

Original article

# Acute exercise is associated with specific executive functions in college students with ADHD: A preliminary study

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## Abstract

**Purpose:** The relationship between acute exercise and executive functions in college students with attention deficit hyperactivity disorder (ADHD) has not been clearly established. The purpose of this preliminary study was to examine the difference in cognitive performance between college students with and without ADHD and to explore the effects of acute exercise on multiple aspects of executive functions and on serum brain derived neurotrophic factor (BDNF).

**Methods:** College students (normal:  $n = 10$ ; ADHD:  $n = 10$ ) performed the Stroop Test, Trail Making Test, and Digit Span Test prior to and after an acute exercise intervention. Blood samples were obtained prior to the pre-test cognitive test performance and then again after exercise and prior to the post-test cognitive test performance.

**Results:** Students with ADHD exhibited impaired executive functions, particularly on inhibition. Additionally, while acute exercise improved all aspects of executive functions in those without ADHD, acute exercise only improved inhibitory performance for those with ADHD. Further, BDNF was not influenced by acute exercise regardless of the subjects' ADHD status.

**Conclusion:** These results provide preliminary evidence for exercise as a potential adjunct treatment for benefitting inhibition in college students with ADHD.

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**Keywords:** Cognition; Executive function; Neurotrophins; Physical activity

## 1. Introduction

Attention deficit hyperactivity disorder (ADHD) is characterized by developmentally inappropriate levels of inattention and/or hyperactivity that result in numerous impairments in academic, social, and occupational domains.<sup>1–3</sup> Although ADHD is typically characterized as being a disorder of children, the symptoms of ADHD are also evident in adults. In fact, approximately 2%–8% of college students exhibit clinical symptoms of ADHD, which is considered the second

largest disability affecting postsecondary students, after learning disabilities.<sup>4</sup> College students with ADHD are at greater risk for behavioral problems (e.g., alcohol use disorders)<sup>5</sup> and psychological difficulties (e.g., depression, anxiety).<sup>6</sup>

Individuals with ADHD also commonly suffer from deficits in cognitive functioning, particularly executive functions. Executive function refers to higher-order cognitive processes, including self-monitoring and/or self-regulating, that are responsible for purposeful and goal-directed behaviors.<sup>7</sup> Impairments of executive functions in college students have translated to poor organizational skills,<sup>8,9</sup> decreased self-control,<sup>3</sup> and increased academic struggles.<sup>4</sup> Also noteworthy is that executive function is not a unitary processes, but it

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involves several distinct sub-constructs such as inhibition, task switching, and working memory,<sup>10</sup> and the executive dysfunction resulting from ADHD is believed to be sensitive to specific sub-constructs of executive function. For instance, Willcutt et al.<sup>11</sup> concluded that although ADHD in children has been associated with impairments in all executive function tasks, the largest impairments have been observed for tasks related to inhibition, working memory, and planning. However, only a few studies have examined executive function performance for college students with ADHD. These previous studies have generally emphasized only a few specific sub-constructs and reveal mixed findings,<sup>12–15</sup> thus suggesting the need for more research in this area.

Importantly, exercise may be a plausible treatment for behavioral symptoms and cognitive performance of persons with ADHD.<sup>16,17</sup> Several meta-analytic reviews have demonstrated the positive influence of acute exercise on cognition.<sup>18–20</sup> Specifically, acute exercise of moderate intensity for 30 min has consistently been associated with improved cognitive functions across multiple cognitive domains including basic information processing,<sup>21</sup> inhibition,<sup>22</sup> and the planning aspects of executive function.<sup>23,24</sup> Recently, improved cognition induced by acute exercise has been observed in individuals with ADHD. For example, acute exercise has yielded positive effects on the inhibition and switching aspects of executive functions<sup>25</sup> along with sustained attention.<sup>26</sup> It should be noted that these studies were focused on children and it is not clear whether they extend to college-aged populations. College students with ADHD appear to be “one of the most understudied age groups with ADHD”.<sup>27</sup> Given the challenges that face college students with ADHD and the supportive extant literature for the positive relationship between exercise and cognition, research exploring the potential benefits of exercise on cognition within this population is warranted.

To be prescribed as adjuvant therapy, it is important to identify potential mechanisms underlying the effects of acute exercise on cognition in persons with ADHD. One logical area of study is neurochemicals that are both important to the profile of ADHD and sensitive to exercise. ADHD has been characterized by decreased levels of brain derived neurotrophic factor (BDNF).<sup>28</sup> As a member of the neurotrophin family, BDNF is involved in neurodevelopmental processes that are responsible for the survival and growth of neurons. BDNF also plays a role in both differentiation and survival of dopaminergic neurons, which are linked to impulse regulation, suggesting that BDNF may impact dopaminergic system dysfunctions associated with ADHD.<sup>29</sup> Recent human study has further linked genetic variations of BDNF to ADHD symptoms, reflecting the involvement of BDNF in the pathogenesis of ADHD.<sup>30</sup> Notably, BDNF concentrations increase as a result of acute exercise<sup>31</sup> and this effect has been positively linked to acute exercise and cognition, possibly through its role in acute mechanisms underlying synaptic plasticity.<sup>32</sup> These findings suggest that BDNF may play a role in explaining benefits of acute exercise on cognitive functions for individuals with ADHD; however, a direct investigation

involving acute exercise, BDNF, cognition, and ADHD has not yet been conducted.

