA mode was not predictive of RT following a correct response. However, RT following a correct response slowed with increased high intensity training, $\beta = .31$, $t(79) = 2.95$, $p = .004$, 95% CI [.07, .68], and accelerated with low intensity training, $\beta = -.16$, $t(79) = -2.63$, $p = .010$, 95% CI [-.38, .00]. In spite of the null PA mode predictors in Model 1, aerobic training, when partitioned by intensity, was predictive of RT following a correct response. High intensity aerobic training, $\beta = .30$, $t(73) = 2.64$, $p = .010$, 95% CI [-.01, .63], and low intensity aerobic training, $\beta = -.13$, $t(73) = -2.35$, $p = .021$, 95% CI [-.34, .06], were significant predictors in Model 3. The pattern of findings was consistent with those seen in Model 2 and demonstrate that high intensity aerobic training slowed RT and low intensity aerobic training accelerated RT. In addition, the findings are accordant with those of the SART Mean RT. Again, none of the models predicted a significant proportion of variance.

Table 6. Sustained Attention to Response Task Reaction Time Following an Error - Model 2

	β	*SE*	*t(79)*	*p*	*Resampling Pairwise* β	BCa 95% CI	
						LL	*UL*
Age	-0.10	0.08	-1.20	.233	-0.09	-0.28	0.09
Sex	0.54	0.21	2.63	.01	0.54	-0.29	1.03
BMI	0.00	0.07	-0.01	.994	-0.03	-0.31	0.15
Sleep Hours	0.06	0.08	0.81	.422	0.09	-0.17	0.33
Sleep Quality	-0.03	0.09	-0.27	.787	-0.06	-0.28	0.15
Weekly Sitting Time	-0.02	0.07	-0.29	.774	0.02	-0.18	0.29
High Intensity Training	0.09	0.12	0.77	.445	0.11	-0.23	0.44
Moderate Intensity Training	-0.07	0.15	-0.46	.649	-0.13	-0.49	0.22
Low Intensity Training	-0.13	0.08	-1.70	.093	-0.13	-0.34	0.09

Note. Sleep Hours, Sleep Quality, High Intensity Training, Moderate Intensity Training, and Low Intensity Training, reported as average daily value. BMI = Body Mass Index.

Table 7. Sustained Attention to Response Task Reaction Time Following A Correct Response - Model 3

	β	*SE*	*t(73)*	*p*	*Resampling Pairwise* β	BCa 95% CI	
						LL	*UL*
Age	-0.06	0.06	-1.11	.272	-0.06	-0.22	0.14
Sex	0.28	0.18	1.60	.114	0.21	-0.69	0.74
BMI	-0.01	0.06	-0.18	.857	-0.09	-0.59	0.14
Average Sleep Hours	0.09	0.07	1.23	.222	0.10	-0.29	0.37
Average Sleep Quality	0.06	0.10	0.57	.567	0.04	-0.30	0.28
Weekly Sitting Time	-0.09	0.07	-1.30	.197	0.01	-0.20	0.41
HIAT	0.30	0.11	2.64	.010	0.31	-0.01	0.63
MIAT	-0.03	0.08	-0.34	.737	-0.05	-0.36	0.18
LIAT	-0.13	0.05	-2.35	.021	-0.14	-0.34	0.06
HIRT	0.27	0.25	1.08	.285	0.15	-0.57	0.77
MIRT	-0.25	0.20	-1.27	.210	-0.22	-0.72	0.45
LIRT	0.00	0.06	0.07	.943	-0.05	-0.39	0.16
HIFT	-0.05	0.17	-0.26	.792	0.14	-0.40	1.08
MIFT	-0.12	0.13	-0.94	.352	-0.26	-0.73	0.16
LIFT	-0.03	0.12	-0.23	.821	0.04	-0.37	0.41

Note. Sleep Hours, Sleep Quality, Aerobic Training, HIAT, MIAT, LIAT, HIRT, MIRT, LIRT, HIFT, MIFT, and LIFT reported as average daily value.

3.4 Backwards Digit Span Proportion of Correct Responses

No effect of PA was found for accuracy on the Backwards Digit Span Task. None of the models predicted a significant proportion of variance.

3.5 Sternberg Task

The mean RT for the two-digit sequence was subtracted from the six-digit sequence, providing a single value indicating the difference in serial memory search time. A small value indicates less difference between the two and six-digit sequence RT, while a large score indicates a greater disparity in retrieval length. None of the tested predictors were significant in Models 1 or 2. However, high intensity flexibility training was a significant predictor of longer serial search times during the Sternberg Task, $\beta = .35$, $t(73) = 2.15$, $p = .035$, 95% CI [-.21, .80]. Neither Model 1, Model 2, nor Model 3 predicted a significant proportion of variance. A paired samples t-test revealed a significant difference in RT between the two conditions $t(97) = -10.16$, $p < .001$, such that mean RT for the six-digit sequence was greater than the two-digit sequence.

3.6 Covariates

Only one covariate consistently predicted cognitive performance. Sex was a significant predictor of performance on ANT executive control, ANT alerting, SART mean RT, SART proportion of errors, SART RT following an error, SART RT following a correct response (Model 2), and Backwards Digit Span proportion of correct responses. A Welch's t-test was conducted to determine if cognitive performance varied systematically by sex. The test confirmed that ANT executive control, ANT alerting, SART proportion of errors, and SART RT following an error all differed between the sexes. While this helps explain why sex emerged as a predictor on seven cognitive processes, it does not explain the predictive nature on the assessments that did not differ statistically between males and females.

Executive control was predicted in each of the three tested models by sex, $\beta = .51$, $t(85) = 2.45$, $p = .016$, 95% CI [.09, 1.22]; $\beta = .47$, $t(85) = 2.32$, $p = .023$, 95% CI [.07, 1.14]; $\beta = .49$, $t(79) = 2.29$, $p = .025$, 95% CI [-.04, 1.23]. Sex was also predictive of alerting scores in Model 1, $\beta = .66$, $t(85) = 4.71$, $p < .001$, 95% CI [.30, 1.14], Model 2, $\beta = .75$, $t(85) = 4.28$, $p < .001$, 95% CI [.36, 1.46], and Model 3, $\beta = .61$, $t(79) = 4.36$, $p < .001$, 95% CI [.15, 1.04]. However, orienting was not predicted by sex in any of the models. None of the other covariates predicted performance on the executive control, alerting, or orienting components of the Test.

In both Model 1 and Model 2, SART mean RT was significantly predicted by sex and weekly sitting. As with performance on executive control and alerting, females were typically outperformed by males such that males had faster responses to non-target stimuli, Model 1: $\beta = .37$, $t(79) = 2.38$, $p = .020$, 95% CI [-.25, .76]; Model 2: $\beta = .37$, $t(79) = 2.67$, $p = .009$, 95% CI [-.13, .79]. Unexpectedly, as weekly sitting increased, RT decreased, Model 1: $\beta = -.11$, $t(79) = -2.32$, $p = .023$, 95% CI [-.22, .29]; Model 2: $\beta = -.09$, $t(79) = -2.18$, $p = .032$, 95% CI [-.19, .33]. However, in Model 2 Age was also found to be a significant predictor of mean RT, such that as age increased, RT decreased, $\beta = -.09$, $t(79) = -2.41$, $p = .018$, 95% CI [-.19, .07]. In the final model the relationship between mean RT and age, $\beta = -.09$, $t(73) = -2.60$, $p = .011$, 95% CI [-.18, .18], and sex, $\beta = .32$, $t(73) = 2.38$, $p = .020$, 95% CI [-.50, .72], held, though weekly sitting was no longer significant.

