The effect of acute exercise on cognitive performance in children with and without ADHD

By: Aaron T. Piepmeier, Chia-Hao Shih, Margaret Whedon, Lauren M. Williams, Matthew E. Davis, David A. Henning, SeYun Park, Susan D. Calkins, Jennifer L. Etnier.

Piepmeier, A.T., Shih, C.-H., Whedon, M., Williams, L., Davis, M., Henning, D., Park, S., Calkins, S.D., & Etnier, J.L. (2015). The effect of acute exercise on cognitive performance in children with and without ADHD. Journal of Sport and Health Science, 4(1), 97-104. doi: 10.1016/j.jshs.2014.11.004

Abstract:

Background

Attention deficit hyperactivity disorder (ADHD) is a common childhood disorder that affects approximately 11% of children in the United States. Research supports that a single session of exercise benefits cognitive performance by children, and a limited number of studies have demonstrated that these effects can also be realized by children with ADHD. The purpose of this study was to examine the effect of acute exercise on cognitive performance by children with and without ADHD.

Methods

Children with and without ADHD were asked to perform cognitive tasks on 2 days following treatment conditions that were assigned in a random, counterbalanced order. The treatment conditions consisted of a 30-min control condition on 1 day and a moderate intensity exercise condition on the other day.

Results

Exercise significantly benefited performance on all three conditions of the Stroop Task, but did not significantly affect performance on the Tower of London or the Trail Making Test.

Conclusion

children with and without ADHD realize benefits in speed of processing and inhibitory control in response to a session of acute exercise, but do not experience benefits in planning or set shifting.

Keyword: Executive function | Physical activity | Stroop Test | Tower of London Test | Trail Making Test

*****Note: Full text of article below**

HOSTED BY
ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Journal of Sport and Health Science 4 (2015) 97–104
www.jshs.org.cn

Original article

The effect of acute exercise on cognitive performance in children with and without ADHD

Aaron T. Piepmeier [a], Chia-Hao Shih [a], Margaret Whedon [b], Lauren M. Williams [a], Matthew E. Davis [a], David A. Henning [a], SeYun Park [a], Susan D. Calkins [b], Jennifer L. Etnier [a,*]

[a] *Department of Kinesiology, University of North Carolina at Greensboro, Greensboro, NC 27412, USA*
[b] *Department of Human Development and Family Studies, University of North Carolina at Greensboro, Greensboro, NC 27412, USA*

Received 15 October 2014; revised 10 November 2014; accepted 20 November 2014
Available online 6 January 2015

Abstract

Background: Attention deficit hyperactivity disorder (ADHD) is a common childhood disorder that affects approximately 11% of children in the United States. Research supports that a single session of exercise benefits cognitive performance by children, and a limited number of studies have demonstrated that these effects can also be realized by children with ADHD. The purpose of this study was to examine the effect of acute exercise on cognitive performance by children with and without ADHD.
Methods: Children with and without ADHD were asked to perform cognitive tasks on 2 days following treatment conditions that were assigned in a random, counterbalanced order. The treatment conditions consisted of a 30-min control condition on 1 day and a moderate intensity exercise condition on the other day.
Results: Exercise significantly benefited performance on all three conditions of the Stroop Task, but did not significantly affect performance on the Tower of London or the Trail Making Test.
Conclusion: children with and without ADHD realize benefits in speed of processing and inhibitory control in response to a session of acute exercise, but do not experience benefits in planning or set shifting.

Keywords: Executive function; Physical activity; Stroop Test; Tower of London Test; Trail Making Test

1. Introduction

From 2003 to 2011 in the United States, the estimated prevalence of 4–17 year olds diagnosed with attention deficit hyperactivity disorder (ADHD) increased from 7.8% to 11%.[1] The *Diagnostic and Statistical Manual of Mental Disorders* (DSM-V)[2] has classified three distinct presentations of ADHD: Predominantly Inattentive, Predominantly Hyperactive-Impulsive, and Combined (inattentive and hyperactive-impulsive). For children between 12 and 16 years old, their diagnosis into an ADHD category is dependent on the development of multiple symptoms prior to age 12 years, and the experience of these symptoms for the past 6 months at a level where they are deemed as disruptive or inappropriate for the child's developmental level. Currently, 6.1% of children in the U.S. are taking medication to reduce ADHD symptoms. As well as producing an estimated US$31.6 billion in costs for the U.S.,[3] by definition symptoms of ADHD interfere with aspects of social, academic, and work life. The impetus for this study comes from these personal and economic burdens connected to ADHD, and the purpose is to provide further exploration into the effect of exercise on the cognitive performance of children with ADHD.

Theories as to the etiology of ADHD have been linked to neurological differences in the structure[4] and function[5] of the prefrontal cortex. This area of the brain is responsible for the

* Corresponding author.
E-mail address: jletnier@uncg.edu (J.L. Etnier)
Peer review under responsibility of Shanghai University of Sport.

2095-2546/$ - see front matter Copyright © 2015, Shanghai University of Sport. Production and hosting by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jshs.2014.11.004

performance of a set of higher order cognitive tasks, designated as "executive function" tasks that require response inhibition, planning, working memory, updating, and task switching.[6−9] Research has shown that individuals with ADHD perform significantly worse on neuropsychological tasks requiring executive function than do children without ADHD.[10−13] As a result, it is important to explore interventions that may benefit executive function by children with ADHD.