Accordingly, the purpose of the present preliminary study was threefold. Specifically, the investigation was designed to: a) identify the deficits in multiple cognitive functions, particularly executive functions, in college students with ADHD, b) test the impact of acute exercise on cognitive functions in college students with and without ADHD, and c) explore whether acute exercise influences BDNF for students with and without ADHD. It was hypothesized that the students with ADHD would exhibit multiple cognitive dysfunctions compared to their counterparts without ADHD, and that acute exercise would benefit these cognitive functions, particularly executive functions, regardless of ADHD status. Lastly, lower levels of BDNF were expected in students with ADHD before conducting acute exercise. This preliminary study will provide initial evidence relative to the potential value of acute exercise interventions as adjuncts to current ADHD treatment modalities for college students.

## 2. Methods

### 2.1. Participants

Twenty college students between the ages of 18–25 years (age:  $21.75 \pm 1.99$  year, mean  $\pm$  SD) were recruited at Southern Illinois University Edwardsville, IL, USA. Ten students identified with ADHD and registered with the university disabilities office were recruited. To be eligible, these students provided written documentation of their ADHD diagnosis from a medical professional in which the ADHD diagnosis met standard processes based upon *Diagnostic and Statistical Manual of Mental Disorders*.<sup>1</sup> Nine of 10 participants with ADHD were taking stimulant medication. Students without ADHD were recruited via undergraduate classes and flyers placed around campus. Participants were excluded if they had major sensorimotor handicaps (e.g., deafness, blindness), psychosis, inadequate comprehension of the English language, or failed to demonstrate that they were healthy enough to safely complete a single bout of exercise. Table 1 presents the participants' demographic characteristics. This study was approved by the university's Institutional Review Board. Participants provided informed consent and this study was approved by the university's Institutional Review Board.

### 2.2. Cognitive function measures

#### 2.2.1. Stroop Test

The Stroop Test was used to measure inhibition.<sup>33</sup> The Stroop Test consisted of two conditions: Stroop Color and Stroop Color-Word. The Stroop Color condition consisted of 50 trials with rectangles printed in colored ink. The Stroop Color-Word condition also consisted of 50 trials, but with names of colors printed in different color ink (e.g., “BLUE” printed in green ink). For both conditions, the participant was instructed to verbally identify the color of the ink as quickly as possible. Trials in each condition were displayed on a sheet of

Table 1  
Participants' detail demographic characteristics.

Variables	Group	
	Non-ADHD (n = 10)	ADHD (n = 10)
Gender (F/M)	3/7	5/5
Age (year) <sup>a</sup>	24.40 ± 1.84	21.1 ± 2.02
Height (in)	69.5	67.3
Weight (lb)	177.5	148.2
BMI (kg/m <sup>2</sup> ) <sup>a</sup>	25.85 ± 3.19	22.88 ± 2.78
Race (%)		
Caucasian	100	80
African American	0	20
Disorder (%)		
Obsessive compulsive disorder	—	10
Oppositional defiant disorder	—	10
Major depressive disorder	—	0
ADHD type (%)		
Hyperactive, inattentive, combined		20, 10, 30
Medicine (%)		80
Concerta, Ritalin	—	20, 10
Adderall, Vyvanse	—	40, 10

<sup>a</sup> Values are presented as means ± SD.

paper, and the participant was asked to progress through the trials from top to bottom (10 trials) and left to right column (5 columns). The Stroop Color condition was identified as a measure of basic information processing or visual attention; whereas, the Stroop Color-Word condition represented a measure of the inhibition aspect of executive function. The Stroop Test was selected because the test measures multiple cognitive functions and is sensitive to the effects of acute exercise.<sup>34–36</sup> Lower Stroop Test values (i.e., faster completion times) are indicative of better cognitive performance.

### 2.2.2. Trail Making Test (TMT)

The TMT was used to assess task-switching.<sup>37</sup> The TMT consists of two conditions: Trail Making Test Part A (TMT-Part A) and Part B (TMT-Part B). TMT-Part A consists of encircled numbers from 1 to 25 randomly spread across a sheet of paper. The participant must connect the numbers in order, beginning with 1 and ending with 25, in as little time as possible. TMT-Part B is more complex and requires the participant to connect numbers and letters in an alternating pattern (1-A-2-B-3-C, etc.) in as little time as possible. TMT-Part A was designed to assess visual attention, whereas TMT-Part B was used to measure the task-switching aspect of executive function. Lower TMT values are indicative of better cognitive performance.

