

EFFECTS OF ACUTE EXERCISE ON ATTENTION, HYPERACTIVITY, MOTIVATION,
AND MOOD IN YOUNG ADULT MEN WITH ELEVATED SYMPTOMS OF ATTENTION
DEFICIT HYPERACTIVITY DISORDER

by

KATHRYN MARIE FRITZ

(Under the Direction of Patrick O'Connor)

ABSTRACT

This thesis determined the influence of acute moderate intensity exercise on attention, hyperactivity, motivation, and mood in adult men reporting symptoms of attention deficit hyperactivity disorder (ADHD). This crossover experiment involved 32 men and measured the outcomes before and twice after 20 minutes of exercise or a seated rest control. Condition (Exercise versus Rest) X Time (Baseline, Post-1 and Post2) ANOVAs tested hypothesized interactions that exercise alone would induce improvements in the outcomes. Results revealed exercise alone significantly increased vigor and motivation to complete mental work and decreased fatigue, depression, and confusion. Exercise did not affect attention task performances or leg activity. Leg activity was higher during the more difficult cognitive task. In men reporting elevated symptoms of ADHD 20 minutes of moderate intensity exercise enhanced motivation for cognitive tasks, increased feelings of energy and reduced feelings of fatigue, confusion, and depression but had no effect on attention or hyperactivity.

INDEX WORDS: acute exercise, ADHD, attention, accelerometry, fatigue, motivation, vigor

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KATHRYN MARIE FRITZ

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by

KATHRYN MARIE FRITZ

Major Professor: Patrick J. O'Connor
Committee: Rodney K. Dishman
Michael D. Schmidt

Electronic Version Approved:

Suzanne Barbour
Interim Dean of the Graduate School
The University of Georgia
August 2015

DEDICATION

To Mom and Dad. I would not be where I am, doing what I do if it was not for you two. Thank you for always encouraging me to learn and keep an open mind. Most importantly, thank you for being willing to listen when I needed it and thank you for putting up with me.

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CHAPTER 1

INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) symptoms are common among adults. Results from a survey study of ~20,000 adults found that 6.2% screened positive for adult ADHD [1]. Population prevalence rates of those with an adult ADHD diagnosis have been reported to range from 2.5-5.2% [2-5]. Those with ADHD symptoms have been shown to have poorer performance on cognitive tests [6], have reduced grade point averages [7], and report higher rates of traffic accidents than those reporting no ADHD symptoms [1]. Stimulant medications are commonly prescribed for treatment of ADHD symptoms [8]. For those without an ADHD diagnosis, nonmedical use of stimulant medications has been reported to be 8.9%. The rate is higher among individuals reporting elevated ADHD symptoms [9], possibly indicating attempted symptom management. Prescription stimulant medications are associated with negative side effects such as sleep difficulties, appetite suppression, and irritability [9]. A further limitation of using stimulant medication to alleviate ADHD symptoms is that 35-50% of ADHD patients do not respond favorably to these medications [10, 11]. Providing safe and effective alternative acute and chronic treatments for adults with ADHD or at risk for ADHD would be beneficial.

There is evidence to suggest that acute aerobic exercise may be beneficial for those with ADHD symptoms. In children with ADHD, improvements in attention have been reported after 20 to 30 minutes of moderate intensity exercise [12-16]. Results from one study also showed reductions in an index of hyperactivity after maximal exercise in boys with ADHD [17]. There

appears to only be one study that has investigated the effects of acute exercise on ADHD symptoms in adults with an ADHD diagnosis [18]. Exercise was associated with improved cognitive performance, but due to design limitations, such as the absence of a no-exercise condition and differences in use of medication among the participants, the findings are difficult to interpret.

The purpose of this thesis is to determine the extent to which an acute bout of moderate intensity exercise affects inattention, hyperactivity, motivation to perform cognitive work, and related mood states in adult men reporting elevated ADHD symptoms.

Chapter 2 of this thesis provides a review of ADHD, deficits associated with ADHD, possible causes and current treatments for ADHD. Next, a review of studies involving acute exercise among individuals with ADHD is discussed. Finally, possible biological mechanisms of how an acute bout of exercise may alleviate ADHD are reviewed.

Chapter 3 of this thesis describes an experiment that was conducted to determine the influence of acute exercise on attention, hyperactivity, motivation to complete cognitive work, and mood in men reporting elevated ADHD symptoms. Novel features of the study include the focus on the influence of acute exercise on signs and symptoms of ADHD in adults at risk for ADHD and the use of accelerometers to objectively measure leg hyperactivity.

References

1. Able, S.L., et al., *Functional and psychosocial impairment in adults with undiagnosed ADHD*. Psychological Medicine, 2007. **37**(01): p. 97-107.
2. Adler, L.A., et al., *Validity of Pilot Adult ADHD Self-Report Scale (ASRS) to Rate Adult ADHD Symptoms**. Annals of Clinical Psychiatry, 2006. **18**(3): p. 145-148.
3. Faraone, S.V. and J. Biederman, *What is the prevalence of adult ADHD? Results of a population screen of 966 adults*. Journal of Attention Disorders, 2005. **9**(2): p. 384-391.
4. Fayyad, J., et al., *Cross-national prevalence and correlates of adult attention-deficit hyperactivity disorder*. The British Journal of Psychiatry, 2007. **190**(5): p. 402-409.
5. Simon, V., et al., *Prevalence and correlates of adult attention-deficit hyperactivity disorder: meta-analysis*. The British Journal of Psychiatry, 2009. **194**(3): p. 204-211.
6. Hervey, A.S., J.N. Epstein, and J.F. Curry, *Neuropsychology of adults with attention-deficit/hyperactivity disorder: a meta-analytic review*. Neuropsychology, 2004. **18**(3): p. 485.
7. Blase, S.L., et al., *Self-Reported ADHD and Adjustment in College Cross-sectional and Longitudinal Findings*. Journal of Attention Disorders, 2009. **13**(3): p. 297-309.
8. Faraone, S.V. and S.J. Glatt, *A comparison of the efficacy of medications for adult attention-deficit/hyperactivity disorder using meta-analysis of effect sizes*. The Journal of clinical psychiatry, 2010. **71**(6): p. 754-763.
9. Rabiner, D.L., et al., *Motives and perceived consequences of nonmedical ADHD medication use by college students are students treating themselves for attention problems?* Journal of Attention Disorders, 2009. **13**(3): p. 259-270.
10. Biederman, J., et al., *A randomized, placebo-controlled trial of OROS methylphenidate in adults with attention-deficit/hyperactivity disorder*. Biological Psychiatry, 2006. **59**(9): p. 829-835.
11. Medori, R., et al., *A randomized, placebo-controlled trial of three fixed dosages of prolonged-release OROS methylphenidate in adults with attention-deficit/hyperactivity disorder*. Biological psychiatry, 2008. **63**(10): p. 981-989.
12. Chang, Y.-K., et al., *Effect of Acute Exercise on Executive Function in Children with Attention Deficit Hyperactivity Disorder*. Archives of Clinical Neuropsychology, 2012. **27**(2): p. 225-237.
13. Gawrilow, C., et al., *Physical activity, affect, and cognition in children with symptoms of ADHD*. Journal of attention disorders, 2013: p. 1087054713493318.
14. Medina, J., et al., *Exercise impact on sustained attention of ADHD children, methylphenidate effects*. ADHD Attention Deficit and Hyperactivity Disorders, 2010. **2**(1): p. 49-58.
15. Piepmeier, A.T., et al., *The effect of acute exercise on cognitive performance in children with and without ADHD*. Journal of Sport and Health Science, (0).
16. Pontifex, M.B., et al., *Exercise improves behavioral, neurocognitive, and scholastic performance in children with attention-deficit/hyperactivity disorder*. The Journal of pediatrics, 2013. **162**(3): p. 543-551.
17. Tantillo, M., et al., *The effects of exercise on children with attention-deficit hyperactivity disorder*. Medicine & Science in Sports & Exercise, 2002.
18. Gapin, J., et al., *Acute exercise is associated with specific executive functions in college students with ADHD: A preliminary study*. Journal of Sport and Health Science, (0).

CHAPTER 2

LITERATURE REVIEW

The purpose of this thesis is to investigate the effects of a single bout of moderate intensity cycling exercise on signs and symptoms of Attention Deficit Hyperactivity Disorder (ADHD), as well as related psychological outcomes including mood and motivation in young adult men reporting elevated ADHD symptoms. The purpose of this chapter is to review relevant background information.

Prevalence of Adult Attention Hyperactivity Disorder (ADHD)

Population prevalence rates of adult ADHD range from 2.5%-5.2% [1-4]. The percentage of college students with adult ADHD has been reported to range from 2.9%-6.6% and some evidence suggests a higher rate for students attending public compared to private institutions [5].

Cognitive Performance among Adults with ADHD

Several studies have indicated that adults with ADHD do not perform as well on cognitive tests when compared to healthy controls. Those with adult ADHD have been shown to commit more omission and commission errors [6-8] and have slower and more variable reaction times [6, 7]. Results from meta-analyses show that adults with ADHD are less accurate in performing cognitive tasks when compared to controls with effect sizes ranging from .38-.65 for attention tasks [6, 9], .55 for working memory [10], and .13-.89 for executive function tests [9, 11]. Severity of ADHD symptoms (both inattention and hyperactivity) has also been shown to be positively correlated with commission errors ($r = .35-.57$) [7, 8] and variability in reaction time ($r = .32$) [7], and negatively correlated with GPA [12]. It has also been shown that adults with

ADHD have lower college grade point averages [5, 13], and are less likely to have graduated from high school or enrolled in college [14].

Possible Causes of ADHD

The causes of ADHD are currently unknown however both environmental and genetic factors have been shown to be associated with ADHD. Genes that have been shown to be associated with the symptoms and incidence of ADHD include the dopamine transporter gene (DAT1), dopamine D4 and D5 receptor gene (DRD4 and DRD5, respectively), and catechol-O-methyltransferase (COMT). Results from studies have revealed associations between ADHD diagnosis and variations in DAT1, DRD4 and DRD5 genes with odds ratios of 1.12-2.4 for DAT1 [15-18], 1.21-1.66 for DRD4 [18-20], and 1.23-1.34 for DRD5 [18, 19]. Results from other studies have not shown an association with ADHD and DAT1 [19, 21] or DRD4 [22]. Variations in the COMT gene have been associated with symptoms of ADHD [23], but a meta-analysis of 16 studies concerning the COMT gene and ADHD found no association [18]. Gene by environment interactions may explain the inconsistent results [24].

Male sex is a risk factor for ADHD in children [25]. Sex-related differences in adult ADHD prevalence are apparent but depend on age and the gender composition of the samples studied [1, 4, 26]. There is little sex-related difference in ADHD in those above 40-years but among people in their twenties there are more men than women with ADHD. This effect in young adults is smaller and less consistent than those observed with samples of children [4]. Other factors that have been shown to be associated with increased risk for ADHD are prenatal smoking [27-30], increased self-reported prenatal stress [28, 31], and being born prematurely [32]. Gene by environment interactions increasingly are being considered as important in ADHD. One study, for instance, showed increased risk for ADHD when exposed to prenatal

smoke depending on genetic variation in the DAT1 gene and the DRD4 gene with increased odds of 1.84 and 2.04 for DAT1 and DRD4, respectively [27, 29, 33]. Others have not shown support for a relationship between prenatal smoking alone [33, 34] and not all studies have reported significant gene by environment interaction effects for increased risk of ADHD [30].

Current Treatments for ADHD, their effectiveness and limitations

Current treatments for adult ADHD include prescription medication and psychotherapy. Prescription stimulants such as methylphenidate, dexamethylphenidate, and mixed amphetamines are the most commonly used medication to treat ADHD [35]. These drugs primarily act to inhibit re-uptake of neurotransmitters and thereby increase dopamine, norepinephrine and neural activity in the frontal cortex and insular cortex which is thought to increase the efficiency of pyramidal neuron signaling and thereby improve ADHD symptoms [36-40]. These medications have been shown to significantly reduce ADHD symptoms in adults when compared to placebo as well as increase feelings of energy, decrease feelings of fatigue, and increase scores on scales, including the Addiction Research Center Inventory scale, used to identify the abuse potential of amphetamines [35, 41-44]. Stimulants also improve performance on cognitive tests by reducing errors, decreasing reaction time, and decreasing variability of reaction time in adults with ADHD when compared to when they are off their medication [45-47]. Effect sizes for reducing ADHD symptoms after treatment have been shown to range from .38-.86 for stimulants [35, 43, 48-51] and from .39-.59 for non-stimulant medication [35, 50]. Results from studies also support the use of psychotherapy for reducing ADHD symptoms in adults [51-54]. Reported response rates, defined as a 30% reduction in ADHD symptoms, range from 47.4%-66% for stimulants [42, 48, 55] and from 63-66% for psychotherapy [54, 56]. Side effects of stimulant medications include

reduced appetite, jitteriness, nausea, increased heart rate, insomnia, and dry mouth [43, 48, 55, 57].

There are a number of limitations with the current ADHD treatments. The cost of treatment is high. The total excess cost of ADHD treatment (the extra health care costs for ADHD patients compared to controls) in the US was estimated as \$31 billion in 2000 [41]. The safety of regular stimulant medication use is not well characterized; neither are the potential effects of the interactions between ADHD medications and other legal and illegal drugs often taken by college students. Moreover, many patients can't or won't adhere to treatment. Non-adherence and discontinuation of ADHD medication has ranged between 13% and 64% [58]. There is a need for other ways for adults with ADHD to manage their symptoms; especially useful would be accessible, inexpensive, safe and effective alternatives.

Effects of Acute Exercise on ADHD related signs and symptoms

The majority of research examining the influence of acute exercise on ADHD-related signs and symptoms has been conducted with children. Although some studies with null findings exist [59, 60], most studies have found positive effects of acute exercise on ADHD-related signs and symptoms [61-65]. After acute moderate intensity exercise lasting 20-30 minutes, children with ADHD have improvements in response accuracy [64, 65], response inhibition [64], impulsivity [62], reaction time [62] and motor impersistence [61]. Results from the studies above suggest that acute exercise is beneficial for children with ADHD symptoms. A recent systematic review based on three of these studies that examined cognitive functions [59, 62, 63] concluded that 30 minutes of exercise appears to improve executive functions of children but more studies are needed to confirm these benefits.