There is support in the literature for the beneficial effects of acute exercise on cognitive performance,[14] and specifically its effect on executive function.[15−17] Meta-analytic research has shown that the beneficial effect of exercise on cognitive performance is especially manifested in children.[18,19] However, there is a paucity of research exploring whether or not exercise may benefit the cognitive performance of children with ADHD. In fact, to date, there have only been a small number of studies that explored the effects of acute exercise on cognitive performance in children with ADHD.

Grassmann et al.[20] conducted a systematic review of articles published between 1980 and 2013 and noted that there were only three studies at that time that had explored the effect of an acute bout of exercise on the cognitive performance of children with ADHD. Of these studies, two observed significant benefits on measures of cognitive performance after participating in a 30-min bout of exercise.[16,21] Medina et al.[21] observed improvements in measures of vigilance and reaction time as assessed with Conners' Continuous Performance Test-II (CCPT-II) following vigorous exercise for 30 min. Chang et al.[16] observed improvements in measures of inhibition and set shifting as assessed with the Stroop Task and Wisconsin Card Sorting Task, respectively, following moderate intensity exercise for 20 min. However, neither of these studies employed a comparison group consisting of children without a diagnosis of ADHD, hence it is not clear from these studies how the effects for children with ADHD compare to those for children without ADHD.[22−24] There are three studies in which effects of exercise were compared between children with and without ADHD.[22−24] Craft[22] tested hyperactivity as a moderator of the effects of exercise on cognitive performance. She explored the effects of short-duration vigorous exercise conditions (i.e., 0, 1, 5, 10 min) on the cognitive performance (i.e., Wechsler Intelligence Scale for Children − Revised Digit Span and Coding, Illinois Test of Psycholinguistic Abilities − Visual Sequential Memory) of children with and without a diagnosis of "hyperactivity" as determined by the Conners' Abbreviated Teacher Rating Scale. Results indicated that children diagnosed as non-hyperactive performed better on the cognitive tasks than those diagnosed with hyperactivity supporting findings of past literature. However, neither group experienced significant changes in performance as a function of exercise. This lack of an improvement in response to exercise may have been due to the short durations of the exercise, given that Chang et al.[14] reported null effects for exercise durations of 0−10 min in duration. Pontifex et al.[23] explored the effects of a 20-min bout of moderate intensity exercise on the cognitive performance of children with and without a diagnosis of ADHD. Cognitive performance was assessed by an inhibitory control task (i.e., Flanker Task), neuroelectrical (i.e., the P3 component of event-related potential, error related negativity) measures of executive function, and academic performance measures of reading comprehension, spelling, and math (i.e., Wide Range Achievement Test, 3rd Edition). Results indicated that both groups experienced significant improvements in measures of cognitive performance (i.e., behavioral) and cognitive function (i.e., neuroelectrical) following exercise. Mahon et al.[24] recruited children with and without ADHD to perform the CCPT-II prior to and following 20 min of intermittent, high-intensity exercise. Children with ADHD were also invited to perform the experimental protocol on a day when they had taken their normal medication and on a day when they had abstained from their medication for 18−24 h. Results of this study indicated that exercise actually resulted in worse performance on the CCPT-II in terms of errors of omission for children with and without ADHD and in terms of reaction time for children with ADHD. Again, this failure to demonstrate benefits to cognitive performance in response to exercise may have been due to the use of a high-intensity, intermittent protocol which resulted in a total exercise session of only 10 min. Overall, the extant literature is mixed with regards to whether or not acute exercise benefits the cognitive performance of children with ADHD, but supports the hypothesis that children diagnosed with ADHD experience cognitive benefits in response to an acute bout of moderate or vigorous intensity exercise that is of sufficient duration (e.g., >20 min).

An exploration into the beneficial effects of exercise on the cognitive performance of children with ADHD is a logical line of research considering that those with ADHD have shown impaired performance on cognitive tasks requiring executive function and exercise has been shown to improve executive function performance in the general population. At this time, there is limited research that has compared the effects of acute exercise on cognitive performance between children with and without ADHD[22−24] and only one study[23] has done this using an exercise protocol that meta-analytic evidence suggests would be expected to improve cognitive performance. However, this study[23] only included one type of executive function measure. Hence, the purpose of this study was to further our understanding of the extent to which 20-min of moderate intensity exercise impacts various aspects of executive function performance by children relative to their ADHD status.

2. Methods

2.1. Participants

Participants consisted of 32 adolescents recruited from a private K−12 school, the local community, and an ADHD clinic. Because a within-subjects design was used, differences in participants as a function of recruitment location were not analyzed. Recruiting was performed through the use of fliers and emails. In addition, on-site recruiting was used in the private K−12 school during a weekly informational assembly.

Due to the age of the participants, parents were required to sign an informed consent and participants were required to sign an informed assent before beginning data collection. In addition, prior to data collection, parents were required to fill out a medical history questionnaire on behalf of the participants to determine if it was safe for the participants to perform moderate intensity aerobic exercise. Data collection took place at a southeastern university, and all procedures were approved by the University's Institutional Review Board prior to recruitment and data collection.