The SART proportion of errors was also predicted by sex in all three models, Model 1: $\beta = -.63$, $t(79) = -2.73$, $p = .008$, 95% CI [-1.15, .00]; Model 2: $\beta = -.56$, $t(79) = -2.69$, $p = .009$, 95% CI [-1.05, .02]; Model 3: $\beta = -.50$, $t(73) = -2.04$, $p = .044$, 95% CI [-1.05, .27]. RT following an error was also significantly predicted by sex in all three models, $\beta = .53$, $t(79) = 2.37$, $p = .020$, 95% CI [-.30, 1.06]; $\beta = .54$, $t(79) = 2.63$, $p = .010$, 95% CI [-.29, 1.03]; $\beta = .57$, $t(73) = 2.78$, $p = .007$, 95% CI [-.36, 1.06]. The observed data pattern may be an expression of speed-accuracy trade-offs. Across all three models, females demonstrated a slowing of post-error response. The finding is consistent with prior work suggesting that females exhibit better post-error monitoring and emphasize accuracy rather than speed. Combined with the SART mean RT results, this study furthers supports the speed-accuracy trade-off reported in attention literature. While males responded faster, they were more prone to errors than females. Finally, sex was predictive of SART RT following a correct response, $\beta = .38$, $t(79) = 2.02$, $p = .047$, 95% CI [-.27, .84].

On working memory tasks, sex was a significant predictor of the proportion of correct responses in the three tested models, $\beta = -.57$, $t(85) = -2.54$, $p = .013$, 95% CI [-1.17, .03]; $\beta = -.63$, $t(85) = -2.48$, $p = .015$, 95% CI [-1.13, .12]; $\beta = -.67$, $t(79) = -3.09$, $p = .003$, 95% CI [-1.28, .02]. Task accuracy on the working memory task is opposite to the sustained attention task, as being female was predictive of committing more errors on the Backwards Digit Span than being male. Though our data show a consistent relationship between sex and the proportion of correct responses on the Backwards Digit Span Task, no covariates were predictive of Sternberg effects.

Table 8. Sex Beta Coefficients in All Models

							BCa 95% CI	
	Model	*β*	*SE*	*t*	*p*	*Resampling Pairwise β*	*LL*	*UL*
ANT Executive Control	1	0.51	0.21	2.45	.016	0.64	0.09	1.22
	2	0.47	0.20	2.32	.023	0.55	0.07	1.14
	3	0.49	0.21	2.29	.025	0.59	-0.04	1.23
ANT Alerting	1	0.66	0.14	4.71	<.001	0.70	0.30	1.14
	2	0.75	0.17	4.28	<.001	0.87	0.35	1.46
	3	0.61	0.14	4.36	<.001	0.62	0.15	1.04
ANT Orienting	1	0.19	0.23	0.80	.427	0.23	-0.37	0.99
	2	0.17	0.22	0.79	.429	0.21	-0.37	0.90
	3	0.21	0.21	1.01	.315	0.25	-0.38	1.01
SART Mean RT	1	0.37	0.15	2.38	.020	0.35	-0.25	0.76
	2	0.37	0.14	2.67	.009	0.37	-0.13	0.79
	3	0.32	0.13	2.38	.020	0.26	-0.50	0.72
SART Proportion of Errors	1	-0.63	0.23	-2.73	.008	-0.63	-1.15	0.00
	2	-0.56	0.21	-2.69	.009	-0.56	-1.05	0.02
	3	-0.50	0.25	-2.04	.044	-0.51	-1.05	0.27
SART RT Following An Error	1	0.53	0.23	2.37	.020	0.52	-0.30	1.06
	2	0.54	0.21	2.63	.010	0.54	-0.29	1.03
	3	0.57	0.20	2.78	.007	0.55	-0.36	1.06
SART RT Following A Correct Response	1	0.36	0.21	1.70	.093	0.32	-0.53	0.80
	2	0.38	0.19	2.02	.047	0.35	-0.27	0.84
	3	0.28	0.18	1.60	.114	0.21	-0.69	0.74
Backwards Digit Span Proportion of Correct Responses	1	-0.57	0.22	-2.54	.013	-0.52	-1.17	0.03
	2	-0.63	0.25	-2.48	.015	-0.53	-1.13	0.12
	3	-0.67	0.22	-3.09	.003	-0.60	-1.28	0.02
Sternberg	1	-0.08	0.24	-0.33	.740	-0.03	-0.89	0.59
	2	0.05	0.20	0.25	.803	0.10	-0.59	0.69
	3	0.06	0.22	0.28	.782	0.12	-0.74	0.76

Chapter 4: Discussion

In this study we sought to explore the PA-cognition relationship in young adults at intermediate timescales. We examined two broad aspects of cognitive function, attention and working memory, and their relation to PA mode, duration, and intensity in a young adult population while accounting for the covariates of age, sex, physical fitness and sleep over a seven-day period. Statistical analysis showed that PA plays an important role in a subset of cognitive processes between the near and long-term periods, with pronounced PA-cognition relationships at intermediate periods. Additionally, we demonstrate that PA modes and intensities differentially effected cognitive processes, such that particular combinations of mode and intensity benefitted cognition processes selectively. Further, we have confirmed the importance of sex as an influential predictor of cognitive performance in seven of nine measured tasks. Generally, these results suggest that PA is predictive of cognitive performance on attentional tasks, but little evidence supports gains in working memory in young adults at intermediate timescales.

4.1 Selective Cognitive Effects

We provide evidence of a relationship between attentional functioning and PA but not working memory and PA. Therefore, the observed pattern of results indicate that PA does not uniformly benefit cognition but instead selectively promotes a subset of cognitive processes. When taken broadly, this study provides evidence for the association between PA and attentional function. However, it should be noted that not all aspects of attentional performance responded identically, likely suggesting the selective benefits of PA on attentional processes. Consistent with the selective benefits of PA on alerting effects on the ANT, we found a link between PA levels and particular cognitive processes assessed by the SART. Mean RT, RT following a correct response, and the proportion of errors were all linked to PA suggesting that PA may accentuate the speed-accuracy trade-off. One particularly evident example of the discriminatory effect of PA on cognition is the selective improvement of alerting but not of executive control or orienting. Our data suggest that executive control is not predicted by PA. However, others have reported that a two week sprint interval training intervention resulted in a significant improvement in the executive control component of the ANT, but did not affect alerting or orienting scores (de Sousa et al., 2018). The same improvement was not seen in our sample despite confirmation of the executive control and orienting effects. That no predictors proved significantly related to orienting effects is unsurprising. In three separate studies utilizing the ANT, neither de Sousa et al. (2018), Huertas et al. (2011) nor Pérez et al. (2014) found effects of PA on orienting despite effects on executive control or alerting. Interestingly, we report that sex was not a predictor of the orienting effect in spite of the relationships seen on the other attentional measures.