It is not well known if adults with ADHD symptoms benefit from an acute bout of exercise. It is plausible, however, based on the available information with children with ADHD as well as the behavioral data with adults without ADHD showing enhanced cognitive performance after moderate intensity exercise lasting 20 minutes or more [66, 67] when cognitive tests are conducted 10 or more minutes after exercise cessation [67]. There appears to be one observational study with adults and one preliminary experimental study using an acute bout of exercise. Results from the observational study showed a negative association between increased self-reported physical activity and impulsivity in male adults with ADHD ($r = -.44$) [68]. Results from the study investigating the effect of 30 minutes of low to moderate intensity treadmill exercise on ADHD symptoms found that exercise was able to increase Stroop task performance but was unable to increase working memory or task-switching performance [69].

Possible Mechanisms by which Acute Exercise may influence ADHD symptoms

Acute exercise may be able to increase attention and reduce hyperactivity in a manner consistent with what has been hypothesized for stimulant medications. Studies, primarily in rodents, using multiple techniques including microdialysis, have shown that brain (including frontal cortex, insular cortex, striatum, and hippocampus) concentrations of DA, NE, and their metabolites are increased during and after acute exercise [70-73]. Results from one study indicated that a low intensity bout of exercise was unable to increase levels of DA when compared to baseline [70]. Others have shown that DA and NE remain elevated in the striatum and hippocampus ranging from 20 to 120 minutes post exercise [70, 71, 73].

Increases in neural activity could require increased blood flow. Some, but not all [74], studies show that acute exercise increases cerebral blood flow [74, 75]. Increased blood flow has been reported in the parietal cortex, the cerebellum, the premotor cortex, and the basal ganglia

[74, 75]. Whether these effects can be attributed to physical activity per se and not novelty because many studies have been conducted with animals and the extent to which rodent and pig studies generalize to humans is uncertain [76]. In humans, acute exercise can transiently increase cerebral blood flow in the thalamus, insula, and prefrontal cortex during dynamic cycling exercise [77, 78] and a meta-analysis suggest that moderate intensity exercise results in a significant increase in both brain blood flow and cerebral oxygenation [77]. A neuroimaging study conducted in 12 regularly exercising (25-40 year old) men and women reported no difference in synaptic dopamine concentration, inferred from DAD2 receptor binding, after 30 minutes of exercise that appeared to be low-to-moderate intensity (treadmill running at ~11 minute per mile pace at a 3.3% grade for the final 10-15 minutes) [79]. These findings may not generalize to ADHD patients performing higher intensity exercise for 20 minutes. A meta-analysis of the acute effects of exercise on cognition reported that the biggest effects were realized among individuals who performed exercise for 20 min or longer [67].

Conclusions

Increasingly it is recognized that signs and symptoms of ADHD can persist into young adulthood and limit the ability of those who experience these symptoms to perform optimally at school and work. Adults with signs and symptoms of ADHD are inadequately treated and there is an urgent need for safe, accessible and effective alternatives for managing the disorder. A single bout of exercise can improve signs and symptoms of ADHD in children. The one study conducted with adults had limitations in study design such as the absence of a no-exercise control condition and failure to control for medication use among participants. Evidence in rodents and humans supports that acute exercise can increase blood flow and neurotransmitters

thought to be relevant to attention; therefore, it is biologically plausible that a single bout of exercise could improve ADHD-related signs and symptoms in adult men.

References

1. Faraone, S.V. and J. Biederman, *What is the prevalence of adult ADHD? Results of a population screen of 966 adults*. Journal of Attention Disorders, 2005. **9**(2): p. 384-391.
2. Fayyad, J., et al., *Cross-national prevalence and correlates of adult attention-deficit hyperactivity disorder*. The British Journal of Psychiatry, 2007. **190**(5): p. 402-409.
3. Kessler, R., et al., *The prevalence and correlates of adult ADHD in the United States: results from the National Comorbidity Survey Replication*. American Journal of Psychiatry, 2006. **163**(4): p. 716-723.
4. Simon, V., et al., *Prevalence and correlates of adult attention-deficit hyperactivity disorder: meta-analysis*. The British Journal of Psychiatry, 2009. **194**(3): p. 204-211.
5. Blase, S.L., et al., *Self-Reported ADHD and Adjustment in College Cross-sectional and Longitudinal Findings*. Journal of Attention Disorders, 2009. **13**(3): p. 297-309.
6. Hervey, A.S., J.N. Epstein, and J.F. Curry, *Neuropsychology of adults with attention-deficit/hyperactivity disorder: a meta-analytic review*. Neuropsychology, 2004. **18**(3): p. 485.
7. Cohen, A.L. and S.K. Shapiro, *Exploring the performance differences on the flicker task and the Conners' Continuous Performance Test in adults with ADHD*. Journal of Attention Disorders, 2007. **11**(1): p. 49-63.
8. Malloy-Diniz, L., et al., *Impulsive behavior in adults with attention deficit/hyperactivity disorder: characterization of attentional, motor and cognitive impulsiveness*. Journal of the International Neuropsychological Society, 2007. **13**(04): p. 693-698.
9. Schoechlin, C. and R.R. Engel, *Neuropsychological performance in adult attention-deficit hyperactivity disorder: meta-analysis of empirical data*. Archives of Clinical Neuropsychology, 2005. **20**(6): p. 727-744.
10. Alderson, R.M., et al., *Attention-deficit/hyperactivity disorder (ADHD) and working memory in adults: A meta-analytic review*. Neuropsychology, 2013. **27**(3): p. 287.
11. Marije Boonstra, A., et al., *Executive functioning in adult ADHD: a meta-analytic review*. Psychological medicine, 2005. **35**(08): p. 1097-1108.
12. Schwanz, K.A., L.J. Palm, and S.A. Brallier, *Attention problems and hyperactivity as predictors of college grade point average*. Journal of Attention Disorders, 2007. **11**(3): p. 368-373.
13. Heiligenstein, E., et al., *Psychological and academic functioning in college students with attention deficit hyperactivity disorder*. Journal of American College Health, 1999. **47**(4): p. 181-185.
14. Barkley, R.A., et al., *Young adult outcome of hyperactive children: adaptive functioning in major life activities*. Journal of the American Academy of Child & Adolescent Psychiatry, 2006. **45**(2): p. 192-202.
15. Cornish, K.M., et al., *Association of the dopamine transporter (DAT1) 10/10-repeat genotype with ADHD symptoms and response inhibition in a general population sample*. Molecular psychiatry, 2005. **10**(7): p. 686-698.
16. Yang, B., et al., *A meta-analysis of association between a VNTR polymorphism in the 3' UTR of dopamine transporter gene and ADHD*. Journal of Attention Disorders, 2009. **13**(3): p. 300-308.

- hyperactivity disorder*. American Journal of Medical Genetics Part B: Neuropsychiatric Genetics, 2007. **144**(4): p. 541-550.
17. Franke, B., et al., *Association of the dopamine transporter (SLC6A3/DAT1) gene 9–6 haplotype with adult ADHD*. American Journal of Medical Genetics Part B: Neuropsychiatric Genetics, 2008. **147**(8): p. 1576-1579.
 18. Gizer, I.R., C. Ficks, and I.D. Waldman, *Candidate gene studies of ADHD: a meta-analytic review*. Human genetics, 2009. **126**(1): p. 51-90.
 19. Li, D., et al., *Meta-analysis shows significant association between dopamine system genes and attention deficit hyperactivity disorder (ADHD)*. Human molecular genetics, 2006. **15**(14): p. 2276-2284.
 20. Sánchez-Mora, C., *DRD4 and its interaction with SLC6A3 as possible risk factors for adult ADHD: A meta-analysis in four European* Journal of Medical Genetics Part B: Neuropsychiatric Genetics, 2011. **156**(5): p. 600-612.
 21. Langley, K., et al., *No support for association between the dopamine transporter (DAT1) gene and ADHD*. American Journal of Medical Genetics Part B: Neuropsychiatric Genetics, 2005. **139**(1): p. 7-10.
 22. Altink, M.E., et al., *The dopamine receptor D4 7-repeat allele influences neurocognitive functioning, but this effect is moderated by age and ADHD status: an exploratory study*. World Journal of Biological Psychiatry, 2012. **13**(4): p. 293-305.
 23. Reuter, M., P. Kirsch, and J. Hennig, *Inferring candidate genes for attention deficit hyperactivity disorder (ADHD) assessed by the World Health Organization Adult ADHD Self-Report Scale (ASRS)*. Journal of neural transmission, 2006. **113**(7): p. 929-938.
 24. Laucht, M., et al., *Interacting effects of the dopamine transporter gene and psychosocial adversity on attention-deficit/hyperactivity disorder symptoms among 15-year-olds from a high-risk community sample*. Archives of General Psychiatry, 2007. **64**(5): p. 585-590.
 25. Gaub, M. and C.L. Carlson, *Gender differences in ADHD: a meta-analysis and critical review*. Journal of the American Academy of Child & Adolescent Psychiatry, 1997. **36**(8): p. 1036-1045.
 26. DuPaul, G.J., et al., *Self-Report of ADHD Symptoms in University Students Cross-Gender and Cross-National Prevalence*. Journal of learning disabilities, 2001. **34**(4): p. 370-379.
 27. Kahn, R.S., et al., *Role of dopamine transporter genotype and maternal prenatal smoking in childhood hyperactive-impulsive, inattentive, and oppositional behaviors*. The Journal of pediatrics, 2003. **143**(1): p. 104-110.
 28. Rodriguez, A. and G. Bohlin, *Are maternal smoking and stress during pregnancy related to ADHD symptoms in children?* Journal of Child Psychology and Psychiatry, 2005. **46**(3): p. 246-254.
 29. Neuman, R.J., et al., *Prenatal smoking exposure and dopaminergic genotypes interact to cause a severe ADHD subtype*. Biological psychiatry, 2007. **61**(12): p. 1320-1328.
 30. Altink, M.E., et al., *The dopamine receptor D4 7-repeat allele affected children and their unaffected siblings interaction*. Journal of Child Psychology and Psychiatry, 2008. **49**(10): p. 1053-1060.
 31. Rice, F., et al., *The links between prenatal stress and offspring development and psychopathology: disentangling environmental and inherited influences*. Psychological medicine, 2010. **40**(02): p. 335-345.

32. Bhutta, A.T., et al., *Cognitive and behavioral outcomes of school-aged children who were born preterm: a meta-analysis*. *Jama*, 2002. **288**(6): p. 728-737.
33. Becker, K., et al., *Interaction of dopamine transporter genotype with prenatal smoke exposure on ADHD symptoms*. *The Journal of pediatrics*, 2008. **152**(2): p. 263-269. e1.
34. Motlagh, M.G., et al., *Adverse effects of heavy prenatal maternal smoking on attentional control in children with ADHD*. *Journal of attention disorders*, 2011. **15**(7): p. 593-603.
35. Faraone, S.V. and S.J. Glatt, *A comparison of the efficacy of medications for adult attention-deficit/hyperactivity disorder using meta-analysis of effect sizes*. *The Journal of clinical psychiatry*, 2010. **71**(6): p. 754-763.
36. Bymaster, F.P., et al., *Atomoxetine increases extracellular levels of norepinephrine and dopamine in prefrontal cortex of rat: a potential mechanism for efficacy in attention deficit/hyperactivity disorder*. *Neuropsychopharmacology*, 2002. **27**(5): p. 699-711.
37. Volkow, N.D., et al., *Relationship between blockade of dopamine transporters by oral methylphenidate and the increases in extracellular dopamine: therapeutic implications*. *Synapse*, 2002. **43**(3): p. 181-187.
38. Wilens, T.E., *Effects of methylphenidate on the catecholaminergic system in attention-deficit/hyperactivity disorder*. *Journal of clinical psychopharmacology*, 2008. **28**(3): p. S46-S53.
39. Stahl, S.M., *Mechanism of action of stimulants in attention-deficit/hyperactivity disorder*. *J Clin Psychiatry*, 2010. **71**(1): p. 12-13.
40. Rubia, K., et al., *Effects of stimulants on brain function in attention-deficit/hyperactivity disorder: a systematic review and meta-analysis*. *Biological psychiatry*, 2013.
41. Birnbaum, H.G., et al., *Costs of attention deficit-hyperactivity disorder (ADHD) in the US: excess costs of persons with ADHD and their family members in 2000*. *Current Medical Research and Opinion®*, 2005. **21**(2): p. 195-205.
42. Carpentier, P.J., et al., *A controlled trial of methylphenidate in adults with attention deficit/hyperactivity disorder and substance use disorders*. *Addiction*, 2005. **100**(12): p. 1868-1874.
43. Spencer, T.J., et al., *Efficacy and safety of dexamethylphenidate extended-release capsules in adults with attention-deficit/hyperactivity disorder*. *Biological Psychiatry*, 2007. **61**(12): p. 1380-1387.
44. Heil, S., et al., *Comparison of the subjective, physiological, and psychomotor effects of atomoxetine and methylphenidate in light drug users*. *Drug and alcohol dependence*, 2002. **67**(2): p. 149-156.
45. Aron, A.R., et al., *Methylphenidate improves response inhibition in adults with attention-deficit/hyperactivity disorder*. *Biological psychiatry*, 2003. **54**(12): p. 1465-1468.
46. Turner, D.C., et al., *Neurocognitive effects of methylphenidate in adult attention-deficit/hyperactivity disorder*. *Psychopharmacology*, 2005. **178**(2-3): p. 286-295.
47. Tucha, O., et al., *Methylphenidate-induced improvements of various measures of attention in adults with attention deficit hyperactivity disorder*. *Journal of neural transmission*, 2006. **113**(10): p. 1575-1592.
48. Medori, R., et al., *A randomized, placebo-controlled trial of three fixed dosages of prolonged-release OROS methylphenidate in adults with attention-deficit/hyperactivity disorder*. *Biological psychiatry*, 2008. **63**(10): p. 981-989.