2.2. ADHD diagnosis

A single question was used to determine if the participants had been diagnosed with ADHD ("has your child been diagnosed with ADHD by a medical professional"). If the participants had an ADHD diagnosis, additional information pertaining to the age of the participants when diagnosed with ADHD, the specific ADHD presentation ("ADHD predominantly hyperactive-impulsive", "ADHD predominantly inattentive", "ADHD combined type", "I don't know"), current medication use (i.e., medication name, dose, and regimen), current alternative treatment or supplement use (i.e., type, dose, and regimen), and the diagnosis of additional disorders (e.g., bipolar disorder, generalized anxiety disorder) were assessed.

2.3. Procedures

Participants were required to come to the lab on 2 days at least 72 h apart. On one of the days they performed a 30-min bout of aerobic exercise (exercise condition), and on the other day they watched a nature documentary for 30 min (non-exercise condition). The order of the conditions was randomized and counterbalanced. Prior to the session, parents were telephoned for scheduling and were told the order of conditions to ensure the participants would arrive prepared to exercise (e.g., wearing proper exercise attire). At this time, the parents also completed a medical history questionnaire over the phone to determine that the participants met the inclusion criteria of being safe to perform moderate intensity aerobic exercise. They were also instructed that the participants should not eat 1 h prior to the sessions and should not exercise prior to the sessions. Additionally, parents were instructed to continue the participants' medication schedule as normal.

Upon arriving at the lab on the first day, the parents signed an informed consent and the participants signed an informed assent. Next, the parents were taken to a waiting room where they completed the demographic and ADHD questionnaires. The participants were fitted with a heart rate (HR) monitor and told to sit quietly for 4 min in order to obtain a measure of resting HR.

During the non-exercise condition, participants were asked to sit on the recumbent cycle ergometer while they watched a nature documentary for 30 min. Measures of HR were obtained every 5 min during the non-exercise condition. During the exercise session, the participants were asked to sit on the recumbent cycle ergometer in order for the seat to be adjusted to the proper distance from the pedals (i.e., when their heel could be placed on the furthest pedal with a straight leg). They were then instructed on how to use the OMNI ratings of perceived exertion scale and the exercise protocol was explained.

After completing the 30-min exercise protocol or the 30-min period of watching the nature documentary, participants sat quietly for approximately 4 min before beginning the cognitive testing. Tests of cognitive performance were administered in the same order each day (i.e., Trail Making, Tower of London, Stroop).

2.4. Exercise condition

Participants performed a 30-min bout of exercise on a LODE Corival Recumbent Cycle-Ergometer (Lode BV, Groningen, The Netherlands), comprised of a 5-min warm-up, 20 min of exercise, and a 5-min cool-down. The OMNI ratings of perceived exertion (RPE) scale were used to assess perceived intensity with a goal of having participants exercise at a moderate intensity for the 20-min period. The display on the recumbent cycle ergometer allowed the participants to monitor their revolutions per minute (RPM) by seeing the location of a light on a continuum, with the RPM being slower when the light is more to the left and faster when it is more to the right. Two pieces of tape were placed on the display and the participants were asked to pedal at a rate that kept the light between the two pieces of tape (i.e., 40−60 RPM). The warm-up started with a resistance of 25 W, and measures of RPE and HR were assessed every minute with the goal of reaching an RPE from 5 to 7 by the end of the warm-up. If the RPE was too high or too low, the resistance was adjusted as necessary (i.e., increased or decreased). Once the warm-up was complete, the participants continued to cycle at an intensity ranging from 5−7 RPE for 20 min. Measures of RPE, HR, and distance (km) were assessed every 5 min and wattage was adjusted if it was found that the RPE was too high or too low. At the end of the 20 min, the resistance was lowered to 25 W for a 5-min cool-down. Water was available for the participants to have throughout the exercise ad libitum.

2.5. Non-exercise condition

All participants watched the same 30-min section of the Planet Earth nature documentary (BBC, 2007). This program was selected based on its entertainment value (i.e., the children enjoyed watching the program) as well as the age-appropriateness of the content (e.g., no scenes of hunting or killing were depicted).

2.6. Exercise related measures

2.6.1. HR

HR was measured by a Polar HR monitor and T-31 coded chest strap (Polar USA, Lake Success, NY, USA). The chest strap automatically synchronizes with the LODE cycle ergometer to display readings of HR during exercise. During the non-exercise condition, the Polar HR monitor was used to obtain readings of HR. HR was recorded before each treatment condition (HR-rest) and every 5 min during each treatment condition. HR-during was calculated by averaging all HR readings during each treatment condition.

2.6.2. Perceived exertion

The Children's OMNI scale[25] was used to measure ratings of perceived exertion and to confirm exercise intensity. This scale uses an illustration of a person riding a bicycle on flat ground and uphill to help children understand how to use it to describe their level of exertion. At the lowest level of exertion (i.e., 0 = "not tired at all"), the person on the bike is smiling, about half-way up the hill, the person is sweating and is leaning over the handlebars (i.e., 6 = "tired"), and at the top of the hill, the person is sweating, hunched over, and has placed their head on the handlebars (i.e., 10 = "very, very tired"). This scale has been found to be valid and reliable.[26] Evidence supports that exercising between 5 and 7 on the OMNI would be predicted to result in children in this age group exercising at between 62% and 72% of age-predicted maximum HR (HR_{max})[25] which would be considered moderate intensity exercise.[27]