While PA was related to a selective benefit for a subset of attentional processes, the same advantages were not observed for working memory tasks. Across both the Sternberg Task and the Backwards Digit Span Task we report limited associations between working memory and PA. These findings are consistent with other investigations on working memory which have shown little support for enhancement due to acute PA interventions (Alves et al., 2014; Chang et al., 2012; Keita Kamijo et al., 2010). Further, these results align with previous research using an *n*-back task, where no effect of PA was found (Hogan, Mata, & Carstensen, 2013) along with other meta-analysis that has suggested that acute moderate intensity PA could have low to moderate detrimental effects on working memory accuracy (McMorris et al., 2011). Despite this, others have reported beneficial effects of PA on working memory tasks (Cox et al., 2016; Guiney & Machado, 2013; Loprinzi et al., 2018). It is possible that due to the comparison of PA at different levels of intensity and mode, the broader link between PA and working memory performance was rendered insignificant. This seems most likely given the increases in IGF-1 and BDNF concentrations in the hippocampus resulting from aerobic and resistance training (Cassilhas et al., 2012).

4.2 Differential Effects of Physical Activity Mode and Intensity

Consistent with the selective effects of PA on a subset of cognitive processes, PA mode and intensity differentially effect cognitive performance on tasks. Therefore, three inferences about how cognitive processes are discriminately affected by intensity and mode can be made. First, intensity alone was predictive of cognitive benefits in only two cognitive assessments. For both SART mean RT and SART RT following a correct response, high intensity training was associated with diminished performance while low intensity training was linked to faster RTs. While evidence suggests that intensity on acute bouts of PA is impactful on near-term cognitive performance (Chang et al., 2012; Kashihara et al., 2009; Lambourne & Tomporowski, 2010), it would also appear meaningful at the intermediate timescale for mean RT and RT following a correct response. However, because intensity independent of modality was not predictive of cognitive performance on the other seven cognitive processes, it appears less important than other aspects of PA. Due to the extended recovery period following PA afforded in this study compared to acute paradigms, specific intensity effects may have been mitigated. Nonetheless, we show that specific combinations of intensity and mode are predictive of both improvements and impairments to cognitive processing relative to other modality and intensity combinations.

Therefore, we suggest that while intensity is undoubtedly impactful on some cognitive processes, mode may be of greater consequence.

Second, resistance and aerobic training produce benefits to cognitive performance differently. In rats, aerobic training was associated with increased BDNF release, whereas resistance training activated IGF-1 pathways (Cassilhas et al., 2012). These findings are further corroborated by Dinoff et al. (2016), who found that following exercise interventions BDNF concentrations were higher but only in aerobic conditions, with no change found in the resistance training conditions. BDNF has been found to be an important moderator of hippocampal decline (K. I. Erickson et al., 2010), so it is surprising that no significant relationships between aerobic PA and working memory were observed. However, Alves et al. (2014) found that an acute bout of high intensity aerobic training resulted in improved selective attention in a Stroop task but, that the same PA intervention failed to elucidated a response in the Backwards Digit Span Task.

Grip strength, a general measure of isometric strength, is related to better RT, reasoning, and visual, number, and prospective memory in adult populations (Firth et al., 2018). However, neither result was borne out in this study. Instead, resistance training was only found to be predictive of improved alerting effects and not of an increase in working memory. Peripheral BDNF concentrations are not elevated by resistance training (Cassilhas et al., 2012; Huang, Larsen, Ried-Larsen, Møller, & Andersen, 2014; Levinger et al., 2008), suggesting that expected benefits to executive control and attention resulting from resistance training should come via IGF-1. Instead, resistance training was a significant predictor of a diminished alerting effect. Resistance training has been associated with increased IGF-1 and diminished BDNF concentration levels (Borst et al., 2001; Cassilhas et al., 2012; Levinger et al., 2008). Given our findings, this could indicate that subsystems of the attentional network are differentially affected by BDNF and IGF-1 levels, and that incorporating multimodal PA has the broadest positive effect.

Dendritic growth in the medial prefrontal cortex has been demonstrated to be effected by a twelve-day running intervention (Brockett, LaMarca, & Gould, 2015). Brockett et al. (2015) report that increased dendrite density, growth, and synaptic protein availability was seen in multiple brain regions, including the medial prefrontal cortex and the hippocampus. In addition, they found larger astrocyte cell bodies in the PA group than the sedentary controls, but that the larger cells were found exclusively in regions associated with improved cognitive performance. Therefore, the witnessed effects of aerobic training on the SART may be an outcome of interactions between dendrite growth, density, protein availability, and the health of supporting cells.

Finally, flexibility training may not serve as an effective PA intervention. Northey et al. (2018), in a meta-analysis of exercise efficacy in adults 50 years or older, found that tai chi, aerobic, resistance, and multicomponent training all produced positive effects, while yoga did not. The presented results indicate that flexibility training was not an effective PA, and instead impaired cognitive performance on alerting, error monitoring in attentional tasks, and working memory serial search. However, others report yoga as an effective intervention for improving both short and long term word recognition tasks (Rocha et al., 2012). High intensity flexibility training was found to be related to greater differences in search times between two- and six-item sequences, suggesting an impairment in serial memory search. However, low to moderate PA concurrent with the Sternberg Task has been shown to reduce serial memory search times in young adults (Quelhas Martins, Kavussanu, Willoughby, & Ring, 2013). Together, evidence suggests benefits to working memory resulting from low to moderate PA, with high intensity flexibility training specifically diminishing performance most significantly. Consistent with the adverse relationship between working memory and flexibility training, flexibility training was associated with a greater alerting effect. Some have equated flexibility training with increased mindfulness (Rocha et al., 2012) however, this may have the resulting impact of diminishing preparation for an imminent stimulus. Flexibility training may serve as worthwhile means of improving muscle tone and improving motor control but it may prohibit timely response to relevant stimuli.

It is conceivable that the flexibility/stretching condition impaired cognitive function compared to aerobic and resistance training simply by reducing the amount of time available to pursue those PA modes. Generally, less support exists for flexibility training as a useful method for improving cognitive function than aerobic or resistance training and it is often used as a control group in randomized control studies (Colcombe et al., 2006, 2004; Liu-Ambrose et al., 2010, 2012). Given that one of the primary reasons for people not participating in PA is time constraints, the allocation of time into a less cognitively effective training regimen may have the compounded consequences of limiting time available for more potent training modes.

4.3 Sex

Sex was observed to be a significant predictor of cognitive performance in seven of nine measured tasks. Despite this, males and females only differed on four of those tasks. Our findings suggest that when controlling for PA, sex emerges as an important predictor of cognitive function. The results of this study clearly demonstrate the importance of sex as a predictor of the efficacy of physical activity on cognitive function. While ANT executive control, ANT alerting, SART proportion of errors, and SART RT following an error differed significantly between males and females, SART mean RT, SART RT following a correct response, and accuracy on the Backwards Digit Span Task were revealed to not be significantly different. However, when holding for age, BMI, sleep quality, hours of sleep, and exercise variables, sex was found to be a significant predictor, despite the statistical equivalence of performance between males and females. It is known that involvement in PA and baseline cognitive performance are known to vary between sexes (Der & Deary, 2006; Swagerman et al., 2015). Therefore, in equating involvement in PA, we may be observing differences in underlying cognitive functioning. Those findings inform our conclusions in three important ways.