49. Koesters, M., et al., *Limits of meta-analysis: methylphenidate in the treatment of adult attention-deficit hyperactivity disorder*. Journal of psychopharmacology, 2009. **23**(7): p. 733-744.
50. Mészáros, A., et al., *Pharmacotherapy of adult attention deficit hyperactivity disorder (ADHD): a meta-analysis*. The International Journal of Neuropsychopharmacology, 2009. **12**(08): p. 1137-1147.
51. Linderkampa, F. and G. Lauthb, *The Efficacy of Pharmacological versus Psychotherapeutic Therapies in Adults with Attention Deficit/Hyperactivity Disorder (ADHD): An Empirical Meta-Analysis*. Verhaltenstherapie, 2011. **21**(4).
52. Philipsen, A., et al., *Structured group psychotherapy in adults with attention deficit hyperactivity disorder: results of an open multicentre study*. The Journal of nervous and mental disease, 2007. **195**(12): p. 1013-1019.
53. Safren, S.A., et al., *Cognitive behavioral therapy vs relaxation with educational support for medication-treated adults with ADHD and persistent symptoms: a randomized controlled trial*. Jama, 2010. **304**(8): p. 875-880.
54. Weiss, M., et al., *A randomized controlled trial of CBT therapy for adults with ADHD with and without medication*. BMC psychiatry, 2012. **12**(1): p. 30.
55. Biederman, J., et al., *A randomized, placebo-controlled trial of OROS methylphenidate in adults with attention-deficit/hyperactivity disorder*. Biological Psychiatry, 2006. **59**(9): p. 829-835.
56. Virta, M., et al., *Adults With ADHD Benefit From Cognitive—Behaviorally Oriented Group Rehabilitation A Study of 29 Participants*. Journal of Attention Disorders, 2008. **12**(3): p. 218-226.
57. Mick, E., D.D. McManus, and R.J. Goldberg, *Meta-analysis of increased heart rate and blood pressure associated with CNS stimulant treatment of ADHD in adults*. European Neuropsychopharmacology, 2013. **23**(6): p. 534-541.
58. Adler, L.D. and A.A. Nierenberg, *Review of medication adherence in children and adults with ADHD*. Postgraduate medicine, 2010. **122**(1): p. 184-191.
59. Craft, D.H., *Effect of prior exercise on cognitive performance tasks by hyperactive and normal young boys*. Perceptual and motor skills, 1983. **56**(3): p. 979-982.
60. Mahon, A.D., et al., *Acute Exercise Effects on Measures of Attention and Impulsivity in Children with Attention Deficit/Hyperactivity Disorder*. Journal of Educational and Developmental Psychology, 2013. **3**(2): p. p65.
61. Tantillo, M., et al., *The effects of exercise on children with attention-deficit hyperactivity disorder*. Medicine & Science in Sports & Exercise, 2002.
62. Medina, J., et al., *Exercise impact on sustained attention of ADHD children, methylphenidate effects*. ADHD Attention Deficit and Hyperactivity Disorders, 2010. **2**(1): p. 49-58.
63. Chang, Y.-K., et al., *Effect of Acute Exercise on Executive Function in Children with Attention Deficit Hyperactivity Disorder*. Archives of Clinical Neuropsychology, 2012. **27**(2): p. 225-237.
64. Gawrilow, C., et al., *Physical activity, affect, and cognition in children with symptoms of ADHD*. Journal of attention disorders, 2013: p. 1087054713493318.
65. Pontifex, M.B., et al., *Exercise improves behavioral, neurocognitive, and scholastic performance in children with attention-deficit/hyperactivity disorder*. The Journal of pediatrics, 2013. **162**(3): p. 543-551.

66. Lambourne, K. and P. Tomporowski, *The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis*. Brain research, 2010. **1341**: p. 12-24.
67. Chang, Y., et al., *The effects of acute exercise on cognitive performance: a meta-analysis*. Brain research, 2012. **1453**: p. 87-101.
68. Abramovitch, A., G. Goldzweig, and A. Schweiger, *Correlates of Physical Activity with Intrusive Thoughts, Worry and Impulsivity in Adults with Attention Deficit/Hyperactivity Disorder: A Cross-sectional Pilot Study*. The Israel journal of psychiatry and related sciences, 2012. **50**(1): p. 47-53.
69. Gapin, J., et al., *Acute exercise is associated with specific executive functions in college students with ADHD: A preliminary study*. Journal of Sport and Health Science, (0).
70. Hattori, S., M. Naoi, and H. Nishino, *Striatal dopamine turnover during treadmill running in the rat: relation to the speed of running*. Brain research bulletin, 1994. **35**(1): p. 41-49.
71. Meeusen, R., et al., *Endurance training effects on neurotransmitter release in rat striatum: an in vivo microdialysis study*. Acta Physiologica Scandinavica, 1997. **159**(4): p. 335-341.
72. McMorris, T., et al., *A test of the catecholamines hypothesis for an acute exercise–cognition interaction*. Pharmacology Biochemistry and Behavior, 2008. **89**(1): p. 106-115.
73. Goekint, M., et al., *Acute running stimulates hippocampal dopaminergic neurotransmission in rats, but has no influence on brain-derived neurotrophic factor*. Journal of Applied Physiology, 2012. **112**(4): p. 535-541.
74. Delp, M.D., et al., *Exercise increases blood flow to locomotor, vestibular, cardiorespiratory and visual regions of the brain in miniature swine*. The Journal of physiology, 2001. **533**(3): p. 849-859.
75. Ide, K. and N.H. Secher, *Cerebral blood flow and metabolism during exercise*. Progress in neurobiology, 2000. **61**(4): p. 397-414.
76. Dishman, R.K., et al., *Neurobiology of exercise*. Obesity, 2006. **14**(3): p. 345-356.
77. Rooks, C.R., et al., *Effects of incremental exercise on cerebral oxygenation measured by near-infrared spectroscopy: A systematic review*. Progress in Neurobiology, 2010. **92**(2): p. 134-150.
78. Williamson, J., et al., *Activation of the insular cortex is affected by the intensity of exercise*. Journal of Applied Physiology, 1999. **87**(3): p. 1213-1219.
79. Wang, G.-J., et al., *PET studies of the effects of aerobic exercise on human striatal dopamine release*. Journal of Nuclear Medicine, 2000. **41**(8): p. 1352-1356.

CHAPTER 3

EFFECTS OF ACUTE EXERCISE ON ATTENTION, HYPERACTIVITY, MOTIVATION, AND MOOD IN YOUNG ADULT MEN WITH ELEVATED SYMPTOMS OF ATTENTION¹

¹Fritz K.M. & O'Connor P.J. To be submitted to *Medicine and Science in Sports and Exercise*.

Abstract

Purpose: Little is known about whether acute exercise affects signs and symptoms of attention deficit hyperactivity disorder (ADHD) in adults. This experiment sought to determine the effects of a single bout of moderate intensity leg cycling exercise on measures of attention, hyperactivity, related mood states, and motivation to complete mental work in adult men reporting elevated ADHD symptoms.

Methods: A repeated measures crossover experiment was conducted with 32 adult men (18-33 years) with symptoms consistent with adult ADHD assessed by the Adult Self-Report Scale V1.1. Measures of attention (CPT, Bakan), motivation to perform the mental work, lower leg physical activity (accelerometry, ActiGraph GTX3) and mood (ARCI, POMS) were measured before and twice after a 20-min seated rest control or exercise condition involving cycling at 65% VO_2 peak. Condition (Exercise versus rest) X Time (Baseline, Post-1 and Post2) ANOVAs tested hypothesized exercise-induced improvements in all outcomes.

Results. Statistically significant Condition x Time interactions were observed for vigor ($F=10.496$, $df=3.583$, 207.787 , $p<.001$, $partial\ eta^2 = .153$), ARCI-Amphetamine, $F(3.799, 235.535)$, $p <.001$, $partial\ eta^2 = .108$, motivation ($F=3.726$, $df=2,116$, $p=.027$, $partial\ eta^2 = .060$), fatigue ($F=2.740$, $df=3.947$, 228.951 , $p<.030$, $partial\ eta^2 = .045$) and confusion ($F=2.580$, $df=3.516$, 203.931 , $p<.046$, $partial\ eta^2 = .043$). No significant interaction effects were observed for hyperactivity or performance (accuracy, errors or reaction time) on tasks requiring sustained attention. When the conditions were combined, leg movement was significantly higher for the more difficult Bakan task compared to the easier CPT at baseline on Day 1 ($t(27) = -2.051$, $p = .05$) and at the second post-treatment time on Day 2 ($t(27) = -2.183$, $p = .038$).

Conclusion. In young men reporting elevated symptoms of ADHD, a 20-minute bout of moderate intensity exercise transiently enhances motivation for cognitive tasks, increases feelings of energy and reduces feelings of fatigue, confusion, and depression but has no effect on the behavioral measures of attention or hyperactivity.

Keywords: accelerometry, ADHD, mood, motivation, vigilance

Introduction

Symptoms of Attention Deficit Hyperactivity Disorder (ADHD) among adults are common. A survey of ~20,000 U.S. adults with no childhood diagnosis of ADHD found that 6.2% reported symptoms of hyperactivity and/or inattention to an extent that they screened positive for ADHD. Those who screened positive for adult ADHD were on average less educated, more likely to be unemployed, and reported more missed work days, traffic citations and accidents compared to those who did not screen positive for adult ADHD [1].

Adults experiencing above average ADHD symptoms at times attempt to self-manage symptoms by taking stimulant medications which increase feelings of energy and clear headedness [2]. Nonmedical use of prescription medication among college students has been reported to be 8.9% [3], and ADHD symptoms are higher among those using non-prescribed stimulant medication compared to stimulant nonusers [3, 4]. Potential negative side effects of stimulant use include sleep difficulties, appetite suppression and irritability [3]. Another limitation of stimulant use is that 35 to 50% of ADHD patients treated do not obtain adequate symptom relief from these medications [5, 6]. Thus, there is ongoing interest in safe and effective alternative techniques for adults to better self-manage ADHD symptoms.

Acute aerobic exercise results in psychological changes that may benefit adults with elevated ADHD symptoms. Behavioral data from healthy adults show that cognitive

performance can be enhanced after 20 or more minutes of moderate intensity aerobic exercise [7]. Twenty to 30 minutes of acute moderate intensity exercise performed by children diagnosed with ADHD has resulted in improvements in attention [8-11] and hyperactivity [12]. Two studies with null findings used short bouts of exercise (~10 mins) which may have been an inadequate exercise stimulus to bring about psychological benefits [13, 14]. One study has been conducted investigating the effects of a single bout of exercise on attention among adults with ADHD [15]. Low-to-moderate intensity treadmill exercise of 35 minutes had no significant effect on working memory or task-switching performance but was associated with better performance on the Stroop test among 10 individuals diagnosed with ADHD. A clear interpretation of these findings is impossible, however, because of several design limitations including the absence of a no-exercise control condition and differences in stimulant medication use among the study participants.

The purpose of the experiment summarized here was to determine if an acute bout of moderate intensity cycling exercise would increase sustained attention, reduce hyperactivity, and improve mood or motivation to complete mental work in young adult men with above average ADHD symptoms. It was hypothesized that after exercise, compared to a no-exercise control condition in which little change was expected, (i) performance on sustained attention tasks would improve, (ii) motivation to complete the tasks would be increased, (iii) lower leg movements (i.e., hyperactivity) during the cognitive tests would be reduced, (iv) related mood states would be improved (e.g., confusion and fatigue would be reduced), and (v) the mood changes would mimic those reported after amphetamine consumption.

Methods

Sample

Participants were recruited using listservs, flyers, and verbal announcements in academic classes. In order to qualify participants had to be male, 18-34 years old, not currently taking central acting medication, without contraindications to exercise, and screen positive for adult ADHD. Smokers were excluded as were those indicating a current mental disorder other than ADHD. An *a priori* statistical power analysis with SPSS version 22 was conducted , and a sample of 32 was sufficient to provide a statistical power of .80 for the hypothesized treatment X time interactions, assuming an alpha error of .05 and a correlation of $r=.90$ between repeated measures across time [16]. An effect size of $d = .30$ was expected and used in the power analysis based on results from two meta-analyses investigating the acute effects of moderate intensity exercise on cognitive performance in adults [7, 17].

Measures

Screening Questionnaires

A questionnaire was used to obtain demographic and health-related background information and to screen out participants using psychoactive medication. 247 individuals completed the screening questionnaire, with 46 men meeting the study inclusion criteria. The Physical Activity Readiness Questionnaire (PAR-Q) is a 7-item questionnaire that was used to determine if an individual had contraindications to maximal exercise. The Godin Leisure-Time Exercise Questionnaire was used to estimate leisure-time physical activity. Respondents were asked to indicate “how many times on average” they completed more than 15 minutes of strenuous, moderate, or mild exercise during a typical 7 day period. Total weekly leisure activity was calculated in arbitrary units by summing the products of the separate components using the

following formula: Total weekly leisure activity score = (9 X Strenuous) + (5 X Moderate) + (3 X Light) [18].

The Adult ADHD Self-Report Scale V1.1 (ASRS V1.1) was used to identify participants who had elevated symptoms of inattention or hyperactivity consistent with ADHD. The ASRS V1.1 is a six-item questionnaire that asks about the frequency of feelings or conduct over the past 6 months with five response categories: never, rarely, sometimes, often, and very often. Four questions involve attention and two concern hyperactivity, the questions are: (1) How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?, (2) How often do you have difficulty getting things in order when you have to do a task that requires organization?, (3) How often do you have problems remembering appointments or obligations?, (4) When you have a task that requires a lot of thought, how often do you avoid or delay getting started?, (5) How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?, and (6) How often do you feel overly active and compelled to do things, like you were driven by a motor? For screening purposes, each question is scored as positive (given a 1) or negative (given a 0) for ADHD and the six items are summed. Answers of “never” and “rarely” are always scored as negative while “often” and “very often” are always scored as positive. For the first three questions, “sometimes” is scored as a positive. A total score > 4 was used because it indicates a person’s symptoms may be consistent with Adult ADHD [19]. The sensitivity, specificity, and total classification accuracy of the ASRS total score was found to be 69.7%, 99.5%, and 97.9%, respectively in a study of 154 adults with ADHD [19]. Adult ADHD predicted from the total ARSR score was associated with a 4-5% reduction in work performance and increased sickness absence in a longitudinal study of more than 6,900 manufacturing workers [20]. Inattention and hyperactivity scores also were obtained from

responses on the ASRS, with questions 1-4 contributing to the inattention score and questions 5 and 6 contributing to the hyperactivity score. The scoring for each response was 0-4 with “never” corresponding to “0” and “very often” corresponding to “4.” Please see the Appendix A for ASRS-V1.1.

Cognitive Tests

The Continuous Performance Task (CPT) was one of two tests used to assess sustained attention. During the CPT participants were presented 12 different letters in Times New Roman (font size 60) (A, C, E, H, K, N, P, Q, S, U, X, Z) individually for 200 ms with an interstimulus interval of 800 ms. Participants were required to respond to a target letter (X) only when preceded by a cue (A). The CPT was 16 minutes in duration with a total of 179 correct responses and 930 total stimuli [21].

The more difficult Bakan Vigilance (dual) Task was also used to assess sustained attention. Random individual numbers (1-9) were presented for 1000 ms. Participants were instructed that they had a primary and secondary objective during the task. The primary objective was to identify any series of three consecutive odd numbers that were different (e.g. 5, 1, 9 or 7, 3, 1) by pressing a button with their right thumb. The secondary task was to identify any presentation of the number “6” and respond by pressing a different button. The Bakan Vigilance Task was also 16 minutes in duration, during which there were a total of 960 stimuli with 8 primary targets and 96 secondary targets.