2.7. Cognitive performance measures

2.7.1. Stroop Test

This task was selected in order to directly compare findings to those of Chang et al.[16] The inhibition component of executive function and general speed of processing were assessed with an adjusted version of the Stroop Task.[28] This task was performed in three parts, part A (Word), part B (Color), and part C (Word/Color). In part A, participants were presented with a piece of paper containing columns of words (i.e., red, green, blue) in black ink. They were instructed to read each word aloud from each column, top to bottom and left to right, as fast as they could. They were told that if they made a mistake, the researcher would say "no", they would need to fix the mistake, and then continue reading. In part B, participants were presented with a piece of paper containing columns of colored blocks (i.e., red, green, blue). Instructions for part B were similar to part A, except that the participants were required to name the color of the ink in the colored blocks as quickly as they could. In part C, participants were presented with a piece of paper containing columns of words (i.e., red, green, blue) in colored ink that did not match the color written (e.g., "blue" written in red ink). Instructions for part C were similar to parts A and B, except that the participants were required to name the *color of the ink* that the words were written in. For example, if the word "red" was written in blue ink the participants should say "blue". Before beginning part C, participants were asked to name the ink of three different words randomly selected from the piece of paper to ensure the directions were understood. Performance was measured by assessing the total time taken to complete each part (A, B, and C) with performance on parts A and B indicative of speed of processing and performance on part C indicative of inhibitory control.

2.7.2. Tower of London

The planning and problem solving components of executive function were assessed using the Tower of London Task. Tower of London software (Sanzen Neuropsychological Assessment Tests) was used to perform this computer-based task. This software allowed the researcher to create a Tower of London Task with multiple patterns and trials. A Tower of London Task was created to match the patterns and trials of The Drexell II Tower of London Task. The computer screen was split into two sections, the "work space" on the left and the "goal state" on the right. This task required participants to rearrange the orientation of three colored balls (red, blue, green) located in the "work space" so it matched that of the colored balls in the "goal state". The "goal state" showed the three balls placed on three "sticks" of differing lengths. The first (longest) stick was able to hold all three balls, the second (shorter) was able to hold two balls, and the third (shortest) was able to hold only one ball. The user interface required the use of a mouse to control which balls were selected and where they were moved. Participants were instructed to match the pattern shown in the "goal state" while making as few moves as possible. They were also informed that only one ball could be moved at a time and balls underneath another ball could not be moved. The participants then completed a practice trial, which initiated the program. This task consisted of 14 trials and progressed from easier trials (could be completed with a minimum of three moves) to more difficult trials (could be completed with a minimum of seven moves). The participants continued working on a given trial until they successfully matched the pattern in the "goal state". Performance was measured by summing the total number of moves across all trials and this provided the measure of planning.

2.7.3. Trail Making Test (TMT)

The set-shifting component of executive function and general speed of cognitive processing were assessed with the TMT. Trail Making software (Sanzen Neuropsychological Assessment Tests) was used to perform this computer-based task. The user interface required the use of a mouse to control the selection of the desired number or letter. This task was performed in two parts, part A (numbers only) and part B (numbers and letters), with each part containing two trials. Prior to each trial, the participants were presented with a screen that contained the instructions for this task. Before each trial, participants were instructed to complete the task as quickly and accurately as possible. Part A (TMT A) presented participants with a screen containing several circles, and inside each circle was a number. The task required participants to click each circle in order (e.g., 1, 2, 3) until all of the circles had been clicked, with trial one containing six circles and trial two containing 24 circles. Part B (TMT B) presented participants with circles that contain either a number or a letter. The task required participants to click each circle in order while alternating between numbers and letters (e.g., 1, A, 2, B, 3, C) until all of the circles had been clicked, with trial one containing six circles, and trial two containing 24 circles. Performance was measured by assessing the total time taken to complete each trial with performance on the TMT A indicative of speed of processing and performance on the TMT B indicative of set-shifting.

2.8. Data analysis

The efficacy of the exercise manipulation was examined based on an analysis of HR using a 2 (Time: HR-rest or HR-during) by 2 (Condition: non-exercise or exercise) within-subjects analysis of variance (ANOVA). Three separate mixed ANOVAs were used to determine the effect of exercise on cognitive performance as a function of ADHD diagnosis. Specifically, for the Tower of London, a 2 (ADHD diagnosis: yes or no) by 2 (Condition: non-exercise or exercise) mixed ANOVA was used for total number of moves across all trials. For the TMT, a 2 (ADHD diagnosis: yes or no) by 2 (Condition: non-exercise or exercise) by 2 (test component: TMT A or TMT B) mixed ANOVA was used for total time taken to complete each trial. Similarly, for the Stroop Test, a 2 (ADHD diagnosis: yes or no) by 2 (Condition: non-exercise or exercise) by 3 (test component: Word, Color, Word/Color) mixed ANOVA was used for total time taken to complete each part. Follow-up tests are presented as appropriate using the Tukey HSD test. Partial η^2 is presented as a measure of effect size for significant effects. All tests were conducted at $\alpha = 0.05$ and performed using SPSS version 22 (IBM SPSS Inc., Chicago, IL, USA).