First, because sex emerged only after controlling for physical activity, support is lent to the theory that males and females are differentially affected by PA. Barha et al. (2017) found that in studies involving more female participants, physical activity had more pronounced effects on cognitive performance in multiple domains. Some of our findings demonstrating how mode and intensity of PA predict cognition may have been enhanced because of the increased effect sizes observed in predominantly female PA-cognition studies. With the presented sample comprised of a majority of women (83%), it is possible that the differences found in performance could be the result of the small male cohort included in the study. In sum, our effects may be driven by the characteristics of our sample population. Therefore, a larger sample with greater parity between the number of male and female participants is required in order to more accurately describe the observed trends.

Second, given the comparable scores on the cognitive assessments and the known effect of sex on effect size, it is possible that an undetected interaction between sex and physical activity occurred. Apart from performance on ANT executive control, ANT alerting, SART proportion of errors, and SART RT following an error, males and females did not differ significantly on performance on the other cognitive tasks, indicating that the effects of other variables included in the models are potentially moderating the effects of sex on the PA-cognition relationship. Further analysis in a larger sample is required to examine how men and women differ across demographic and PA factors on specific cognitive functions. Currently, evidence supports sex differences on PA effects on cognition in other age ranges but, further research is required in young adult samples.

Finally, support for the differences in cognitive processing between sexes has been found in previous research. In a study on chronic exercise and cognition, Pérez and colleagues (2014) also found a significant effect of gender in the alerting condition, such that males had reduced alerting effects compared to females. Males have been shown to have faster RT during a vigilance task compared to females (Blatter et al., 2006). However, in an investigation into sex differences on performance in the SART, Chan (Chan, 2001) found no significant differences on any aspect of the task. Yet, in a go/no-go paradigm, females made more errors of omission and completed each trial more slowly than their male counterparts (Riley et al., 2016), and in a similar task were demonstrated to have better inhibitory control (Yuan, He, Qinglin, Chen, & Li, 2008). PA may act to accentuate previously underlying differences in cognitive performance.

4.4 Limitations and Conclusions

In this study we have demonstrated the effect of PA duration, mode, and intensity on four commonly utilized cognitive measures assessing attention and working memory in young adults during a week-long period. Our results suggest that PA plays an important role in cognition between the near and long-term periods, with pronounced PA-cognition relationships in intermediate periods. In addition, we have confirmed the importance of sex as an influential PA-cognition moderator. Finally, the study has implicated the importance of cognitive assessment on elucidating the PA-cognition link. Despite assessing theoretically similar cognitive processes, it is evident from the differential findings that the neurophysiological effects of PA may achieve these gains selectively.

Three specific limitations of this study should guide future research. First, no direct measurement of PA was made. As with any study using self-reported data, it is anticipated that inaccuracies in data collection will occur. We must then assume that self-reported PA is biased in some way, potentially allowing for incorrect inferences to be drawn. Nevertheless, we have demonstrated that perceived PA is linked with cognitive performance, suggesting that perceptions of PA are an important factor in cognition. Employing a PA monitor would enable quantification of PA during the study period.

Second, the participant sample was largely female. Conclusions from this study about the efficacy of PA on cognitive performance between males and females is reliant on the observed differences in vastly unequal group sizes. Supplementary analysis investigating the female only sample may yield additional information on sex specific effects of PA. Given the strong relationship observed between sex and cognition when accounting for PA effects, it would be prudent to target these associations in additional samples where sex is more evenly balanced.

Finally, this study was correlation in nature and therefore no causality can be claimed from the findings. A vast literature exists examining the potency of specific PA interventions on explicit cognitive tasks exists. While this study was designed to highlight the confluence of factors that mediate the PA-cognition relationship and provide clear evidence for the necessity to compare directly between tasks, PA mode, duration, and intensity, it is unable to speak directly to the benefits of PA on cognition. Instead, it can serve to direct future research and provide insight into some methodological issues that must be addressed in the pre-experimental planning stage. Further examinations of the effect of PA on cognition in this time period and with young adult populations is still required. Randomized control studies should be designed to assess the efficacy of different mode, duration, and intensity combinations experimentally, allowing for inferences of causality to be made.

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Appendices

Appendix A Result Tables

A.1 Attention Network Test

Attention Network Test Executive Control

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	*BCa* 95% CI	
						LL	*UL*
Model 1							
Age	0.06	0.07	0.79	.43	0.09	-0.09	0.29
Sex	0.51	0.21	2.45	.016	0.64	0.09	1.22
BMI	0.04	0.07	0.62	.54	0.03	-0.19	0.22
Sleep Hours	-0.01	0.08	-0.15	.88	-0.04	-0.27	0.15
Sleep Quality	0.03	0.10	0.27	.784	0.03	-0.19	0.27
Sitting Time	-0.04	0.08	-0.52	.605	-0.04	-0.24	0.16
Aerobic Training	-0.12	0.07	-1.87	.065	-0.17	-0.39	0.01
Resistance Training	0.06	0.09	0.69	.491	0.08	-0.20	0.41
Flexibility Training	-0.10	0.09	-1.05	.295	-0.10	-0.48	0.22
Model 2							
Age	0.05	0.07	0.68	.496	0.08	-0.09	0.28
Sex	0.47	0.20	2.32	.023	0.55	0.07	1.14
BMI	0.05	0.07	0.76	.451	0.05	-0.17	0.26
Sleep Hours	0.00	0.07	0.00	.996	-0.01	-0.24	0.17
Sleep Quality	0.03	0.10	0.29	.77	0.03	-0.16	0.25
Sitting Time	-0.03	0.08	-0.39	.697	-0.02	-0.22	0.19
High Intensity Training	0.09	0.09	1.02	.31	0.17	-0.10	0.52

Attention Network Test Executive Control

						BCa 95% CI	
	β	*SE*	*t*	*p*	*Resampling Pairwise β*	*LL*	*UL*
Moderate Intensity Training	-0.13	0.10	-1.33	.189	-0.25	-0.59	0.01
Low Intensity Training	-0.09	0.06	-1.71	.09	-0.07	-0.25	0.14
Model 3							
Age	0.04	0.07	0.53	.601	0.07	-0.10	0.30
Sex	0.49	0.21	2.29	.025	0.59	-0.04	1.23
BMI	0.06	0.08	0.85	.398	0.06	-0.19	0.32
Sleep Hours	0.01	0.09	0.11	.91	-0.03	-0.30	0.21
Sleep Quality	0.02	0.10	0.18	.857	0.05	-0.17	0.29
Weekly Sitting Time	-0.02	0.09	-0.26	.795	-0.02	-0.25	0.19
HIAT	0.14	0.14	1.02	.311	0.15	-0.18	0.58
MIAT	-0.10	0.07	-1.39	.167	-0.17	-0.41	0.04
LIAT	-0.10	0.07	-1.48	.144	-0.11	-0.33	0.12
HIRT	0.10	0.13	0.78	.437	0.11	-0.21	0.62
MIRT	-0.09	0.13	-0.71	.48	-0.12	-0.55	0.30
LIRT	0.05	0.09	0.57	.573	0.09	-0.17	0.47
HIFT	-0.16	0.11	-1.45	.152	-0.16	-0.57	0.25
MIFT	0.04	0.11	0.34	.735	0.01	-0.45	0.34
LIFT	-0.05	0.11	-0.48	.631	-0.01	-0.31	0.38