A Simple Reaction Time task was used to assess psychomotor speed. Participants were presented a warning stimulus (fixation cross) followed by the response stimulus (red circle). Participants were instructed to respond as fast as they could to the red circle by pressing a button on the response pad with their preferred hand. There were 3 practice trials, followed by 5 test

trials. The interval separating the warning stimulus and the response stimulus varied and ranged from 500 ms to 1000 ms.

Motivation to Perform the Cognitive Tasks

A 10- cm visual Analog Scale (VAS) was used to assess motivation to perform the cognitive tasks. Participants indicate their level of motivation to complete mental work using a sliding ruler on a line on the computer. The verbal anchors ranged from 0 indicating “No Motivation” to 100 indicating “Highest Motivation Imaginable.”

Hyperactivity/ Lower Leg Activity Counts

The ActiGraph GTX3 accelerometer was used to measure lower leg movements during the cognitive tests as an index of hyperactivity. Accelerometers are becoming a more common method of measuring hyperactivity in individuals with ADHD. Results from these studies have shown higher activity counts for those diagnosed with ADHD when compared to those without ADHD [22-24]. The participants were told that the accelerometers were being used to measure leg movement during the exercise but the true purpose was to measure leg movement during the cognitive tasks. The dimensions and weight of the device were 4.6 cm X 3.3 cm X 1.5 cm and 19 grams, respectively. A sampling rate of 100 Hz was used. Participants wore one accelerometer on each ankle during testing. Data were downloaded in 1-sec epochs. Useable activity count data from all participants were obtained from 880 seconds during the CPT and 947 seconds during the Bakan. Total activity counts from each test were divided by time and expressed as counts/min.

Mood Questionnaires

The Profile of Mood States-Brief Form (POMS-BF) is a well-validated 30-item questionnaire which was used to assess the intensity of six different moods: tension, anger, depression, confusion, vigor, and fatigue. Responses range from 0 (indicating not at all) to 4

(indicating extremely) [25]. Participants were asked to indicate how they felt “right now, at this moment.”

The Addiction Research Center Inventory is a 49-item questionnaire. Responses to each item on this questionnaire are “True” or “False,” [26]. The amphetamine subscale was developed based on statistical analysis of items selected based on sentence completion statements made by opiate addicts under a no-drug condition and after the consumption of the stimulant d-amphetamine (A-scale) [27]. Experimental administration of amphetamines increases scores on the A-scale [2]. In this study the d-amphetamine sensitive subscale was used. See the Appendix B for ARCI-49 items and scoring of the amphetamine scale.

Procedures

The experiment was a within participants, crossover design with one 20 minute treatment (cycle ergometry at 65% VO_2 peak) and one 20 minute non-exercise comparison (seated rest control). Testing sessions were at the same time of day for most participants, but due to logistical reasons three participants were tested at a different times of day. Cognitive tests and mood questionnaires were administered at three times points for each experimental day (pre-treatment baseline, post-treatment trial 1, and post-treatment trial 2). Order of treatment was blocked randomized in blocks of two. All testing was approved by the University of Georgia Institutional Review Board.

Male students were recruited via student listservs, in-class presentations, and flyers. Potential participants were directed to complete an online screening questionnaire administered via Qualmetrics. The screening questionnaire included an informed consent for screening, a demographic and health-related questionnaire, the PAR-Q, the Godin Leisure-Time Exercise

Questionnaire, and the ASRS. Those completing the screening questionnaire were informed of their eligibility, and if eligible, were invited for baseline testing.

Baseline Day (Day 1)

Upon arrival to the laboratory for the initial visit, participants read the informed consent. If a participant agreed to participate, he then provided written informed consent. After signing the informed consent, the participant then performed practice trials of the cognitive tests (SRT, CPT, and Bakan vigilance task) after first being provided with instructions on how to complete the tasks. Performance on the practice trials was checked to determine if participants understood the instructions. If performance was below a criterion based on a previous study [28], the participant completed another round of practice to insure the instructions were understood.

After completion of the practice trials participants then performed a graded maximal exercise test on a cycle ergometer. Participants were fitted with a Polar heart rate monitor and a face mask to measure expired gasses. Using open circuit spirometry, expired air was collected and analyzed by a Parvo Medics TrueOne 2400 Metabolic Measurement System (Parvo Medics, Inc., Sandy, UT) to determine rates of oxygen uptake and associated cardiorespiratory and metabolic variables. Standard gases of known composition were used to calibrate the oxygen and carbon dioxide analyzers, and a 3-L syringe was used to calibrate the pneumotachometer prior to each testing session. Participants were instructed to maintain a cadence between 60 and 80 revolutions per minute (RPM) during the maximal exercise test and warmed up for three minutes at 50 watts. After the warmup, resistance was increased by 25 watts every 2 minutes until the participant was no longer able to continue. A cool-down at 50 watts began immediately after the participant indicated he was no longer able to continue with the maximal exercise test.

At the end of each stage, overall ratings of perceived exertion (6-20), quadriceps muscle pain intensity (0-10), VO_2 , CO_2 , Ve , RER and heart rate were recorded.

Experimental Days (Days 2 and 3)

After participants arrived at the laboratory, they confirmed no caffeine within 6 hours of testing, no exercise the day of the visit, and a normal prior night's sleep (plus or minus one hour of typical sleep duration). Accelerometers were placed on each ankle. Participants then completed the first trial of mood questionnaires (POMS-BF, ARCI, and VAS of motivation) followed by the first trial of cognitive tests. After completing the cognitive tests, participants then completed another set of the mood questionnaires. Participants were then allocated to one of two 20 minute conditions (quiet rest or cycling at 65% VO_2 peak). For the exercise condition, participants warmed up at 50 watts for 2 minutes, after which resistance was increased. The level of resistance was designed to elicit 65% of a participant's VO_2 peak and was determined using the American College of Sport Medicine's leg cycling equation [29]. For the no-exercise condition, participants sat quietly on the cycle ergometer for 20 minutes. Immediately following the 20 minute condition, participants then repeated the testing outcome procedures twice (post-treatment 1 and post-treatment 2). A summary of the timing of the study procedures is provided in Table 3.1.

Statistical Analysis

Preliminary Analysis

IBM SPSS Statistics (Version 22.0) was used for all data analyses. For the cognitive data, each data file was scored using Cedrus Data Viewer 2.0 (Cedrus Corp., 2007) and then imported into SPSS. Mood, ARCI, and motivation data were scored using excel and then entered into SPSS. Due to technological issues there was a loss of left leg activity data (~16%). All data were

examined for normality (assessed from Kolmogorov-Smirnov tests $<.05$), homoscedasticity and outliers. For some variables outliers were removed (>2 standard deviations from the mean), for others non-normal data (skewness > 2.00) were transformed using log transformation.

Preliminary repeated measures ANOVAs were conducted using all cases and then repeated with outliers removed. Results from these preliminary analyses did not reveal a difference in statistical significance between the approaches for any of the outcome variables. Therefore, the primary analyses used all cases with non-normal variables log transformed.

Primary Analysis

Condition (2: Exercise vs. Rest control) X Time (3: Baseline, Post 1, Post 2) repeated measures ANOVAs and ANCOVAs were used to test the hypotheses which predicted significant Condition X Time interactions for the cognitive performance, hyperactivity, motivation, and mood measures. VO_{2peak} , ventilatory threshold, and self-reported physical activity were used individually as covariates. Using these covariates did not significantly influence the results, consequently only the ANOVA results are presented. A responder analysis was conducted with participants who responded favorably on variables at both post-treatment time points for the exercise condition. RMANOVAs were then conducted for those participants with those variables, comparing responses in the exercise and rest conditions. Adjustments for sphericity, when needed, were made using Huynh-Feldt epsilon. Simple effects analysis was used to decompose significant interactions, using the Bonferroni correction to adjust the degrees of freedom.

Post-hoc Analysis.

Dependent t-tests examined whether leg movement was significantly higher for the more difficult Bakan task compared to the easier CPT on testing days 1 or 2 for the conditions combined.

Results

Participants

Participant characteristics (*M, SD*) are presented in Table 3.2. The participants in this study had lower than average levels of self-reported physical activity compared to prior studies of college men [30] and lower fitness levels on average when compared to large studies of men of the same age category performing cycle ergometry. [31] Two participants in the sample reported having been diagnosed with ADHD.

Outcomes

Descriptive statistics (*M, SD*) for leg activity counts during the cognitive tests, performance on the cognitive tests, mood, and motivation to complete mental work are provided in Tables 3.3-3.5.

Hyperactivity

The condition-by-time interactions for right leg hyperactivity ($p = .324$, $partial\ eta^2 = .029$) and left leg hyperactivity ($p = .474$, $partial\ eta^2 = .046$) during the CPT were not statistically significant. The condition-by-time interactions for right leg hyperactivity ($p = .638$, $partial\ eta^2 = .004$) and left leg hyperactivity ($p = .937$, $partial\ eta^2 = .016$) during the Bakan Vigilance Task were not statistically significant. The activity counts for the right and left legs were combined and summed for those participants with complete data ($n = 23$). The condition-

by-time interaction for summed activity during the CPT was not significant, ($p = .094$, *partial eta*² = .052). The condition-by-time interaction for summed activity during the Bakan Vigilance task was also not statistically significant, ($p = .844$, *partial eta*² = .004). Paired *t*-tests were conducted for each condition to test for differences in activity counts during the CPT and Bakan Vigilance tasks. Results from these analyses revealed that activity counts during the Bakan Vigilance task were significantly higher at baseline, $t(27) = -2.351$, $p = .026$, and at post-treatment 1, $t(27) = -2.394$, $p = .024$. There were no significant differences in activity counts during the two vigilance tasks on the rest day ($p > .05$). Paired *t*-tests were also conducted to test for differences in activity counts during the two vigilance tasks for the first and second visits. Results from these analyses revealed that on the first visit, activity counts during the Bakan Vigilance task were significantly higher than activity counts during the CPT at baseline (i.e., before the experimental condition), $t(27) = -2.051$, $p = .05$. For the second visit, activity counts were significantly higher during the Bakan Vigilance task than during the CPT at post-treatment 2, $t(27) = -2.183$, $p = .038$.

Motivation to complete mental work

As illustrated in Figure 3.1, there was a significant time-by-condition interaction for motivation to complete mental work, $F(2, 116) = 3.726$, $p = .027$, *partial eta*² = .060. Results from simple effects analysis for the main effect of time revealed that for the exercise condition, motivation to complete mental work was significantly higher at post-treatment 1 than at post-treatment 2 ($p = .024$). Results from simple effects analysis looking at the main effect of time for the rest condition revealed that motivation to complete mental work did not significantly change overtime. Results from the simple effects analysis comparing the two conditions revealed that

motivation to complete mental work was significantly higher for the exercise condition than the rest condition at post-treatment 1 ($p = .001$) and post-treatment 2 ($p = .044$).

Simple Reaction Time (SRT)

There was no significant time-by-condition interaction for performance on the simple reaction time test ($p = .153$, $partial\ eta^2 = .029$).

Continuous Performance Test (CPT)

There were no significant condition-by-time interactions for the CPT outcome variables: percentage correct ($p = .880$, $partial\ eta^2 = .002$), false alarm errors ($p = .374$, $partial\ eta^2 = .018$), reaction time ($p = .974$, $partial\ eta^2 < .001$), or omission errors ($p = .788$, $partial\ eta^2 = .001$).

Bakan Vigilance Task

There were no significant time-by-condition interactions for the Primary Bakan Vigilance task: percentage correct ($p = .370$, $partial\ eta^2 = .004$), false alarm errors ($p = .882$, $partial\ eta^2 < .001$), reaction time ($p = .282$, $partial\ eta^2 = .028$), or omission errors ($p = .827$, $partial\ eta^2 = .004$). There were no significant time-by-condition interactions for the Secondary Bakan Vigilance task: percentage correct ($p = .381$, $partial\ eta^2 = .002$), false alarm errors ($p = .762$, $partial\ eta^2 = .005$), reaction time ($p = .874$, $partial\ eta^2 = .001$), and omission errors ($p = .640$, $partial\ eta^2 = .004$).

Profile of Mood States (POMS)

The condition-by-time interactions for tension ($p = .183$, $partial\ eta^2 = .018$) and anger ($p = .217$, $partial\ eta^2 = .020$) were not statistically significant.

As illustrated in Figure 3.2, the condition-by-time interaction for vigor was statistically significant, $F(3.224, 199.900) = 12.630$, $p < .001$, $partial\ eta^2 = .169$. For the main effect of time

during the exercise condition, results from simple effects analyses revealed that vigor was significantly higher at Post-1 than all other time points besides Baseline 1 ($p < .001$). However, vigor scores returned to pre-treatment levels (Baseline 2) by Post 2 ($p = .092$). Results from the simple effects analysis looking at the main effect of time for the rest condition revealed that vigor scores were significantly reduced after the first administration of vigilance tests (CT-1) ($p < .001$) and remained significantly lower than Baseline 1 ($p < .001$). When comparing the rest and exercise conditions, results from the simple effects analysis showed that vigor at post-treatment time points 1 and 2 was significantly higher for the exercise condition ($p < .05$).

As shown in Figure 3.3, the condition-by-time interaction for confusion was statistically significant, $F(3.420, 212.014) = 3.396, p = .046, partial\ eta^2 = .052$. Results from simple effects analysis looking at the main effect of time revealed that confusion scores at all three post-treatment time points were not significantly different from confusion scores at Baseline 1 in the exercise condition ($p > .05$). For the rest condition confusion was significantly increased after the first administration of the vigilance tests (CT-1) ($p = .005$) and remained significantly elevated ($p < .05$). When comparing the exercise and rest conditions, results from simple effects analysis showed that confusion was significantly lower for the exercise condition at post-treatment time points 1 and 2 ($p < .05$).

As illustrated in Figure 3.4, the condition-by-time interaction for depression was statistically significant, $F(2.646, 164.052) = 3.299, p = .027, partial\ eta^2 = .051$. Results from simple effects analysis revealed that for the exercise condition, depression scores at post-1 were significantly lower when compared to baseline depression scores ($p = .001$) and depression scores returned to baseline values by post-2. Depression scores in the rest condition did not significantly change over time ($p > .05$). When comparing the exercise and rest conditions, results from simple

effects analysis revealed that depression scores were significantly lower for the exercise condition at post-1 ($p = .005$).