3. Results

The sample consisted of 14 participants who had been diagnosed with ADHD (5 girls, 9 boys) and 18 participants who had not been diagnosed with ADHD (7 girls, 11 boys). As expected, there was a significant difference in ADHD symptoms ($F(1, 30) = 61.25$, $p < 0.01$), reported for those diagnosed with ADHD (43.50 ± 6.04, mean $\pm$ SD) as compared to those who had not been diagnosed with ADHD (25.56 ± 6.72). Of those diagnosed with ADHD, two were combined type, six were predominately inattentive, two were predominately hyperactive-impulsive, and for four children, the parent did not know the type. The average age of the sample was 10.7 ± 2.27 years and the average body mass index was 18.36 ± 10.66. Additional descriptive information for the groups can be found in Table 1.

Table 1
Descriptive information for the total sample and for the subgroups of children with and without attention deficit hyperactivity disorder (ADHD).

Variable	Non-ADHD ($n = 18$)	ADHD ($n = 14$)	Total ($n = 32$)
Age in years (mean ± SD)	11.22 ± 2.43	10.14 ± 1.96	10.75 ± 2.27
Gender (female: male)	7:11	5:9	12:20
BMI (mean ± SD)	19.21 ± 3.14	17.30 ± 1.99[a]	18.53 ± 2.90[a]
Medications (Yes:No)	N/A	10:4	N/A
Medications taken[b]			
Amphetamine stimulants		6	
Methylphenidate stimulants		3	
Unknown mechanism		1	
ADHD type	N/A		N/A
Inattentive		6	
Hyperactive-impulsive		2	
Combined		2	
Don’t know		4	

[a] The sample size for this variable was reduced by 4 because parents declined to provide this information for their child.
[b] Amphetamine stimulants included: Adderall ($n = 2$), Vyvanse ($n = 3$), and amphetamine/dextroamphetamine ($n = 1$); Methylphenidate stimulants included: Focalin ($n = 1$), Daytrana ($n = 1$), and Concerta ($n = 1$); Unknown mechanism included Provigil ($n = 1$).

3.1. Exercise manipulation

The 2×2 within-subjects ANOVA for HR revealed a significant main effect for time ($F(1, 23) = 116.46$, $p < 0.01$, partial $\eta^2 = 0.84$). The main effect for condition also reached significance ($F(1, 23) = 134.12$, $p < 0.01$, partial $\eta^2 = 0.85$). Moreover, the interaction of Time $\times$ Condition reached significance ($F(1, 23) = 213.91$, $p < 0.01$, partial $\eta^2 = 0.90$). Follow-up analysis showed that the significant difference between the two conditions was observed for HR-during (exercise: 147.70 ± 18.37 bpm; control: 84.02 ± 4.13 bpm) but not for HR-rest (exercise: 85.79 ± 12.71 bpm; control: 85.33 ± 12.80 bpm). The average HR for the exercise condition was 68% of age-predicted HR_{max}, thus confirming that the participants were exercising at a moderate intensity. In addition to establishing that there were significant differences in HR as a function of exercise, descriptive statistics also showed that RPE during exercise (6.29 ± 1.36) was located in our target range of moderate intensity exercise. These findings suggested that our exercise manipulation was successful.

3.2. Stroop Test

The $2 \times 2 \times 3$ mixed ANOVA revealed a significant main effect for condition ($F(2, 58) = 4.88$, $p = 0.04$, partial $\eta^2 = 0.14$), such that participants used less time to complete the test in the exercise condition (33.71 ± 1.33 s) than in the non-exercise condition (35.58 ± 1.24 s). A main effect for test component also reached significance ($F(2, 58) = 134.13$, $p < 0.01$, partial $\eta^2 = 0.82$) and follow-up analyses showed that participants used significantly less time to complete part A (Word) (26.95 ± 0.70 s) and part B (Color) (28.90 ± 1.28 s) than part C (Word/Color) (48.08 ± 2.07 s). No other statistically significant findings were observed ($p > 0.05$).

3.3. Tower of London

The 2×2 mixed ANOVA showed that neither the main effects for ADHD diagnosis nor condition nor the interaction between ADHD diagnosis and condition reached statistical significance ($p > 0.05$).

3.4. Trail Making Test

The 2 by 2 by 2 mixed ANOVA revealed a significant main effect for test component($F(1, 30) = 107.44$, $p < 0.01$, partial $\eta^2 = 0.78$), indicating that participants used less time to complete TMT A (24.04 ± 1.38 s) than TMT B (38.88 ± 2.41 s). No other statistically significant findings were observed ($p > 0.05$).

4. Discussion

The purpose of this study was to extend our understanding of the effects of an acute bout of moderate intensity exercise on performance of executive function tasks relative to ADHD status. Results from this study provide mixed support for the hypothesis that acute exercise would benefit executive function performance. Interpreting these results is made challenging by the limited research in which acute effects of exercise on executive function tasks have been tested in children and particularly in children with ADHD.