Attention Network Test Alerting

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	BCa 95% CI	
						LL	*UL*
Model 1							
Age	-0.08	0.08	-1.05	.298	-0.03	-0.20	0.22
Sex	0.66	0.14	4.71	.	0.70	0.30	1.14
BMI	-0.01	0.06	-0.23	.819	-0.01	-0.16	0.15
Sleep Hours	-0.05	0.09	-0.59	.559	0.02	-0.21	0.30
Sleep Quality	0.09	0.08	1.14	.257	0.15	-0.01	0.36
Weekly Sitting Time	0.00	0.07	0.07	.946	0.04	-0.14	0.24
Aerobic Training	0.11	0.07	1.47	.146	0.07	-0.15	0.26
Resistance Training	-0.32	0.10	-3.30	.001	-0.35	-0.67	-0.08
Flexibility Training	0.42	0.08	5.05	.	0.50	0.22	1.00
Model 2							
Age	-0.12	0.08	-1.54	.127	-0.07	-0.26	0.15
Sex	0.75	0.17	4.28	.	0.87	0.35	1.46
BMI	-0.01	0.08	-0.14	.885	0.00	-0.17	0.19
Sleep Hours	-0.01	0.09	-0.11	.911	0.10	-0.13	0.45
Sleep Quality	0.05	0.07	0.77	.446	0.12	-0.04	0.31
Weekly Sitting Time	0.02	0.06	0.27	.787	0.04	-0.14	0.30
High Intensity Training	0.03	0.10	0.27	.785	0.10	-0.23	0.45
Moderate Intensity Training	0.13	0.12	1.04	.302	0.03	-0.37	0.32
Low Intensity Training	0.02	0.09	0.17	.864	0.04	-0.17	0.33
Model 3							
Age	-0.08	0.08	-1.01	.314	-0.02	-0.20	0.22
Sex	0.61	0.14	4.36	.	0.62	0.15	1.04
BMI	-0.02	0.06	-0.38	.706	-0.02	-0.19	0.17
Average Sleep Hours	-0.06	0.08	-0.80	.427	0.01	-0.22	0.32

Attention Network Test Alerting

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	BCa 95% CI *LL*	BCa 95% CI *UL*
Average Sleep Quality	0.09	0.07	1.26	.21	0.17	-0.02	0.37
Weekly Sitting Time	0.01	0.08	0.17	.867	0.06	-0.14	0.30
HIAT	0.10	0.11	0.93	.357	0.16	-0.12	0.49
MIAT	0.10	0.07	1.39	.168	0.09	-0.17	0.30
LIAT	0.00	0.08	0.00	1.	-0.02	-0.26	0.18
HIRT	-0.05	0.11	-0.42	.676	-0.02	-0.35	0.41
MIRT	-0.29	0.10	-2.81	.006	-0.36	-0.87	0.06
LIRT	-0.06	0.09	-0.65	.517	-0.09	-0.38	0.16
HIFT	0.03	0.19	0.15	.881	0.03	-0.56	0.52
MIFT	0.26	0.17	1.53	.13	0.16	-0.32	0.59
LIFT	0.12	0.14	0.88	.382	0.30	-0.14	0.99

Attention Network Test Orienting

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	BCa 95% CI *LL*	BCa 95% CI *UL*
Model 1							
Age	0.00	0.09	-0.05	.962	0.01	-0.21	0.21
Sex	0.19	0.23	0.80	.427	0.23	-0.37	0.99
BMI	0.06	0.09	0.63	.532	0.06	-0.15	0.28
Sleep Hours	-0.13	0.10	-1.37	.175	-0.10	-0.33	0.15
Sleep Quality	-0.07	0.09	-0.85	.398	-0.04	-0.24	0.20
Weekly Sitting Time	-0.10	0.11	-0.92	.359	-0.14	-0.38	0.07
Aerobic Training	-0.14	0.09	-1.63	.106	-0.14	-0.34	0.09

Attention Network Test Orienting

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	BCa 95% CI	
						LL	*UL*
Resistance Training	0.00	0.13	0.02	.982	-0.06	-0.55	0.23
Flexibility Training	0.03	0.12	0.27	.784	0.05	-0.35	0.43
Model 2							
Age	0.00	0.09	0.02	.986	0.02	-0.19	0.24
Sex	0.17	0.22	0.79	.429	0.21	-0.37	0.90
BMI	0.05	0.09	0.56	.58	0.04	-0.16	0.25
Sleep Hours	-0.11	0.09	-1.19	.236	-0.08	-0.30	0.17
Sleep Quality	-0.09	0.08	-1.06	.291	-0.05	-0.26	0.18
Weekly Sitting Time	-0.10	0.11	-0.90	.369	-0.14	-0.37	0.07
High Intensity Training	-0.03	0.13	-0.21	.835	-0.07	-0.52	0.25
Moderate Intensity Training	0.04	0.14	0.31	.761	0.02	-0.31	0.33
Low Intensity Training	-0.14	0.08	-1.71	.092	-0.11	-0.33	0.09
Model 3							
Age	0.01	0.09	0.11	.909	0.03	-0.20	0.26
Sex	0.21	0.21	1.01	.315	0.25	-0.38	1.01
BMI	0.05	0.09	0.58	.566	0.05	-0.20	0.28
Average Sleep Hours	-0.14	0.11	-1.32	.191	-0.13	-0.42	0.16
Average Sleep Quality	-0.06	0.09	-0.73	.468	-0.03	-0.25	0.24
Weekly Sitting Time	-0.10	0.11	-0.91	.367	-0.15	-0.39	0.10
HIAT	-0.02	0.16	-0.10	.924	-0.08	-0.54	0.25
MIAT	0.02	0.09	0.20	.842	0.00	-0.27	0.24
LIAT	-0.13	0.09	-1.45	.151	-0.09	-0.31	0.17
HIRT	0.00	0.19	0.01	.995	0.02	-0.44	0.49
MIRT	0.04	0.18	0.23	.816	0.04	-0.58	0.66
LIRT	-0.07	0.13	-0.57	.567	-0.14	-0.53	0.18

Attention Network Test Orienting

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	BCa 95% CI *LL*	BCa 95% CI *UL*
HIFT	-0.15	0.19	-0.80	.424	-0.15	-0.81	0.28
MIFT	-0.02	0.17	-0.10	.917	-0.02	-0.44	0.43
LIFT	0.20	0.17	1.20	.233	0.22	-0.21	0.63