As illustrated in figure 3.5, the condition-by-time interaction for fatigue was statistically significant, $F(4, 248) = 2.616, p = .036, partial\ eta^2 = .040$. Results from simple effects analysis looking at the main effect of time revealed that fatigue scores for the exercise condition at post-treatment 1 and post-treatment 2 were not significantly different from Baseline 1 fatigue scores ($p > .05$), but fatigue was significantly higher at post-treatment 3 than Baseline 1 ($p < .001$). For the rest condition, fatigue scores were significantly higher at post-treatment 2 and 3 than at Baseline 1 ($p < .001$). When comparing the exercise and rest conditions, results from the simple effects analysis revealed that fatigue was significantly lower for the exercise condition at the post-treatment time point 2 ($p = .035$).

Addiction Research Center Inventory

As illustrated in figure 3.6, the condition-by-time interaction for the ARCI A subscale was statistically significant, $F(3.799, 235.535) = 7.525, p < .001, partial\ eta^2 = .108$. Results from simple effects analysis revealed that looking at the main effect of time for the exercise condition, ARCI A subscale scores were significantly higher at post-1 compared to all other time points ($p < .001$) with scores returning to baseline values by post 2. For the rest condition, ARCI A subscale scores were highest as the baseline 1 compared to all other time points ($p < .006$) besides post-1 ($p = .843$). Results from the simple effects analysis showed that scores on the ARCI A subscale were significantly higher for the exercise condition at post-treatment 1 ($p < .001$) and post-treatment 2 ($p = .003$) when compared to the rest condition.

Responder Analysis

Results from the responder analysis indicated that 11 participants responded favorably after exercise for accuracy on the Bakan Vigilance Secondary Task. The condition-by-time interaction was statistically significant, $F(2, 36)$, $p = .023$, $partial\ eta^2 = .189$. Results from simple effects analysis revealed that for the exercise condition, accuracy significantly increased from baseline to post-treatment 1 ($p < .001$) and to post-treatment 2 ($p = .01$). There were no differences in performance over time for the rest condition, nor were there differences in performance between the exercise and rest conditions.

Discussion

The purpose of the current study was to determine the effects of a single bout of moderate intensity exercise on attention, hyperactivity, mood, and motivation for mental work in men reporting above average ADHD symptoms. The primary finding was that when compared to a no-exercise control condition, 20 minutes of moderate intensity cycling exercise enhanced motivation for mental work, increased feelings of energy and reduced feelings of fatigue, confusion, and depression, but had no effect on cognitive performance or hyperactivity. To our knowledge, this is the first study to measure changes in mood in adult men reporting elevated ADHD symptoms.

Acute exercise had the largest effect on increasing feelings of vigor. The finding is consistent with results from other studies with fatigued or normal adults showing increases in feelings of vigor after an acute bout of exercise [32, 33]. While it is plausible that exercise-induced feeling of energy might provoke hyperactivity among those at increased risk for ADHD, increased vigor scores after the exercise condition were not accompanied by significantly higher leg hyperactivity levels compared to the rest condition. Responses for vigor were similar to

responses on the ARCI A subscale (see Figures 3.2 and 3.6). Increased scores in the ARCI A subscale after administration of a prescription stimulant (Ritalin) have been shown to be related to feelings of energy and level of stimulation [34]. The increase in vigor scores reported after exercise could possibly be due to a similar mechanism to that of prescription stimulants. Brain imaging studies have revealed increases in dopamine (DA) after acute administration of a prescription stimulants [35]. Increases in DA have also been reported after acute exercise in animals [36, 37] but not in humans [38].

Immediately after exercise the increased feelings of fatigue induced by the attention tasks was attenuated. This resulted in significantly lower fatigue scores when compared to the rest condition. This finding is potentially interesting as it suggests that 20 minutes of moderate intensity exercise may delay the fatiguing effects of cognitive tests requiring sustained attention in adults reporting ADHD symptoms. One previous study investigated the effects of 60 minutes of moderate intensity exercise on mental fatigue and cognitive performance in healthy college students [39]. Results from this study did not show an attenuating effect of exercise on increased feelings of mental fatigue induced by 40 minutes of cognitive testing. Adults at increased risk for ADHD may respond to exercise and cognitive testing with a pattern that differs from adults who are not at risk for ADHD.

Motivation to complete mental work was significantly higher after the exercise condition when compared to seated rest. This finding is unique because motivation to complete mental work has rarely been measured in studies examining the cognitive effects of acute exercise. Twenty minutes of moderate intensity exercise resulted in significant increases in motivation to complete the cognitive tasks. Previous studies have shown that individuals with ADHD have reduced DA receptor availability in the nucleus accumbens (NAcc), an area thought to be

involved with motivation [40, 41]. DA receptor availability in the NAcc has also been shown to be positively related to scores for trait motivation [40]. The finding in the present study suggests that moderate intensity exercise could be beneficial for those with signs and symptoms of ADHD who may have a more difficult time staying motivated to complete mental work. One plausible mechanism for how acute exercise might increase motivation for mental work could be an increase in DA in the areas involved with motivation such as the NAcc. Results from animal studies have shown increases in DA after acute exercise [36, 37]. Whether or not increases in DA after acute exercise are related to changes in motivation to complete mental work needs to be further investigated.

The significant improvements in mood after the exercise condition were not accompanied by significantly better performance on the attention tasks compared to the rest condition. One reason for the null findings in regards to the attention tasks may be the exercise stimulus used. The exercise duration and intensity used in this study was based on previous research in healthy adults [7, 17] and in children with ADHD [9, 11, 42]. Adults with ADHD or those with elevated ADHD symptoms may require a different “dose” of exercise than the one used in the current study to be able to experience improvements in attention. Another reason the acute exercise bout did not have an effect on cognitive performance may be due to the cognitive tests used in this study. The CPT and Bakan Vigilance Task require sustained attention to perform well. It may have been useful to have administered an inhibitory control test (e.g., Stroop test, switch-test, or Go/No-Go task) in lieu of one of the sustained attention tasks to assess other dimensions of the deficits associated with ADHD symptoms. It may be noteworthy that a sub-set of participants did respond to exercise by improving the accuracy of their performance on the secondary task of the

Bakan. The finding implies that acute exercise could improve certain aspects of attention in some individuals.

To our knowledge, only one previous study has examined the effects of acute exercise on an index of hyperactivity [12]. The results revealed that motor impersistence (i.e., the measure of hyperactivity used) was improved after maximal exercise but not after submaximal (65-75% VO_{2peak}) or seated rest. Thus, the absence of significant differences in hyperactivity after exercise in the present study may have been due to inadequate exercise intensity.

It is interesting that hyperactivity was significantly higher during the Bakan Vigilance task when compared to the CPT. The Bakan Vigilance task is a dual task that is more cognitively demanding than the CPT and may have used more attentional resources. This finding runs counter to traditional thinking that attention and hyperactivity are negatively related. The present finding is consistent with one study which showed that in adults with ADHD, hyperactivity assessed by accelerometry was significantly higher during two working memory tasks when compared to a control condition [43]. Previous studies that did not use accelerometry have investigated hyperactivity relationships with cognitive performance and found mixed results. One study with healthy, non-ADHD adults found worse performance with increased hyperactivity [44] and one study of children with ADHD found improved performance with increased hyperactivity [45].

The primary findings of the current study were that after 20 minutes of moderate intensity exercise, men characterized by elevated ADHD symptoms reported improvements in mood and increased motivation to complete mental work. The improvements in mood were transient, lasting approximately 45 minutes. The effects of immediate release stimulants have been found to last about 3 hours, and individuals taking these drugs require repeated administration across

the day to manage their ADHD symptoms [46]. One previous study investigated the effects of administration of d-amphetamine on changes in mood in low and high sensation seekers using similar measures to those in the current study. Results from that study showed increases in feelings of vigor and scores on the ARCI d-amphetamine scale that were similar to those in the current study, but these effects did not occur until 50-110 minutes after drug administration [47]. The effects of acute moderate exercise may not last as long as the effects of stimulant medications based on findings from the current study, but the effects of acute exercise could be more immediate, meaning these individuals could possibly benefit sooner when compared to stimulant medications. It is also worth noting that the high sensation seeking individuals in the Kelly et al. 2009 study had higher ADHD symptomology when compared to the low sensation seekers. The high sensation seekers also started with similar vigor and ARCI d-amphetamine scores to those in the current study. The increases on these measures after administration of d-amphetamine were not large as those seen in the current study. It would be interesting to directly compare the effects of acute exercise and short-acting stimulant medications with regards to changes in vigor and ARCI d-amphetamine scores.

Even though the significant mood findings were not accompanied by significant improvements in cognitive performance or hyperactivity, they do provide evidence for a beneficial effect of acute moderate intensity exercise for those experiencing ADHD symptoms. Results from this study could indicate that after exercise, these individuals may persist longer in tasks requiring sustained mental effort. The one study conducted with adults diagnosed with ADHD found significant post-exercise improvements in performance on the Stroop task in the color-word condition though a non-exercise control condition was not employed [15]. Tasks that emphasize inhibitory functions may be more sensitive to an exercise stimulus than tasks that lack

such emphasis. This could explain why in the current study, exercise did not have an effect on cognitive performance and why results from another study found a significant effect of exercise on cognitive performance [15]. A possible reason for the null results found in the present study could be that different brain regions and circuits are used in cognitive versus motivational processes. Previous studies have indicated that the dorsolateral prefrontal cortex (DLPFC) and the inferior frontal cortex (IFC) appear to be more involved with cognitive processes, including attention and inhibitory control, whereas the orbitofrontal cortex (OFC) appears to be more important in regulating motivational and emotional processing [29, 30]. Although speculative, there is a possibility that the exercise stimulus used here affected the above mentioned brain areas differently.

It is also noteworthy that the participants on the average had lower fitness levels compared to men of a similar age who completed a peak exercise test on a cycle ergometer [31]. This did not appear to be primarily because of an inadequate test. All but one participant were characterized by perceived exertion, heart rate and respiratory quotient responses that supported peak exercise test performance. The finding is consistent with the observation that compared to healthy adults, patients with mental disorders are more often characterized by low cardiorespiratory fitness and fail to meet criteria supportive of a maximal effort [48].

The current study is not without limitations. One limitation is the generalizability of results to adults diagnosed with ADHD. Participants included in the current study screened positive for ADHD based upon responses to the ASRS-V1.1., and were not required to have an ADHD diagnosis. The cognitive tests used in this study assessed the ability to sustain attention, but may have been insensitive to change with exercise in the group studied. More difficult or engaging tasks or those emphasizing other psychological outcomes may have yielded different

results. There is the possibility that moderate intensity exercise could have a positive effect on cognitive performance, but the tests used in the current study did not emphasize those processes that may have been most influenced (e.g., inhibitory control). Others have suggested that using multiple assessments (i.e., cognitive batteries) could assist in obtaining a better overall perspective of the effects of acute exercise on cognitive performance [49]. Another limitation of the current study was measuring hyperactivity only in the lower limbs as there may be individual differences in fidgeting based on which body location is assessed (e.g., legs vs. arms). With the devices used in the current study (i.e., Actigraph GTX3 accelerometer) it would have been difficult to measure head or upper limb movements without participants being more consciously aware of the devices and which might have increased the chance of participants guessing the hypotheses of the study.

In conclusion, results from the current study suggest that men reporting above average ADHD symptoms may benefit from an acute bout of moderate intensity exercise by experiencing increases in mood and motivation to complete mental work. Future studies with adults at increased risk for, and diagnosed with, ADHD should investigate if acute exercise affects cognitive performance on different types of tasks than the ones used in the current study. It would also be beneficial to determine if various duration and intensities of exercise are able to more greatly affect hyperactivity [12].

References

1. Able, S.L., et al., *Functional and psychosocial impairment in adults with undiagnosed ADHD*. Psychological Medicine, 2007. **37**(01): p. 97-107.
2. Ballard, M.E., D.A. Gallo, and H. de Wit, *Amphetamine increases errors during episodic memory retrieval*. Journal of clinical psychopharmacology, 2014. **34**(1): p. 85.
3. Rabiner, D.L., et al., *Motives and perceived consequences of nonmedical ADHD medication use by college students are students treating themselves for attention problems?* Journal of Attention Disorders, 2009. **13**(3): p. 259-270.
4. Arria, A.M., et al., *Persistent nonmedical use of prescription stimulants among college students: possible association with ADHD symptoms*. Journal of attention disorders, 2011. **15**(5): p. 347-356.
5. Medori, R., et al., *A randomized, placebo-controlled trial of three fixed dosages of prolonged-release OROS methylphenidate in adults with attention-deficit/hyperactivity disorder*. Biological psychiatry, 2008. **63**(10): p. 981-989.
6. Biederman, J., et al., *A randomized, placebo-controlled trial of OROS methylphenidate in adults with attention-deficit/hyperactivity disorder*. Biological Psychiatry, 2006. **59**(9): p. 829-835.
7. Chang, Y., et al., *The effects of acute exercise on cognitive performance: a meta-analysis*. Brain research, 2012. **1453**: p. 87-101.
8. Gawrilow, C., et al., *Physical activity, affect, and cognition in children with symptoms of ADHD*. Journal of attention disorders, 2013: p. 1087054713493318.
9. Medina, J., et al., *Exercise impact on sustained attention of ADHD children, methylphenidate effects*. ADHD Attention Deficit and Hyperactivity Disorders, 2010. **2**(1): p. 49-58.
10. Piepmeier, A.T., et al., *The effect of acute exercise on cognitive performance in children with and without ADHD*. Journal of Sport and Health Science, (0).
11. Pontifex, M.B., et al., *Exercise improves behavioral, neurocognitive, and scholastic performance in children with attention-deficit/hyperactivity disorder*. The Journal of pediatrics, 2013. **162**(3): p. 543-551.
12. Tantillo, M., et al., *The effects of exercise on children with attention-deficit hyperactivity disorder*. Medicine & Science in Sports & Exercise, 2002.
13. Craft, D.H., *Effect of prior exercise on cognitive performance tasks by hyperactive and normal young boys*. Perceptual and motor skills, 1983. **56**(3): p. 979-982.
14. Mahon, A.D., et al., *Acute Exercise Effects on Measures of Attention and Impulsivity in Children with Attention Deficit/Hyperactivity Disorder*. Journal of Educational and Developmental Psychology, 2013. **3**(2): p. p65.
15. Gapin, J., et al., *Acute exercise is associated with specific executive functions in college students with ADHD: A preliminary study*. Journal of Sport and Health Science, (0).
16. D'Amico, E.J., T.B. Neilands, and R. Zambarano, *Power analysis for multivariate and repeated measures designs: A flexible approach using the SPSS MANOVA procedure*. Behavior Research Methods, Instruments, & Computers, 2001. **33**(4): p. 479-484.
17. Lambourne, K. and P. Tomporowski, *The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis*. Brain research, 2010. **1341**: p. 12-24.