Results from the Stroop Task revealed that performance (total time) was faster in parts A (Word) and B (Color) compared to part C (Word/Color). These findings are consistent with the nature of the cognitive task. Performance on parts A and B relate to cognitive processing speed and are typically performed quickly, while part C is a measure of inhibition and requires longer to perform accurately. Importantly, results indicated that performance was superior after the exercise condition compared to the non-exercise condition. That is, performance was improved following exercise compared to performance after the control condition, and the size of this effect was not distinguishable between processing speed and inhibition (i.e., the interaction effect was non-significant). These findings are similar to those reported by Chang et al.[29] in a study of the effects of acute exercise on Stroop Task performance by older adults, but are different from those of Chang et al.[16] who observed a condition by task interaction for children showing that benefits from exercise were specific to part C (inhibition) of the Stroop Task. The reason for the difference in findings between the two studies with children is not completely clear. Both studies used moderate intensity exercise performed for 20 min with a 5-min warm-up and a 5-min cool-down, thus perhaps the differences are due to differences in design between the two studies. Chang et al.[16] used a mixed design whereby participants performed the Stroop Task prior to and following the treatment condition to which they were randomly assigned. By contrast, in this study participants only performed the Stroop Task following the treatment, but performed both treatments over the course of the study. It is possible that Stroop effects are evident across all tasks when there is not an opportunity for learning on the same day. However, future research will be necessary to determine whether or not this is an appropriate explanation for these disparate findings.

Results from the Tower of London Task showed that an acute bout of exercise did not significantly influence performance on this task. This finding was somewhat surprising given past evidence that planning tasks are sensitive to the effects of a single session of exercise performed by college-aged students[17] and by physically active older women.[30] Again, identifying a reason for the lack of an effect in this study is challenging. It is possible that the difference is due to the differences in the age of the participants and this explanation is supported by meta-analytic evidence that effects from acute exercise are negligible for elementary-aged children, but are significant and positive for young adults and older adults.[14] However, given that the examination of moderators within a meta-analysis is inherently confounded by other variables (see Etnier et al.[18] for an explanation) and the aforementioned evidence supporting benefits of acute exercise for cognitive performance by children,[18,19] this explanation seems unlikely. Another possible explanation might be related to the intensity of the exercise. Córdova et al.[30] demonstrated that significant benefits to performance on the Tower of Hanoi (which is similar to the Tower of London and also assesses planning) were only evident when older women exercised at ∼79% of age-predicted HR_{max} (90% of anaerobic threshold) and were not evident at lower or higher intensities of exercise. This is a higher intensity of exercise than was used in this study and hence might explain the different results. However, this explanation falls flat when one considers that the exercise intensity in the Chang et al. study[17] was very similar to that used in this study. A possible explanation for differences between the Chang et al. study[17] and this study could relate again to the difference in design. Chang et al.[17] tested participants pre- and post-treatment and so the disparate findings may again suggest that exercise effects on executive function tasks differ depending upon the presence of within-day learning effects. Of course, we are merely speculating as to potential reasons for our different results and future research will be needed to ascertain the veracity of these explanations.

Results from the TMT indicated that performance (total time) on TMT A was faster than TMT B regardless of exercise or ADHD diagnosis. This difference in performance was expected because TMT A is a measure of cognitive processing speed while TMT B is a measure of set shifting. Compared to simple processing speed, set shifting requires a greater amount of cognitive capacity, which may be reflected in the time to complete the task. However, the lack of an effect of exercise was unexpected given that the TMT is a frontally dependent task that was expected to benefit from an acute bout of exercise and given past studies supporting beneficial effects.[30] Again, the failure to observe benefits in this study may have been due to the intensity of the exercise. Córdova et al.[30] only reported benefits for TMT B and only during the 90% of aerobic threshold condition (∼79% age-predicted HR_{max}) and this is a substantially higher exercise intensity than was used in this study.

Although it is interesting to consider why benefits of acute exercise were not observed for all of the executive function tasks administered in this study, it is impossible to identify an incontrovertible reason for this *a posteriori*. Rather, we hope that the demonstration that effects may differ as a function of the particular type of executive function being assessed will encourage further research. This is consistent with Etnier and Chang's[31] plea for researchers to acknowledge that all executive function tasks may not respond in the same way to exercise. The finding that the effects of exercise on cognitive performance were not moderated by ADHD status is an important finding. This is consistent with findings reported by Pontifex et al.[23] indicating that the beneficial effects of acute exercise for response accuracy during a Flankers Test are equivalent for children with and without ADHD. This is an intriguing finding because it suggests that children with ADHD can benefit from a single session of exercise just as much as children without ADHD. It is of further import because of the fact that the children in this study were instructed to take their prescribed medications for ADHD and all (except 4) were taking stimulant medications.[c] Hence, the benefits of exercise upon cognitive performance were observed above and beyond any benefits achieved through pharmacological intervention. Although our small number of unmedicated children did not allow us to statistically test the effects of this variable in this study, it is interesting to contemplate whether or not the benefits of acute exercise might be greater for participants who are not medicated. To our knowledge, this has only been examined in one study[24] previous to this study and the results indicated that the effects of exercise (which in that study were detrimental) were not influenced by whether or not the children with ADHD were medicated or not medicated. Further study focused on examining whether or not medication use moderates the influence of exercise on cognitive performance by children with ADHD is an important direction as benefits of exercise as an adjuvant behavioral therapy have been demonstrated,[16,21,23] but it is also possible that exercise may be able to provide benefits in the absence of medications.

It is important to point out some of the limitations of this study. First, and as previously mentioned, it might have been beneficial to have asked participants to perform the cognitive tasks prior to the treatment condition in addition to performing them after the treatment condition. This is not really a limitation *per se*, but it is a design consideration that would have helped to control for any day-to-day variability in cognitive task performance. However, the design that was used is very similar to that used by Pontifex et al.[23] and, similarly, benefits were observed on an executive function task measuring inhibition. A second consideration is that participants were instructed to take their medications as they normally would which resulted in variety in the medications being taken by the participants in this study. Four children were not taking medications at all and others differed with regards to the medication type, the dose, or the dosing regimen. Clearly, this limits our ability to understand the extent to which exercise benefits children on various medications and the extent to which it benefits children with ADHD on- and off-medication.