A.2 Sustained Attention to Response Task

Sustained Attention to Response Task Mean Reaction Time

						BCa 95% CI	
	β	*SE*	*t*	*p*	*Resampling Pairwise β*	*LL*	*UL*
Model 1							
Age	-0.07	0.04	-1.72	.089	-0.03	-0.15	0.15
Sex	0.37	0.15	2.38	.02	0.35	-0.25	0.76
BMI	-0.03	0.06	-0.46	.647	-0.12	-0.49	0.06
Sleep Hours	0.02	0.06	0.39	.697	0.04	-0.25	0.25
Sleep Quality	0.03	0.06	0.50	.615	-0.01	-0.28	0.14
Weekly Sitting Time	-0.11	0.05	-2.32	.023	-0.03	-0.22	0.29
Aerobic Training	-0.12	0.05	-2.40	.019	-0.15	-0.32	-0.01
Resistance Training	0.10	0.06	1.60	.113	0.00	-0.34	0.20
Flexibility Training	-0.04	0.08	-0.50	.615	0.05	-0.22	0.39
Model 2							
Age	-0.09	0.04	-2.41	.018	-0.07	-0.19	0.07
Sex	0.37	0.14	2.67	.009	0.37	-0.13	0.79
BMI	0.00	0.05	0.00	.996	-0.08	-0.46	0.09
Sleep Hours	0.04	0.05	0.80	.424	0.09	-0.17	0.33
Sleep Quality	0.03	0.06	0.50	.618	-0.01	-0.28	0.16
Weekly Sitting Time	-0.09	0.04	-2.18	.032	-0.01	-0.19	0.33
High Intensity Training	0.24	0.08	3.01	.003	0.32	0.09	0.64
Moderate Intensity Training	-0.13	0.09	-1.45	.15	-0.26	-0.69	0.00
Low Intensity Training	-0.13	0.05	-2.80	.007	-0.12	-0.30	0.06
Model 3							
Age	-0.09	0.04	-2.60	.011	-0.05	-0.18	0.18
Sex	0.32	0.13	2.38	.02	0.26	-0.50	0.72

Sustained Attention to Response Task Mean Reaction Time

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	BCa 95% CI	
						LL	*UL*
BMI	-0.01	0.05	-0.14	.886	-0.08	-0.52	0.12
Average Sleep Hours	0.07	0.06	1.18	.241	0.13	-0.18	0.43
Average Sleep Quality	0.01	0.06	0.12	.907	-0.03	-0.31	0.17
Weekly Sitting Time	-0.08	0.05	-1.79	.078	0.02	-0.17	0.40
HIAT	0.18	0.07	2.49	.015	0.21	-0.04	0.49
MIAT	-0.04	0.06	-0.70	.488	-0.07	-0.33	0.13
LIAT	-0.10	0.04	-2.52	.014	-0.09	-0.27	0.10
HIRT	0.17	0.18	0.95	.344	0.01	-0.69	0.52
MIRT	-0.14	0.14	-1.02	.31	-0.12	-0.61	0.47
LIRT	0.02	0.04	0.37	.709	-0.04	-0.31	0.14
HIFT	0.03	0.14	0.23	.817	0.33	-0.24	1.69
MIFT	-0.07	0.10	-0.69	.491	-0.33	-0.98	0.07
LIFT	-0.10	0.08	-1.23	.222	0.01	-0.37	0.50

Sustained Attention to Response Task Proportion of Errors

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	BCa 95% CI	
						LL	*UL*
Model 1							
Age	0.02	0.11	0.23	.822	-0.01	-0.24	0.21
Sex	-0.63	0.23	-2.73	.008	-0.63	-1.15	0.00
BMI	-0.13	0.11	-1.17	.247	-0.08	-0.29	0.17
Sleep Hours	-0.15	0.10	-1.53	.129	-0.14	-0.38	0.08
Sleep Quality	-0.12	0.11	-1.08	.283	-0.10	-0.32	0.15

Sustained Attention to Response Task Proportion of Errors

						BCa 95% CI	
	β	*SE*	*t*	*p*	*Resampling Pairwise β*	*LL*	*UL*
Weekly Sitting Time	0.09	0.10	0.91	.365	0.03	-0.20	0.24
Aerobic Training	0.10	0.09	1.06	.293	0.09	-0.11	0.30
Resistance Training	-0.20	0.13	-1.53	.13	-0.18	-0.51	0.13
Flexibility Training	0.25	0.11	2.19	.032	0.22	-0.23	0.55
Model 2							
Age	-0.02	0.11	-0.16	.873	-0.03	-0.26	0.18
Sex	-0.56	0.21	-2.69	.009	-0.56	-1.05	0.02
BMI	-0.09	0.11	-0.78	.435	-0.06	-0.27	0.17
Sleep Hours	-0.09	0.10	-0.93	.357	-0.10	-0.35	0.13
Sleep Quality	-0.12	0.11	-1.10	.273	-0.10	-0.30	0.13
Weekly Sitting Time	0.08	0.10	0.78	.435	0.04	-0.19	0.26
High Intensity Training	0.09	0.15	0.59	.554	0.09	-0.29	0.42
Moderate Intensity Training	-0.11	0.17	-0.61	.544	-0.10	-0.45	0.29
Low Intensity Training	0.15	0.08	1.80	.075	0.13	-0.07	0.34
Model 3							
Age	-0.01	0.11	-0.09	.927	-0.04	-0.30	0.19
Sex	-0.50	0.25	-2.04	.044	-0.51	-1.05	0.27
BMI	-0.08	0.11	-0.67	.507	-0.05	-0.27	0.24
Average Sleep Hours	-0.12	0.10	-1.16	.252	-0.11	-0.36	0.14
Average Sleep Quality	-0.12	0.11	-1.06	.294	-0.11	-0.33	0.14
Weekly Sitting Time	0.06	0.11	0.57	.572	0.01	-0.23	0.24
HIAT	-0.07	0.17	-0.44	.663	-0.08	-0.45	0.29
MIAT	-0.14	0.11	-1.20	.235	-0.15	-0.40	0.13
LIAT	0.17	0.08	2.13	.037	0.19	-0.02	0.40
HIRT	-0.13	0.22	-0.60	.55	-0.16	-0.67	0.39

Sustained Attention to Response Task Proportion of Errors

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	BCa 95% CI *LL*	BCa 95% CI *UL*
MIRT	0.10	0.18	0.55	.581	0.14	-0.39	0.69
LIRT	-0.13	0.10	-1.34	.184	-0.12	-0.41	0.14
HIFT	0.13	0.22	0.61	.544	0.22	-0.32	0.89
MIFT	0.18	0.21	0.82	.415	0.15	-0.44	0.61
LIFT	0.02	0.16	0.13	.899	-0.07	-0.57	0.34