18. Godin, G. and R. Shephard, *A simple method to assess exercise behavior in the community*. Canadian journal of applied sport sciences. Journal canadien des sciences appliquees au sport, 1985(10): p. 141-6.
19. Kessler, R.C., et al., *The World Health Organization Adult ADHD Self-Report Scale (ASRS): a short screening scale for use in the general population*. Psychological medicine, 2005. **35**(02): p. 245-256.
20. Kessler, R., et al., *The prevalence and workplace costs of adult attention deficit hyperactivity disorder in a large manufacturing firm*. Psychological medicine, 2009. **39**(01): p. 137-147.
21. Rosvold, H.E., et al., *A continuous performance test of brain damage*. Journal of consulting psychology, 1956. **20**(5): p. 343.
22. Dane, A.V., R.J. Schachar, and R. Tannock, *Does actigraphy differentiate ADHD subtypes in a clinical research setting?* Journal of the American Academy of Child & Adolescent Psychiatry, 2000. **39**(6): p. 752-760.
23. Inoue, K., et al., *Clinical evaluation of attention-deficit hyperactivity disorder by objective quantitative measures*. Child Psychiatry and Human Development, 1998. **28**(3): p. 179-188.
24. Tsujii, N., et al., *Association between activity level and situational factors in children with attention deficit/hyperactivity disorder in elementary school*. Psychiatry and clinical neurosciences, 2007. **61**(2): p. 181-185.
25. McNair, D., et al., *Profile of Mood States-Brief Form*. Multi-Health Systems (MHS), North Tonawanda, NY, 2003.
26. Arasteh, K., et al., *Response patterns of the Spanish version of the 49-item short form of the Addiction Research Center Inventory after the use of sedatives, stimulants, and opioids*. Drug and alcohol dependence, 1999. **55**(1): p. 117-125.
27. Haertzen, C.A., *An Overview of Addiction Research Center Inventory Scales (ARCI): An Appendix and Manual of Scales*. 1974.
28. Maridakis, V., P.J. O'Connor, and P.D. Tomporowski, *Sensitivity to change in cognitive performance and mood measures of energy and fatigue in response to morning caffeine alone or in combination with carbohydrate*. International Journal of Neuroscience, 2009. **119**(8): p. 1239-1258.
29. Glass, S., G.B. Dwyer, and A.C.o.S. Medicine, *ACSM's metabolic calculations handbook*. 2007: Lippincott Williams & Wilkins.
30. Wang, C.-Y., et al., *Cardiorespiratory fitness levels among US adults 20–49 years of age: findings from the 1999–2004 National Health and Nutrition Examination Survey*. American journal of epidemiology, 2010. **171**(4): p. 426-435.
31. Loe, H., et al., *Aerobic capacity reference data in 3816 healthy men and women 20–90 years*. 2013.
32. Loy, B.D., P.J. O'Connor, and R.K. Dishman, *The effect of a single bout of exercise on energy and fatigue states: a systematic review and meta-analysis*. Fatigue: Biomedicine, Health & Behavior, 2013. **1**(4): p. 223-242.
33. Hansen, C.J., L.C. Stevens, and J.R. Coast, *Exercise duration and mood state: how much is enough to feel better?* Health Psychology, 2001. **20**(4): p. 267.
34. Looby, A. and M. Earleywine, *Expectation to receive methylphenidate enhances subjective arousal but not cognitive performance*. Experimental and clinical psychopharmacology, 2011. **19**(6): p. 433.

35. Volkow, N.D., et al., *Methylphenidate-elicited dopamine increases in ventral striatum are associated with long-term symptom improvement in adults with attention deficit hyperactivity disorder*. The Journal of Neuroscience, 2012. **32**(3): p. 841-849.
36. Hattori, S., M. Naoi, and H. Nishino, *Striatal dopamine turnover during treadmill running in the rat: relation to the speed of running*. Brain research bulletin, 1994. **35**(1): p. 41-49.
37. Meeusen, R., et al., *Endurance training effects on neurotransmitter release in rat striatum: an in vivo microdialysis study*. Acta Physiologica Scandinavica, 1997. **159**(4): p. 335-341.
38. Wang, G.-J., et al., *PET studies of the effects of aerobic exercise on human striatal dopamine release*. Journal of Nuclear Medicine, 2000. **41**(8): p. 1352-1356.
39. Moore, R.D., et al., *The influence of exercise-induced fatigue on cognitive function*. Journal of sports sciences, 2012. **30**(9): p. 841-850.
40. Volkow, N.D., et al., *Motivation deficit in ADHD is associated with dysfunction of the dopamine reward pathway*. Mol Psychiatry, 2011. **16**(11): p. 1147-1154.
41. Cubillo, A., et al., *A review of fronto-striatal and fronto-cortical brain abnormalities in children and adults with Attention Deficit Hyperactivity Disorder (ADHD) and new evidence for dysfunction in adults with ADHD during motivation and attention*. Cortex, 2012. **48**(2): p. 194-215.
42. Chang, Y.-K., et al., *Effect of Acute Exercise on Executive Function in Children with Attention Deficit Hyperactivity Disorder*. Archives of Clinical Neuropsychology, 2012. **27**(2): p. 225-237.
43. Hudec, K.L., et al., *Working Memory Contributes to Elevated Motor Activity in Adults With ADHD An Examination of the Role of Central Executive and Storage/Rehearsal Processes*. Journal of attention disorders, 2014. **18**(4): p. 357-368.
44. Farley, J., E. Risko, and A. Kingstone, *Everyday Attention and Lecture Retention: The Effects of Time, Fidgeting, and Mind Wandering*. Frontiers in Psychology, 2013. **4**.
45. Hartanto, T., et al., *A trial-by-trial analysis reveals more intense physical activity is associated with better cognitive control performance in attention-deficit/hyperactivity disorder*. Child Neuropsychology, 2015(ahead-of-print): p. 1-9.
46. Modi, N.B., B. Lindemulder, and S.K. Gupta, *Single -and Multiple- Dose Pharmacokinetics of an Oral Once -a- Day Osmotic Controlled-OROS®(methylphenidate HCl) Formulation*. The Journal of Clinical Pharmacology, 2000. **40**(4): p. 379-388.
47. Kelly, T.H., et al., *Performance and subjective effects of diazepam and d-amphetamine in high and low sensation seekers*. Behavioural pharmacology, 2009. **20**(5-6): p. 505.
48. Lavoie, K.L., et al., *Are exercise stress tests appropriate for assessing myocardial ischemia in patients with major depressive disorder?* American Heart Journal, 2004. **148**(4): p. 621-627.
49. Etnier, J.L. and Y.-K. Chang, *The effect of physical activity on executive function: a brief commentary on definitions, measurement issues, and the current state of the literature*. Journal of sport & exercise psychology, 2009(31): p. 469-83.

Figure Captions

Figure 3.1.: Motivation to complete mental work (0-100) (mean and SE) for the exercise and rest conditions. Motivation was significantly higher after exercise when compared to the rest condition.

Figure 3.2.: Profile of Mood States (POMS) Vigor (mean and SE) scores in the exercise and rest conditions. Cognitive tests were performed before (CT-1) and twice after the treatments (CT-2, CT-3). There was a significant increase in vigor scores after exercise that persisted to the second post-treatment time period.

Figure 3.3.: Profile of Mood States (POMS) Depression (mean and SE) scores in the exercise and rest conditions. Cognitive tests were performed before (CT-1) and twice after the treatments (CT-2, CT-3). There was a significant decrease in depression scores after exercise at the first post-treatment time period.

Figure 3.4.: Profile of Mood States (POMS) Fatigue (mean and SE) scores in the exercise and rest conditions. Cognitive tests were performed before (CT-1) and twice after the treatments (CT-2, CT-3). The increase in fatigue caused by the cognitive tests was attenuated after exercise at the first post-treatment time period

Figure 3.5.: Profile of Mood States (POMS) Confusion (mean and SE) scores in the exercise and rest conditions. Cognitive tests were performed before (CT-1) and twice after the treatments (CT-2, CT-3). There was a significant decrease in confusion scores after exercise at both the first and second post-treatment time periods

Figure 3.6.: Addiction Research Center Inventory d-amphetamine (A) subscale (mean and SE) scores in the exercise and rest conditions. Cognitive tests were performed before (CT-1)

and twice after the treatments (CT-2, CT-3). There was a significant increase in scores on the A subscale after exercise at both the first and second post-treatment time periods.

Table 3.1. Timing of study procedures

Time (hours:min)	Task	Test Phase
Day 1		
0:00-0:02	Greet participant	Practice
0:02-0:10	Participant completes informed consent	Practice
0:10-0:15	Put Accelerometers on participant	Practice
0:15-0:18	Explain and Practice Simple Reaction Time test	Practice
0:18-0:28	Explain and Practice Bakan Vigilance Task	Practice
0:28-0:38	Explain and Practice Continuous Performance Test	Practice
0:38-0:43	Check Performance and repeat practice trials if need be	Practice
0:43-1:03	Perform Maximal Exercise test	Practice
1:03-1:05	Remove Accelerometers	Practice
1:05-1:06	Schedule next visit	Practice
Days 2 & 3		
0:00-0:02	Greet participant	Baseline
0:02-0:05	Confirm compliance to requested pre-test procedures	Baseline
0:05-0:10	Put Accelerometers on participant	Baseline
0:10-0:13	POMS & ARCI questionnaires	Baseline 1
0:13-0:14	Motivation to complete mental work (VAS)	Baseline
0:14-0:15	Simple Reaction Time task (SRT-1)	Baseline
0:15-0:31	Continuous Performance Task (CPT-1_	Baseline
0:31-0:47	Bakan Vigilance Task (BVT-1)	Baseline
0:47-0:50	POMS & ARCI questionnaires	Baseline 2
0:50-1:10	Experimental Condition (20 min quiet seated rest or 20 min cycling at 65% VO ₂ peak)	Treatment
1:10-1:13	POMS & ARCI questionnaires	Post-Treatment 1
1:13-1:14	Motivation to complete mental work (VAS)	Post-Treatment 1
1:14-1:15	Simple Reaction Time Task (SRT-2)	Post-Treatment 1
1:15-1:31	Continuous Performance Task (CPT-2)	Post-Treatment 1
1:31-1:47	Bakan Vigilance Task (BVT-2)	Post-Treatment 1
1:47-1:50	POMS & ARCI questionnaires	Post-Treatment 2
1:50-1:51	Motivation to complete mental work (VAS)	Post-Treatment 2
1:51-1:52	Simple Reaction Time task (SRT-3)	Post-Treatment 2
1:52-2:08	Continuous Performance Task (CPT-3)	Post-Treatment 2
2:08-2:24	Bakan Vigilance Task (BVT-3_	Post-Treatment 2
2:24-2:27	POMS & ARCI questionnaires	Post-Treatment 2
2:27-2:29	Remove Accelerometers	

Table 3.2.

Descriptive characteristics of the sample			
Measure	Mean	SD	Range
Sample Characteristics:			
Age (years)	21	2.9	18-33
Height (cm)	177.9	7.0	163-191
Weight (kg)	75.9	12.2	52.7-113.2
BMI	23.9	3.0	16.6-32.4
VO _{2peak} :			
VO _{2peak} (ml/kg/min)	38.2	7.2	25.2-55.4
Power _{peak} (watts)	225.8	40.4	150-325
RER _{peak} (VCO ₂ /VO ₂)	1.2	.1	.99-1.5
RPE _{peak} (6-20)	18.1	1.7	13-20
HR _{Max} (bpm)	188.7	8.2	169-202
Leg pain _{peak} (0-10)	7.6	1.8	3-10
Power output at 65% VO _{2peak}	127.9	25.9	69-191
Godin leisure-time physical activity			
Strenuous	26.7	13.1	0-63
Moderate	15.9	9.6	0-35
Mild	14.4	7.4	3-30
Total Score	57.0	23.2	9-103
ADHD symptoms (ASRS V1.1)			
Inattention (0-16)	9.9	1.9	7-14
Hyperactivity (0-8)	5.4	1.1	4-8
Total Score (0-6)	4.6	0.8	4-6

Table 3.3

Means and Standard Deviations for CPT Performance and raw leg movements during the CPT						
Measure	Exercise			Rest		
	Baseline	Post-Treatment 1	Post-Treatment 2	Baseline	Post-Treatment 1	Post-Treatment 2
CPT Accuracy (%)	94.1 (4.4)	90.7 (7.9)	88.9(11.0)	92.3 (6.0)	89.0 (10.2)	88.1 (12.3)
False Alarms Errors (%)	1.5 (0.9)	2.1 (1.1)	2.6 (2.0)	1.6 (0.8)	2.1 (1.0)	2.4 (1.1)
Reaction Time (ms)	325.4 (43.6)	310.9 (56.0)	300.9 (60.8)	329.9 (45.8)	314.6 (57.5)	305.9 (67.1)
Omission Errors (%)	5.9 (4.4)	9.3 (7.9)	10.9 (10.9)	7.7 (6.0)	11.0 (10.2)	11.9 (12.3)
Right leg movements (counts/min)	164.5 (220.8)	139.6 (130.3)	201.0 (193.1)	184.3 (180.5)	247.8 (301.1)	195.4 (184.0)
Left leg movements (counts/min)	128.0 (132.9)	177.2 (239.5)	243.8 (307.4)	188.8 (153.5)	189.3 (274.5)	191.4 (134.2)

Table 3.4
Means and Standard Deviations for Simple Reaction Time and Bakan Vigilance Task performance and raw leg movements during the Bakan.