It has been said that "Few studies will answer all of the questions surrounding a topic, and most good studies will raise new ones …".[32] This statement aptly describes the findings of this study. Although we anticipated that exercise would benefit performance across a variety of executive function tasks, we found that exercise only benefited performance on speed of processing and inhibitory control as measured by the Stroop Task and did not benefit performance on planning, set shifting, or speed of processing as measured by TMT. Given that previous studies have not compared the effects of acute exercise across a variety of executive function tasks for children, this is clearly an important direction for future research. Additionally, future research could be designed to see if a more intense exercise session would result in more comprehensive benefits on measures of executive function, or on cognitive performance more broadly, or if there is a way to design the exercise intervention to achieve a larger cognitive benefit. Finally, we anticipated that exercise might benefit cognitive performance by the children with ADHD more so than it benefited the children without ADHD. This was based on the expectation that since ADHD is characterized by frontal lobe dysfunction, exercise would have the opportunity to result in a bigger cognitive benefit for these individuals. However, we found that where exercise did have benefits, the benefits were equal between the two groups and this is consistent with past research.[23] However, we recognize that our findings are limited by the inclusion of children with ADHD who were off-medication and by the wide variety of medication regimens used by our sample. Hence, future research would benefit from testing the effects of acute exercise in children with ADHD on-medication and off-medication and in cases where the medication regimen is similar. Mahon et al.[24] did pursue this question in their research, but their exercise protocol was not one that would have been expected to result in significant benefits given meta-analytic evidence[14] that high intensity exercise and exercise shorter than 10 min in duration has negligible effects on cognitive performance performed immediately after the exercise session. Hence, this is clearly a direction for research that could be dramatically expanded upon.

5. Conclusion

Though future studies should be performed to replicate and extend these findings, results from this study illustrate that for children with and without a diagnosis of ADHD, a single session of moderate intensity exercise benefits processing

[c] The three-way mixed ANOVA for the Stroop Task was conducted with the four non-medicated participants removed. Results indicated that the main effect for condition became non-significant ($F(1, 25) = 1.49$, $p = 0.23$, partial $\eta^2 = 0.06$), the main effect for component remained significant ($F(2, 24) = 127.28$, $p = 0.00$, partial $\eta^2 = 0.91$), and the interaction of Condition $\times$ Component ($F(2, 24) = 2.95$, $p = 0.07$, partial $\eta^2 = 0.20$), approached significance. Examination of the means for the main effect for condition and for the Condition $\times$ Component interaction indicated that performance was generally better following exercise as compared to following the movie condition. These results suggest that our significant condition main effect decreased but was not eradicated by the removal of the effects observed in the children with ADHD who were off-medication. This emphasizes the importance of conducting further research to explore the potential benefits of exercise for children with ADHD who are on medication, for children with ADHD who are off medication, and for children without ADHD.

speed and inhibitory control as assessed using the Stroop Task. These results confirm past findings that exercise benefits children with and without ADHD[23] and extends the literature by demonstrating that these effects are limited to measures of inhibitory control and speed of processing. Given the challenges facing children with ADHD, the prevalence of this disease, and the promising evidence for acute exercise benefits for children without ADHD, it is startling that there are still only a handful of studies that have examined the potential of acute exercise for children with ADHD. Clearly, future research designed to further our understanding of the task-specificity of the effects, of how to maximize the benefits, and of how ADHD medication usage influences the effects is warranted.

Acknowledgment

The authors wish to thank Meg Haas and Michael Castellano for their assistance with data collection. We also thank Greensboro Day School for assistance with the recruitment of participants.