Sustained Attention to Response Task Reaction Time Following An Error

	β	*SE*	*t(79)*	*p*	*Resampling Pairwise β*	BCa 95% CI *LL*	BCa 95% CI *UL*
Model 1							
Age	-0.08	0.09	-0.96	.338	-0.07	-0.26	0.13
Sex	0.53	0.23	2.37	.02	0.52	-0.30	1.06
BMI	-0.01	0.07	-0.18	.861	-0.05	-0.33	0.14
Sleep Hours	0.03	0.08	0.44	.66	0.05	-0.20	0.26
Sleep Quality	-0.02	0.09	-0.21	.834	-0.05	-0.28	0.15
Weekly Sitting Time	-0.03	0.08	-0.39	.697	0.01	-0.21	0.26
Aerobic Training	-0.13	0.07	-1.83	.07	-0.15	-0.34	0.04
Resistance Training	-0.04	0.10	-0.40	.691	-0.09	-0.40	0.22
Flexibility Training	0.06	0.10	0.57	.573	0.09	-0.30	0.43
Model 2							
Age	-0.10	0.08	-1.20	.233	-0.09	-0.28	0.09
Sex	0.54	0.21	2.63	.01	0.54	-0.29	1.03
BMI	0.00	0.07	-0.01	.994	-0.03	-0.31	0.15

Sustained Attention to Response Task Reaction Time Following An Error

	β	*SE*	*t(79)*	*p*	*Resampling Pairwise β*	BCa 95% CI *LL*	BCa 95% CI *UL*
Sleep Hours	0.06	0.08	0.81	.422	0.09	-0.17	0.33
Sleep Quality	-0.03	0.09	-0.27	.787	-0.06	-0.28	0.15
Weekly Sitting Time	-0.02	0.07	-0.29	.774	0.02	-0.18	0.29
High Intensity Training	0.09	0.12	0.77	.445	0.11	-0.23	0.44
Moderate Intensity Training	-0.07	0.15	-0.46	.649	-0.13	-0.49	0.22
Low Intensity Training	-0.13	0.08	-1.70	.093	-0.13	-0.34	0.09
Model 3							
Age	-0.11	0.09	-1.29	.201	-0.08	-0.30	0.14
Sex	0.57	0.20	2.78	.007	0.55	-0.36	1.06
BMI	0.02	0.07	0.21	.836	-0.02	-0.33	0.21
Average Sleep Hours	0.10	0.08	1.24	.218	0.13	-0.17	0.39
Average Sleep Quality	-0.02	0.09	-0.19	.848	-0.07	-0.32	0.15
Weekly Sitting Time	-0.05	0.08	-0.58	.562	0.02	-0.20	0.32
HIAT	0.01	0.10	0.11	.914	0.00	-0.24	0.30
MIAT	-0.10	0.08	-1.17	.247	-0.10	-0.33	0.17
LIAT	-0.09	0.08	-1.24	.22	-0.09	-0.31	0.14
HIRT	-0.23	0.12	-1.90	.062	-0.31	-0.83	0.07
MIRT	0.16	0.12	1.30	.198	0.18	-0.35	0.76
LIRT	0.01	0.09	0.09	.929	-0.04	-0.29	0.22
HIFT	0.31	0.21	1.47	.146	0.44	-0.12	1.30
MIFT	-0.01	0.15	-0.06	.95	-0.15	-0.65	0.32
LIFT	-0.26	0.15	-1.78	.079	-0.14	-0.55	0.41

Sustained Attention to Response Task Reaction Time Following A Correct Response

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	BCa 95% CI	
						LL	*UL*
Model 1							
Age	-0.06	0.06	-0.91	.365	-0.04	-0.19	0.14
Sex	0.36	0.21	1.70	.093	0.32	-0.53	0.80
BMI	-0.03	0.08	-0.37	.714	-0.13	-0.55	0.08
Sleep Hours	0.05	0.09	0.59	.557	0.03	-0.31	0.26
Sleep Quality	0.08	0.09	0.91	.366	0.04	-0.27	0.24
Weekly Sitting Time	-0.13	0.07	-1.96	.053	-0.05	-0.26	0.32
Aerobic Training	-0.14	0.07	-1.93	.057	-0.17	-0.37	0.01
Resistance Training	0.14	0.08	1.76	.082	0.06	-0.30	0.28
Flexibility Training	-0.06	0.10	-0.60	.55	0.01	-0.28	0.41
Model 2							
Age	-0.07	0.06	-1.27	.208	-0.08	-0.24	0.07
Sex	0.38	0.19	2.02	.047	0.35	-0.27	0.84
BMI	0.00	0.07	0.00	1.	-0.08	-0.50	0.12
Sleep Hours	0.06	0.07	0.78	.436	0.07	-0.24	0.29
Sleep Quality	0.09	0.09	0.98	.329	0.05	-0.28	0.25
Weekly Sitting Time	-0.11	0.06	-1.79	.078	-0.02	-0.21	0.34
High Intensity Training	0.31	0.11	2.95	.004	0.37	0.07	0.68
Moderate Intensity Training	-0.16	0.12	-1.36	.176	-0.24	-0.58	0.05
Low Intensity Training	-0.16	0.06	-2.63	.01	-0.18	-0.38	0.00
Model 3							
Age	-0.06	0.06	-1.11	.272	-0.06	-0.22	0.14
Sex	0.28	0.18	1.60	.114	0.21	-0.69	0.74
BMI	-0.01	0.06	-0.18	.857	-0.09	-0.59	0.14
Average Sleep Hours	0.09	0.07	1.23	.222	0.10	-0.29	0.37

Sustained Attention to Response Task Reaction Time Following A Correct Response

						BCa 95% CI	
	β	*SE*	*t*	*p*	*Resampling Pairwise β*	*LL*	*UL*
Average Sleep Quality	0.06	0.10	0.57	.567	0.04	-0.30	0.28
Weekly Sitting Time	-0.09	0.07	-1.30	.197	0.01	-0.20	0.41
HIAT	0.30	0.11	2.64	.01	0.31	-0.01	0.63
MIAT	-0.03	0.08	-0.34	.737	-0.05	-0.36	0.18
LIAT	-0.13	0.05	-2.35	.021	-0.14	-0.34	0.06
HIRT	0.27	0.25	1.08	.285	0.15	-0.57	0.77
MIRT	-0.25	0.20	-1.27	.21	-0.22	-0.72	0.45
LIRT	0.00	0.06	0.07	.943	-0.05	-0.39	0.16
HIFT	-0.05	0.17	-0.26	.792	0.14	-0.40	1.08
MIFT	-0.12	0.13	-0.94	.352	-0.26	-0.73	0.16
LIFT	-0.03	0.12	-0.23	.821	0.04	-0.37	0.41