Measure	Exercise			Rest		
	Baseline	Post-1	Post-2	Baseline	Post-1	Post-2
Bakan Vigilance Primary Task						
Accuracy (%)	79.0(26.7)	70.6 (28.6)	74.2 (23.3)	76.6 (21.1)	69.0 (21.9)	68.5 (25.8)
False Alarm Errors (%)	0.8 (4.5)	2.8 (6.2)	2.4 (6.0)	2.0 (4.7)	3.6 (7.4)	3.6 (5.8)
Reaction Time (ms)	611.1 (90.2)	594.7 (134.6)	626.3 (101.6)	631.9 (66.6)	622.9 (64.7)	601.5 (81.6)
Omission Errors (%)	20.2 (24.9)	26.6 (26.0)	23.4 (22.5)	21.4 (21.0)	27.4 (22.2)	27.8 (25.1)
Bakan Vigilance Secondary Task						
Accuracy (%)	91.1 (8.7)	90.2(17.8)	90.6 (8.6)	89.1 (15.3)	89.6 (12.0)	89.1 (10.8)
False Alarm Errors (%)	0.7 (1.3)	0.6 (0.8)	0.7 (1.0)	0.6 (1.2)	0.7 (1.1)	0.5 (0.7)
Reaction Time (ms)	650.7 (56.8)	644.3 (75.1)	642.1 (52.5)	659.4 (58.3)	657.9 (72.2)	653.2 (58.0)
Omission Errors (%)	8.3 (8.4)	9.2 (17.8)	8.7 (8.8)	10.3 (15.4)	9.7 (12.1)	10.0 (10.7)
Simple Reaction Time test						
Reaction Time (ms)	254.3 (30.3)	243.9 (20.0)	248.0(23.0)	254.0 (30.3)	255.8 (23.1)	251.2 (20.2)
Right leg movements (counts/min)	276.0 (274.9)	297.8 (337.3)	266.9 (319.3)	221.2 (183.0)	259.3 (221.2)	254.6 (279.0)
Left leg movements (counts/min)	257.9 (228.3)	205.7 (200.9)	249.0 (316.7)	277.3 (221.7)	307.6 (316.4)	295.0 (275.5)

Table 3.5

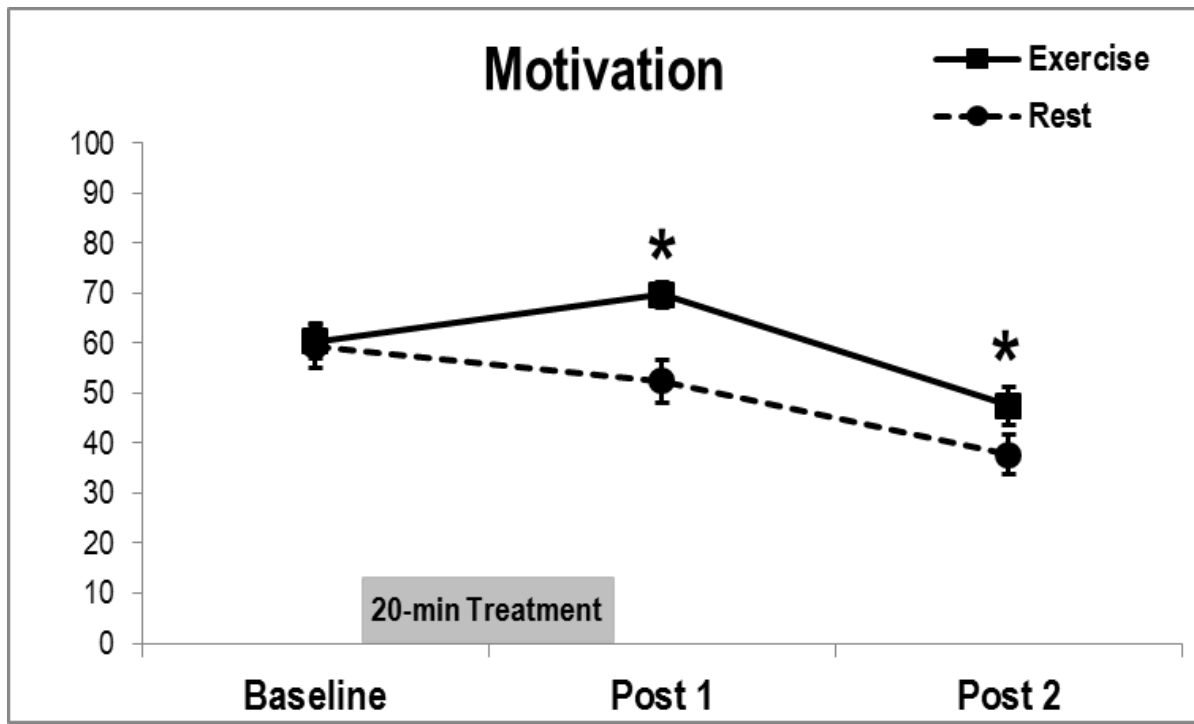
Means and Standard Deviations for Mood and Motivation scores in the Exercise Condition.

Measure	Baseline-1	Baseline-2	Post-1	Post-2	Post-3
Tension	2.0(2.6)	1.7 (2.0)	1.1 (1.6)	1.1 (1.6)	1.2 (1.4)
Depression	1.4 (2.2)	1.5 (2.2)	0.1 (0.246)	0.3 (0.9)	0.7 (1.4)
Anger	1.0 (1.4)	2.0 (2.868)	0.2 (0.5)	1.4 (1.7)	2.6 (3.3)
Vigor	6.8 (4.3)	3.3 (4.3)	8.8 (4.6)	4.5 (4.0)	3.4 (3.7)
Fatigue	3.6 (3.0)	5.9 (4.2)	3.7 (3.3)	4.0 (3.2)	6.6 (2.8)
Confusion	3.1 (1.5)	4.0 (2.0)	2.7 (1.5)	3.4 (1.8)	3.6 (1.5)
Motivation to complete mental work	60.3 (19.6)		69.7 (14.3)		47.5(21.2)
ARCI A subscale	3.4 (2.1)	2.2 (1.8)	5.5 (2.2)	3.2 (2.6)	2.6 (2.2)

Table 3.6
Means and Standard Deviations for Mood and Motivation scores in the Rest Condition.

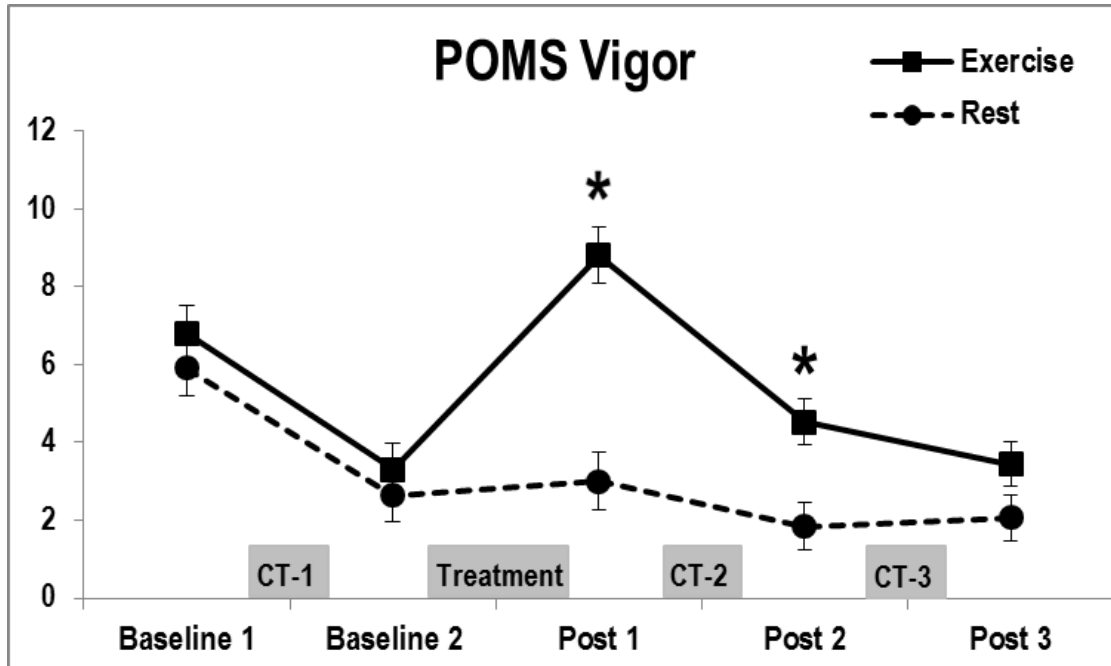
Measure	Baseline-1	Baseline-2	Post-1	Post-2	Post-3
Tension	1.7 (2.0)	1.5 (2.0)	0.9 (1.4)	1.4 (1.9)	1.5 (1.9)
Depression	1.0 (2.0)	1.2 (1.9)	0.8(1.3)	1.0 (1.9)	1.2 (2.1)
Anger	1.0 (1.2)	1.7 (2.0)	0.9 (1.0)	2.1 (2.4)	2.3 (3.3)
Vigor	5.9 (4.0)	2.6 (3.1)	3.0 (3.8)	1.8 (2.8)	2.1 (2.8)
Fatigue	3.7(3.1)	6.4 (4.2)	4.1 (3.0)	5.9 (3.8)	6.2 (4.2)
Confusion	3.1 (1.5)	4.2 (1.8)	4.0 (1.6)	4.3 (1.9)	4.3 (1.8)
Motivation to complete mental work	59.3 (22.9)		52.4 (23.2)		37.7 (21.6)
ARCI A subscale	3.4 (1.9)	1.9 (1.4)	2.5 (2.1)	1.6 (1.2)	1.8 (1.6)

Figure 3.1



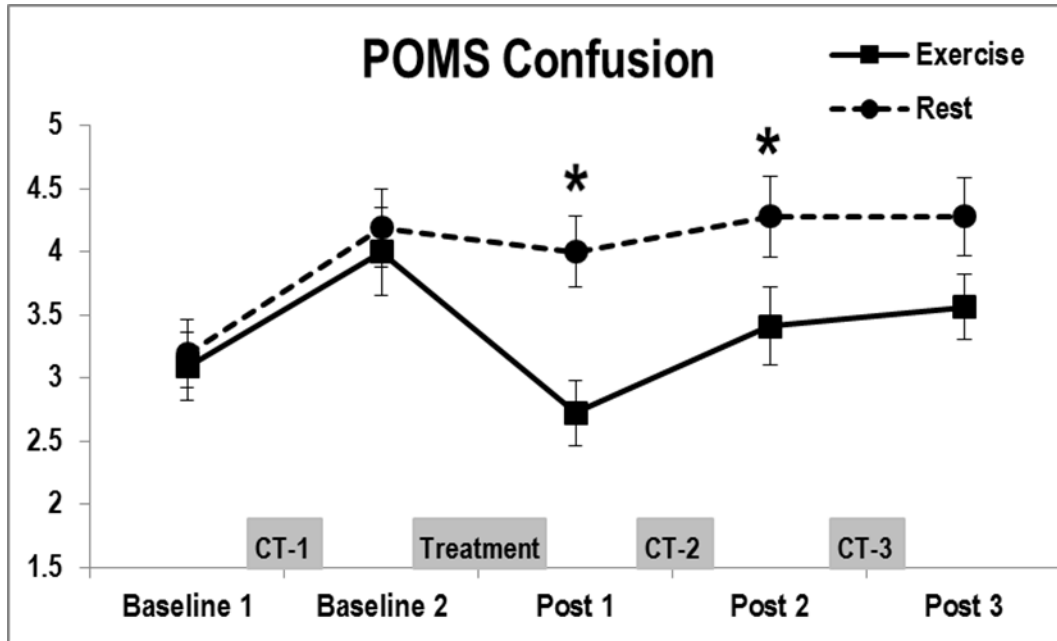
Significant difference between the exercise and seated rest condition: $(p < .05)$.

Figure 3.2



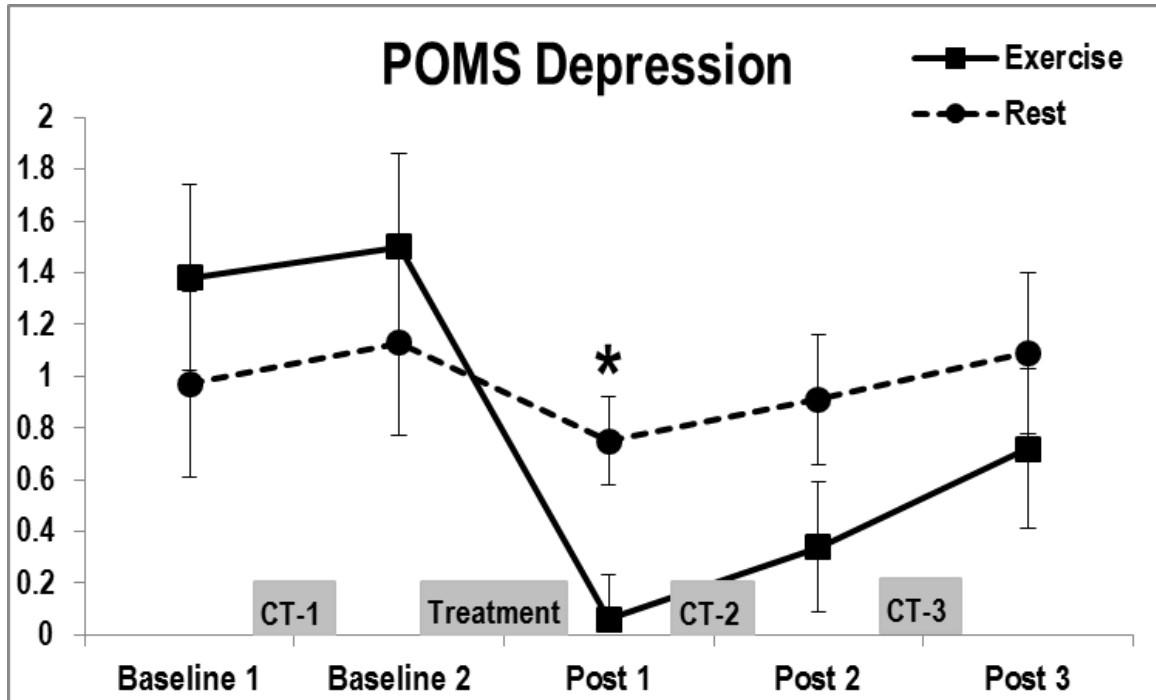
Significant difference between the exercise and seated rest condition: $(p < .05)$.

Figure 3.3.



Significant difference between the exercise and seated rest condition: $(p < .05)$.

Figure 3.4.



Significant difference between the exercise and seated rest condition: $(p < .05)$.

Figure 3.5.