References

1. Visser SN, Danielson ML, Bitsko RH, Holbrook JR, Kogan MD, Ghandour RM, et al. Trends in the parent-report of health care provider-diagnosed and medicated attention-deficit/hyperactivity disorder: United States, 2003—2011. *J Am Acad Child Psy* 2014;**53**:34—46.
2. American Psychiatric Association. *Diagnostic and statistical manual of mental disorders*. 5th ed. Arlington, VA: American Psychiatric Publishing; 2013.
3. Birnbaum HG, Kessler RC, Lowe SW, Secnik K, Greenberg PE, Leong SA, et al. Costs of attention deficit-hyperactivity disorder (ADHD) in the US: excess costs of persons with ADHD and their family members in 2000. *Curr Med Res Opin* 2005;**21**:195—205.
4. Helpern JA, Adisetiyo V, Falangola MF, Hu C, Di Martino A, Williams K, et al. Preliminary evidence of altered gray and white matter microstructural development in the frontal lobe of adolescents with attention-deficit hyperactivity disorder: a diffusional kurtosis imaging study. *J Magn Reson Imaging* 2011;**33**:17—23.
5. Bush G, Valera EM, Seidman LJ. Functional neuroimaging of attention-deficit/hyperactivity disorder: a review and suggested future directions. *Biol Psychiatry* 2005;**57**:1273—84.
6. Hughes C, Graham A. Measuring executive functions in childhood: problems and solutions? *Child Adolesc Ment Health* 2002;**7**:131—42.
7. Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD. The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. *Cogn Psychol* 2000;**41**:49—100.
8. Rabbitt P. Introduction: methodologies and models in the study of executive function. *Methodol Frontal Exec Funct* 1997:1—38.
9. Chan RCK, Shum D, Toulopoulou T, Chen EYH. Assessment of executive functions: review of instruments and identification of critical issues. *Arch Clin Neuropsych* 2008;**23**:201—16.
10. Fischer M, Barkley RA, Smallish L, Fletcher K. Executive functioning in hyperactive children as young adults: attention, inhibition, response perseveration, and the impact of comorbidity. *Dev Neuropsychol* 2005;**27**:107—33.
11. Pennington BF, Ozonoff S. Executive functions and developmental psychopathology. *J Child Psychol Psychiatr* 1996;**37**:51—87.
12. Shallice T, Marzocchi GM, Coser S, Del Savio M, Meuter RF, Rumiati RI. Executive function profile of children with attention deficit hyperactivity disorder. *Dev Neuropsychol* 2002;**21**:43—71.
13. Willcutt EG, Doyle AE, Nigg JT, Faraone SV, Pennington BF. Validity of the executive function theory of attention-deficit/hyperactivity disorder: a meta-analytic review. *Biol Psychiat* 2005;**57**:1336—46.
14. Chang YK, Labban JD, Gapin JI, Etnier JL. The effects of acute exercise on cognitive performance: a meta-analysis. *Brain Res* 2012;**1453**:87—101.
15. Chang YK, Chu IH, Chen FT, Wang CC. Dose-response effect of acute resistance exercise on Tower of London in middle-aged adults. *J Sport Exerc Psy* 2011;**33**:866.
16. Chang YK, Liu S, Yu HH, Lee YH. Effect of acute exercise on executive function in children with attention deficit hyperactivity disorder. *Arch Clin Neuropsych* 2012;**27**:225—37.
17. Chang YK, Tsai CL, Hung TM, So EC, Chen FT, Etnier JL. Effects of acute exercise on executive function: a study with a tower of london task. *J Sport Exerc Psychol* 2011;**33**:847.
18. Etnier JL, Salazar W, Landers DM, Petruzzello SJ, Han M, Nowell P. The influence of physical fitness and exercise upon cognitive functioning: a meta-analysis. *J Sport Exerc Psychol* 1997;**19**:249—77.
19. Sibley BA, Etnier JL. The relationship between physical activity and cognition in children: a meta-analysis. *Pediatr Exerc Sci* 2003;**15**:243—56.
20. Grassmann V, Alves MV, Santos-Galduróz RF, Galduróz JCF. Possible cognitive benefits of acute physical exercise in children with ADHD a systematic review. *J Atten Disord* 2014. 1087054714526041. http://dx.doi.org/10.1177/1087054714526041.
21. Medina JA, Netto TLB, Muszkat M, Medina AC, Botter D, Orbetelli R, et al. Exercise impact on sustained attention of ADHD children, methylphenidate effects. *Atten Defic Hyperact Disord* 2010;**2**:49—58.
22. Craft DH. Effect of prior exercise on cognitive performance tasks by hyperactive and normal young boys. *Percept Motor Skill* 1983;**56**:979—82.
23. Pontifex MB, Saliba BJ, Raine LB, Picchietti DL, Hillman CH. Exercise improves behavioral, neurocognitive, and scholastic performance in children with attention-deficit/hyperactivity disorder. *J Pediatr* 2013;**162**:543—51.
24. Mahon AD, Dean RS, McIntosh DE, Marjerrison AD, Cole AS, Woodruff ME, et al. Acute exercise effects on measures of attention and Impulsivity in children with attention Deficit/Hyperactivity disorder. *J Educ Develop Psychol* 2013;**3**:65.
25. Robertson RJ, Goss FL, Boer NF, Peoples JA, Foreman AJ, Dabayebeh IM, et al. Children's OMNI scale of perceived exertion: mixed gender and race validation. *Med Sci Sports Exerc* 2000;**32**:452—8.
26. AC Utter, Robertson RJ, Nieman DC, Kang J. Children's OMNI scale of perceived exertion: walking/running evaluation. *Med Sci Sports Exerc* 2002;**34**:139—44.
27. American College of Sports Medicine. *ACSM's guidelines for exercise testing and prescription*. Lippincott Williams & Wilkins; 2013.
28. Stroop JR. Studies of interference in serial verbal reactions. *J Exper Psychol* 1935;**18**:643—62.
29. Chang YK, Chu CH, Wang CC, Song TF, Wei GX. Effect of acute exercise and cardiovascular fitness on cognitive function: an event-related cortical desynchronization study. *Psychophysiology* 2014;**52**:342—51.
30. Córdova C, Silva VC, Moraes CF, Simões HG. Nóbrega OT. Acute exercise performed close to the anaerobic threshold improves cognitive performance in elderly females. *Braz J Med Biol Res* 2009;**42**:458—64.
31. Etnier JL, Chang YK. The effect of physical activity on executive function: a brief commentary on definitions, measurement issues, and the current state of the literature. *J Sport Exerc Psychol* 2009;**31**:469—83.
32. Laub JH. NIJ Journal 269: Director's Message. *NIJ J* 2012;**269**.