A.3 Backwards Digit Span

Backwards Digit Span Proportion of Correct Responses

						BCa 95% CI	
	β	*SE*	*t*	*p*	*Resampling Pairwise β*	*LL*	*UL*
Model 1							
Age	0.01	0.10	0.11	.915	0.02	-0.17	0.27
Sex	-0.57	0.22	-2.54	.013	-0.52	-1.17	0.03
BMI	-0.05	0.10	-0.48	.633	-0.06	-0.28	0.16
Sleep Hours	-0.16	0.12	-1.38	.171	-0.15	-0.37	0.12
Sleep Quality	0.01	0.10	0.12	.903	0.02	-0.16	0.25
Weekly Sitting Time	0.09	0.09	0.95	.343	0.09	-0.13	0.27
Aerobic Training	-0.14	0.10	-1.36	.177	-0.15	-0.37	0.11
Resistance Training	-0.16	0.20	-0.83	.406	-0.10	-0.48	0.47
Flexibility Training	0.29	0.19	1.54	.128	0.23	-0.23	0.67
Model 2							
Age	-0.04	0.11	-0.36	.719	-0.01	-0.23	0.24
Sex	-0.63	0.25	-2.48	.015	-0.53	-1.13	0.12
BMI	-0.04	0.10	-0.40	.692	-0.04	-0.27	0.17
Sleep Hours	-0.08	0.10	-0.86	.392	-0.07	-0.28	0.20
Sleep Quality	-0.02	0.09	-0.20	.844	0.00	-0.19	0.20
Weekly Sitting Time	0.12	0.09	1.43	.157	0.11	-0.09	0.31
High Intensity Training	0.31	0.17	1.87	.066	0.24	-0.13	0.65
Moderate Intensity Training	-0.29	0.16	-1.81	.074	-0.22	-0.57	0.20
Low Intensity Training	-0.04	0.09	-0.40	.689	-0.03	-0.25	0.21
Model 3							

Backwards Digit Span Proportion of Correct Responses

						BCa 95% CI	
	β	*SE*	*t*	*p*	*Resampling Pairwise β*	*LL*	*UL*
Age	0.00	0.11	-0.01	.995	0.02	-0.21	0.28
Sex	-0.67	0.22	-3.09	.003	-0.60	-1.28	0.02
BMI	-0.01	0.09	-0.15	.884	-0.03	-0.29	0.19
Average Sleep Hours	-0.12	0.10	-1.13	.264	-0.10	-0.34	0.17
Average Sleep Quality	0.03	0.10	0.31	.761	0.03	-0.19	0.27
Weekly Sitting Time	0.13	0.10	1.31	.194	0.12	-0.11	0.32
HIAT	0.22	0.17	1.30	.198	0.14	-0.21	0.54
MIAT	-0.17	0.10	-1.69	.095	-0.11	-0.35	0.28
LIAT	-0.10	0.09	-1.04	.3	-0.11	-0.39	0.10
HIRT	-0.13	0.16	-0.85	.397	-0.13	-0.68	0.27
MIRT	-0.17	0.16	-1.04	.304	-0.10	-0.69	0.57
LIRT	0.02	0.12	0.17	.862	0.04	-0.24	0.46
HIFT	0.21	0.23	0.92	.36	0.24	-0.23	1.12
MIFT	-0.07	0.24	-0.29	.77	-0.09	-0.53	0.55
LIFT	0.14	0.19	0.76	.447	0.10	-0.36	0.53

A.4 Sternberg Task

Sternberg

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	BCa 95% CI *LL*	BCa 95% CI *UL*
Model 1							
Age	0.03	0.08	0.41	.685	0.00	-0.20	0.19
Sex	-0.08	0.24	-0.33	.74	-0.03	-0.89	0.59
BMI	-0.06	0.09	-0.67	.508	0.00	-0.25	0.30
Sleep Hours	0.01	0.10	0.05	.959	-0.02	-0.30	0.20
Sleep Quality	0.11	0.08	1.39	.169	0.20	0.00	0.47
Weekly Sitting Time	-0.02	0.09	-0.26	.797	-0.11	-0.39	0.17
Aerobic Training	0.02	0.09	0.18	.855	0.01	-0.21	0.27
Resistance Training	-0.17	0.11	-1.55	.125	-0.13	-0.46	0.17
Flexibility Training	0.03	0.19	0.13	.894	-0.01	-0.53	0.45
Model 2							
Age	0.02	0.08	0.25	.8	-0.01	-0.22	0.18
Sex	0.05	0.20	0.25	.803	0.10	-0.59	0.69
BMI	-0.05	0.10	-0.48	.629	0.00	-0.24	0.29
Sleep Hours	0.00	0.09	-0.02	.981	-0.05	-0.32	0.18
Sleep Quality	0.13	0.08	1.50	.137	0.21	0.00	0.45
Weekly Sitting Time	-0.04	0.09	-0.49	.628	-0.12	-0.42	0.15
High Intensity Training	-0.11	0.15	-0.69	.491	-0.14	-0.50	0.23
Moderate Intensity Training	0.07	0.11	0.62	.539	0.15	-0.13	0.57
Low Intensity Training	-0.10	0.09	-1.07	.289	-0.16	-0.43	0.09
Model 3							

Sternberg

	β	*SE*	*t*	*p*	*Resampling Pairwise β*	BCa 95% CI	
						LL	*UL*
Age	0.01	0.07	0.18	.856	-0.04	-0.27	0.16
Sex	0.06	0.22	0.28	.782	0.12	-0.74	0.76
BMI	-0.04	0.08	-0.46	.648	0.01	-0.24	0.31
Average Sleep Hours	0.05	0.10	0.48	.63	0.03	-0.23	0.30
Average Sleep Quality	0.09	0.08	1.12	.267	0.18	-0.07	0.45
Weekly Sitting Time	-0.06	0.08	-0.65	.517	-0.14	-0.44	0.16
HIAT	-0.13	0.10	-1.41	.164	-0.11	-0.36	0.22
MIAT	-0.03	0.08	-0.40	.694	0.03	-0.28	0.41
LIAT	0.03	0.08	0.36	.72	-0.02	-0.31	0.25
HIRT	-0.31	0.20	-1.54	.127	-0.30	-0.86	0.23
MIRT	0.28	0.18	1.52	.132	0.26	-0.42	0.97
LIRT	-0.14	0.09	-1.60	.114	-0.12	-0.38	0.19
HIFT	0.35	0.16	2.15	.035	0.30	-0.21	0.80
MIFT	0.07	0.15	0.46	.649	0.09	-0.33	0.69
LIFT	-0.28	0.16	-1.71	.091	-0.35	-0.98	0.07

A.5 Proportion of Variance

F Scores

		R2adj	*F*	*p*
ANT Executive Function				
	Model 1	-.01	0.85	.57
	Model 2	-.003	0.97	.47
	Model 3	-.06	0.64	.83
ANT Alerting				
	Model 1	.14	2.64	.009
	Model 2	.05	1.54	.15
	Model 3	.1	1.67	.074
ANT Orienting				
	Model 1	-.05	0.49	.88
	Model 2	-.06	0.45	.91
	Model 3	-.11	0.4	.97
SART Total RT				
	Model 1	-.03	0.68	.72
	Model 2	.02	1.2	.3
	Model 3	-.03	0.82	.65
SART Proportion of Errors				
	Model 1	-.01	0.93	.5
	Model 2	-.02	0.83	.6
	Model 3	-.03	0.83	.65
SART RT Following an Error				
	Model 1	-.01	0.93	.51
	Model 2	-.01	0.94	.49
	Model 3	-.03	0.8	.67
SART RT Following a Correct Response				
	Model 1	-.04	0.64	.76
	Model 2	.04	1.36	.22
	Model 3	-.02	0.89	.57
Backwards Digit Span Proportion of Correct Responses				
	Model 1	-.01	0.88	.54
	Model 2	-.02	0.79	.62
	Model 3	-.05	0.68	.79
Sternberg				
	Model 1	-.05	0.55	.83
	Model 2	-.04	0.67	.74
	Model 3	-.05	0.71	.77