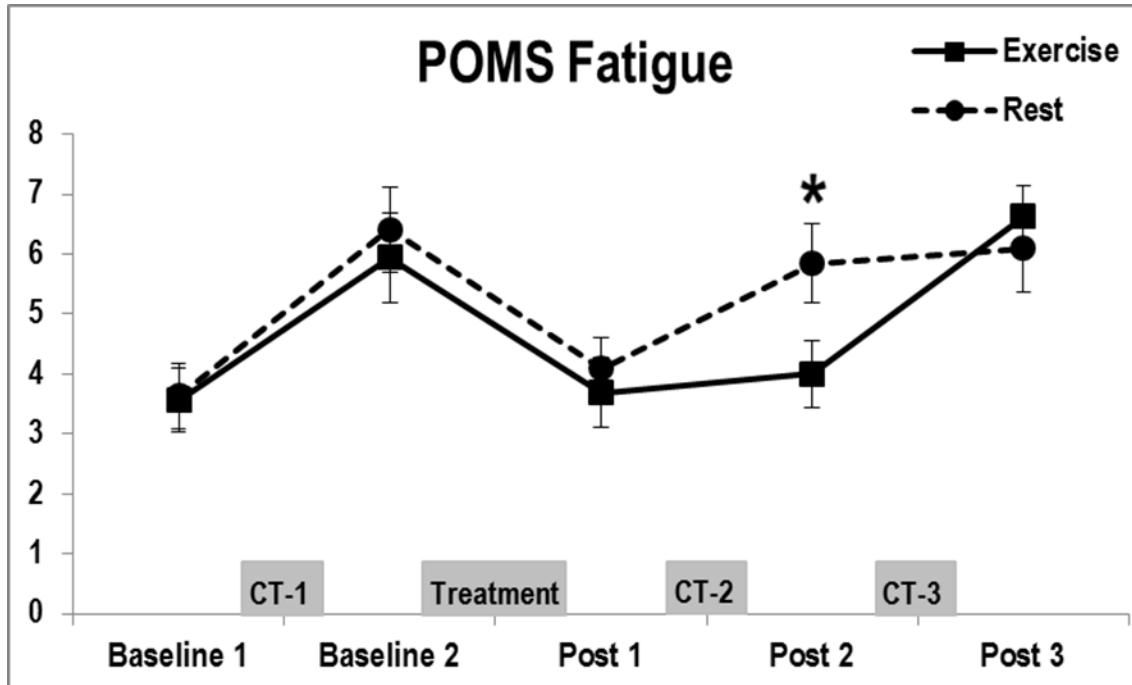
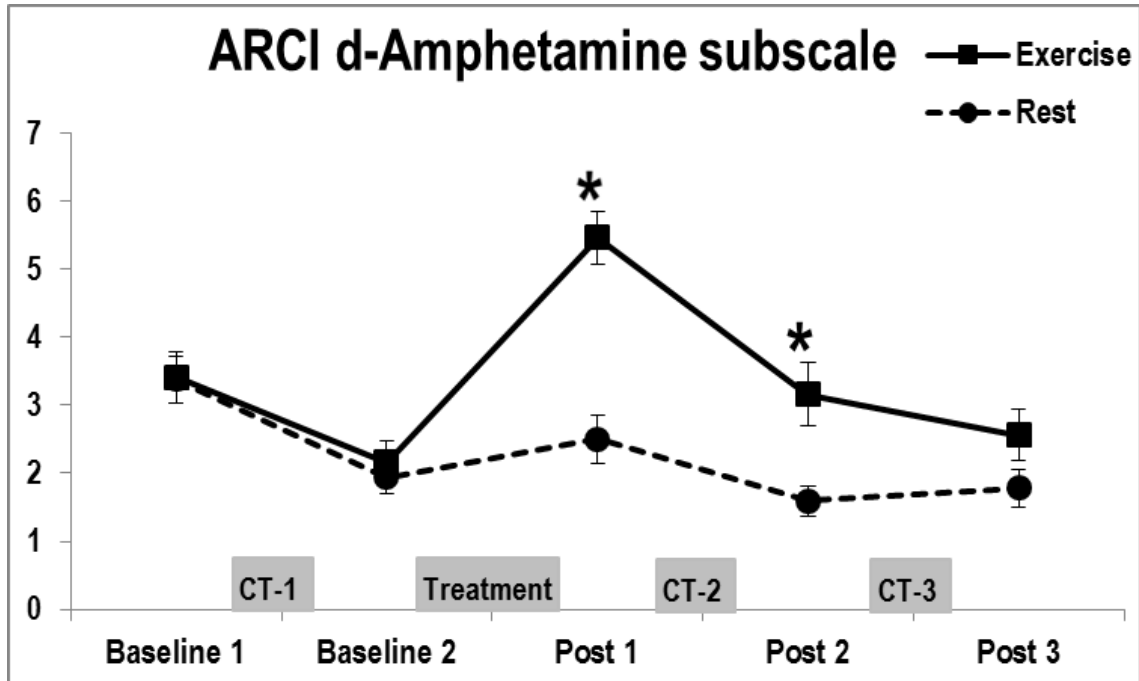


Figure 3.6.



Significant difference between the exercise and seated rest condition: $*(p < .05)$.

CHAPTER 4

CONCLUSION

The purpose of this thesis was to investigate the effects of a single bout of moderate intensity exercise on signs and symptoms of Attention Deficit Hyperactivity Disorder (ADHD) in young adult men reporting elevated ADHD symptoms.

ADHD symptoms are common among US adults and have been reported to range up to 6.2% [1]. Adults experiencing ADHD symptoms may attempt to self-medicate with stimulants which are associated with negative side effects [2], and in 35-50% of individuals, do not always reduce ADHD symptoms in a clinically meaningful way [3, 4]. Previous studies have indicated acute exercise may alleviate ADHD signs and symptoms as indicated with cognitive performance [5-8] and measures of hyperactivity [9]. To our knowledge, one previous study has been conducted with adults diagnosed with ADHD [7]. Results revealed increased performance on the Stroop test after moderate intensity exercise for those with ADHD, but interpretation of the findings is difficult due to limitations in study design such as the absence of a no-exercise control condition and differences in medication use among study participants.

The purpose of the experiment included in this thesis was to determine the effects of acute moderate intensity cycling exercise on attention, lower limb hyperactivity, mood, and motivation to complete mental work. The primary findings of the investigation were that after 20 minutes of moderate intensity exercise, men reporting elevated ADHD symptoms had increased motivation to complete mental work and vigor and reported reduced feelings of fatigue, depression and confusion when compared to a no-exercise control condition. There were no

differences in cognitive performance or hyperactivity between the exercise and rest conditions. To our knowledge this is the first study to attempt to measure the effects of acute exercise on attention, hyperactivity, mood, and motivation for cognitive tasks in men screening positive for ADHD.

After the exercise condition, participants reported significantly higher levels of vigor which previous studies have also shown [10]. After the exercise condition there was also an attenuation in feelings of fatigue induced by ~32 minutes of cognitive testing. Results from one previous study using a 60 minute bout of moderate intensity cycling exercise did not reveal an attenuating effect of exercise on feelings of mental fatigue after 40 minutes of cognitive testing [11]. This could indicate differences between samples with and without increased risk for ADHD or that when exercising at a moderate intensity, short bouts versus longer bouts, could be more beneficial when trying to reduce the fatiguing effects of mental work lasting ~30 minutes or more. Future studies should try to determine how different intensities and durations of exercise affect feelings of fatigue associated with cognitive tests.

Results from this study indicate that individuals with signs and symptoms of ADHD may experience mood improvements after 20 minutes of moderate intensity exercise. An interesting finding of the study was participants reported significantly higher motivation to complete mental work after exercise when compared to the no-exercise condition. This increased motivation to complete mental work, however, was not associated with increased cognitive performance. It could be that the cognitive tests used in this study were limited because they focused primarily on one cognitive process (vigilance) and an effect may have been seen if a different type of cognitive task had been used such as one that focused on inhibitory control. Future studies should include cognitive tasks that assess different cognitive processes as it is possible that

exercise affects these processes differently. It has also been suggested by others that including multiple cognitive tests assessing different aspects of cognition may help to better assess participants' cognitive performance [12]. Results from this study should also encourage other researchers investigating the effects of exercise on cognitive performance to measure motivation to complete mental work. The increase in motivation could indicate individuals at increased risk for ADHD would be more likely to persist during longer, naturally occurring mental work such as studying for exams.

Lastly, results from the study did not reveal an effect of exercise on hyperactivity. To our knowledge, only one previous study has measured hyperactivity in children with ADHD and found improvements in hyperactivity only after maximal exercise [9]. For adults with ADHD symptoms, this could indicate that more intense exercise is needed to see an improvement in hyperactivity. It would be interesting to investigate the effects of a more intense exercise bout, such as a high intensity interval training session, on hyperactivity in those with ADHD symptoms.

In conclusion, 20 minutes of moderate intensity exercise may benefit men reporting elevated ADHD symptoms. These benefits include increased motivation to complete mental work and feelings of vigor, an attenuation of feelings of fatigue associated with sustained vigilance testing, and a reduction in confusion and depression. The exercise stimulus used in the experiment was unable to affect cognitive performance and hyperactivity. Acute exercise has been shown to improve cognitive performance in healthy adults, and the exercise stimulus used in this study was based on results from two meta-analyses [13, 14]. It is possible that adults with ADHD and with elevated ADHD symptoms require a more intense and or longer bout of exercise in order to improve attention. Future studies should aim to determine the influence of

various exercise types, intensities, and durations on signs and symptoms of ADHD in adults with ADHD or at risk for ADHD.

References

1. Able, S.L., et al., *Functional and psychosocial impairment in adults with undiagnosed ADHD*. Psychological Medicine, 2007. **37**(01): p. 97-107.
2. Rabiner, D.L., et al., *Motives and perceived consequences of nonmedical ADHD medication use by college students are students treating themselves for attention problems?* Journal of Attention Disorders, 2009. **13**(3): p. 259-270.
3. Medori, R., et al., *A randomized, placebo-controlled trial of three fixed dosages of prolonged-release OROS methylphenidate in adults with attention-deficit/hyperactivity disorder*. Biological psychiatry, 2008. **63**(10): p. 981-989.
4. Biederman, J., et al., *A randomized, placebo-controlled trial of OROS methylphenidate in adults with attention-deficit/hyperactivity disorder*. Biological Psychiatry, 2006. **59**(9): p. 829-835.
5. Medina, J., et al., *Exercise impact on sustained attention of ADHD children, methylphenidate effects*. ADHD Attention Deficit and Hyperactivity Disorders, 2010. **2**(1): p. 49-58.
6. Pontifex, M.B., et al., *Exercise improves behavioral, neurocognitive, and scholastic performance in children with attention-deficit/hyperactivity disorder*. The Journal of pediatrics, 2013. **162**(3): p. 543-551.
7. Gapin, J., et al., *Acute exercise is associated with specific executive functions in college students with ADHD: A preliminary study*. Journal of Sport and Health Science, (0).
8. Gawrilow, C., et al., *Physical activity, affect, and cognition in children with symptoms of ADHD*. Journal of attention disorders, 2013: p. 1087054713493318.
9. Tantillo, M., et al., *The effects of exercise on children with attention-deficit hyperactivity disorder*. Medicine & Science in Sports & Exercise, 2002.
10. Loy, B.D., P.J. O'Connor, and R.K. Dishman, *The effect of a single bout of exercise on energy and fatigue states: a systematic review and meta-analysis*. Fatigue: Biomedicine, Health & Behavior, 2013. **1**(4): p. 223-242.
11. Moore, R.D., et al., *The influence of exercise-induced fatigue on cognitive function*. Journal of sports sciences, 2012. **30**(9): p. 841-850.
12. Etner, J.L. and Y.-K. Chang, *The effect of physical activity on executive function: a brief commentary on definitions, measurement issues, and the current state of the literature*. Journal of sport & exercise psychology, 2009(31): p. 469-83.
13. Lambourne, K. and P. Tomporowski, *The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis*. Brain research, 2010. **1341**: p. 12-24.
14. Chang, Y., et al., *The effects of acute exercise on cognitive performance: a meta-analysis*. Brain research, 2012. **1453**: p. 87-101.

Appendices

Adult ADHD Self-Report Scale-V1.1 (ASRS-V1.1)					
	Never	Rarely	Sometimes	Often	Very Often
1. How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?					
2. How often do you have difficulty getting things in order when you have to do a task that required organization?					
3. How often do you have problems remembering appointments or obligations?					
4. When you have a task that requires a lot of thought, how often do you avoid or delay getting started?					
5. How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?					
6. How often do you feel overly active and compelled to do things, like you were driven by a motor?					

Note: Participants had to have at least 4 checked boxes in the shaded areas to be included in the study. For inattention and hyperactivity scores, items 1-4 were used for inattention and items 5 and 6 for hyperactivity.

Addiction Research Center Inventory

1. My speech is slurred.	T F	26. My thoughts come more easily than usual.	T F
2. I am not as active as usual.	T F	27. I feel less discouraged than usual.	T F
3. I have a feeling of dragging along rather than coasting.	T F	28. I am in the mood to talk about the feeling I have.	T F
4. I feel sluggish.	T F	29. I feel more excited than dreamy.	T F
5. My head feels heavy.	T F	30. Answering these questions was very easy today.	T F
6. I feel like avoiding people although I usually do not feel this way.	T F	31. My memory seems sharper to me than usual.	T F
7. I feel dizzy.	T F	32. I feel as if I could write for hours.	T F
8. It seems harder than usual to move around.	T F	33. I feel very patient.	T F
9. I am moody.	T F	34. Some parts of my body are tingling.	T F
10. People might say that I am a little dull today.	T F	35. I have a weird feeling.	T F
11. I feel drowsy.	T F	36. My movements seem faster than usual.	T F
12. I am full of energy.	T F	37. I have better control over myself than usual.	T F
13. Today I say things in the easiest possible way.	T F	38. My movements seem slower than usual.	T F
14. Things around me seem more pleasing than usual.	T F	39. I find it hard to keep my mind on a task or job.	T F
15. I have a pleasant feeling in my stomach.	T F	40. I don't feel like reading anything right now.	T F
16. I fear I will lose the contentment that I have now.	T F	41. It seems I'm spending longer than I should on each of these questions.	T F
17. I feel in complete harmony with the world and those about me.	T F	42. My hands feel clumsy.	T F
18. I can completely appreciate what others are saying when I am in this mood.	T F	43. I notice my hand shakes when I try to write.	T F
19. I would be happy all the time if I felt as I feel now.	T F	44. I have a disturbance in my stomach.	T F
20. I feel so good that I know other people can tell it.	T F	45. I feel an increasing awareness of bodily sensations.	T F
21. I feel as if something pleasant had just happened to me.	T F	46. I feel anxious and upset.	T F
22. I would be happy all the time if I felt as I do now.	T F	47. I have unusual weakness of my muscles.	T F
23. I feel more clear headed than dreamy.	T F	48. A thrill has gone through me one or more times since I started this test.	T F
24. I feel as if I would be more popular with people today.	T	49. My movements are free, relaxed, and pleasurable.	T F
25. I feel a very pleasant emptiness.	F		
	F		

Note: Items 24-27, 29-35 contributed to the d-amphetamine sensitive (A) subscale.