### 2.2.3. Digit Span (DS) Test

The DS Test, a subtest of the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV), was used to assess working memory.<sup>38</sup> The DS is sensitive to deficits in attention and executive functioning, and researchers have recommended that it be used in diagnosing ADHD.<sup>39</sup> The DS contains two conditions: the Digits Forward (DS Forward) and Digits Backward (DS Backward) tasks.<sup>40</sup> The DS Forward task

involves listening to a sequence of numbers from two to eight digits long (e.g., 6-8-2) and immediately repeating back the sequence aloud in order. The DS Backward task follows the same procedure except that the participant must repeat the number sequences in reverse order (e.g., 2-8-6). Scores on the DS reflect the number of digits in the longest sequence a participant successfully repeats before two consecutive failed trials, with higher scores indicative of better cognitive performance. The DS was used to measure basic information processing (i.e., DS Forward) and the working memory (i.e., DS Backward) aspect of executive function.

### 2.3. Neurotrophic measure

Blood sampling for BDNF was utilized in the present study. All blood sampling was performed by a trained phlebotomist using standard techniques. A 4-mL venous blood sample was obtained prior to and following exercise (total of 8 mL for each participant). The blood sample was centrifuged and aliquoted into storage tubes and frozen until analysis for BDNF. The serum BDNF concentrations were measured in duplicate using an ELISA (R & D systems, Minneapolis, MN, USA) following the manufacturer's instructions.

### 2.4. Exercise-related measures

#### 2.4.1. Heart rate (HR)

HR was measured using a Polar HR Monitor (Model FT 4; Polar Electror Oy, Kempele, Finland) during the entire experimental protocol. HR was recorded every minute for the duration of the activity.

#### 2.4.2. HR reserve (HRR)

HRR is a recommended method for establishing exercise intensity.<sup>41</sup> HRR was calculated as maximal HR minus resting HR.<sup>42</sup> To assess resting HR, participants were instructed to sit comfortably and quietly in a chair for 5 min. Maximal HR was estimated using the formula 220–age. The HRR data were used to test for differences in exercise intensity by treatment condition.

### 2.5. Experimental procedure

Participants were requested to individually visit the laboratory once. One day prior to the testing session, the participant was instructed to sleep according to a typical schedule and not to have caffeine during the test day. At the beginning of the session, each participant was briefly introduced to the study and instructed to complete questionnaires including demographic information (e.g., gender, age, height, weight, BMI, race, and ADHD characteristics) and the Physical Activity Readiness Questionnaire to confirm their inclusion criteria and ensure the safety to conduct exercise. Additional written documents of ADHD diagnosis were required for participants with ADHD.

Participants were then introduced to the Stroop Test, TMT, and DS and performed practice trials. Next, each participant

was administered the three cognitive tasks according to the test instructions in a randomized order to provide pre-test data. Following the cognitive tasks, the participant completed a single bout of supervised aerobic exercise on a treadmill (Trackmaster: Model TMX425C, Full Vision, Inc., Newton, KS, USA). The exercise protocol involved a warm-up period of 5 min to get the participant to the target HR zone, a steady-state exercise period of 30 min at a moderate intensity of 50%–65% HRR, and a cool down period of 5 min to return HR close to resting level. An alarm was set on the HR monitor to alert researchers when the HR was either above or below target rate and adjustments were made to the treadmill speed. The exercise protocol was informed by ACSM recommendations,<sup>41</sup> and was designed based upon previous studies to maximize the potential for cognitive improvements.<sup>19,25</sup> Following exercise, the cognitive tasks were again administered to each participant and this was considered the post-test measure.

HR was monitored and measured at 1-min intervals during exercise. Blood samples were obtained at two time points: once immediately before performance of the pre-test measures of cognitive performance and again following the completion of the exercise protocol but before the post-test measures of cognitive performance.

## 2.6. Statistical analysis

Because the data were skewed due to the small sample size, nonparametric univariate analysis including Mann–Whitney *U* and Chi-square tests were applied where appropriate. Demographic variables were first compared between ADHD and non-ADHD groups via Mann–Whitney *U* (e.g., age, BMI) and Chi-square (e.g., gender, race) tests. Mann–Whitney *U* tests and effect size (ES) calculations (Cohen's *d*) were utilized to compare ADHD and non-ADHD groups in pre-test cognitive performance on the Stroop Test, TMT, and DS.

To identify the changes in cognitive performance associated with acute exercise, separate Mann–Whitney *U* tests were utilized to compare differences between pre- and post-test cognitive performance on all cognitive tasks (i.e., Stroop Test, TMT, and DS) for the ADHD and non-ADHD groups. Similar analyses were also used to assess the changes in BDNF levels. Cohen's *d* was provided to determine the magnitude of acute exercise effect on cognitive performance and BDNF levels. Alpha was set at 0.05 for the significance level.

## 3. Results

### 3.1. Demographic and pre-test measures

No significant demographic differences in gender, age, height, weight, BMI, or race were observed between ADHD and non-ADHD groups (all  $p > 0.05$ ). Additionally, no significant differences emerged for HRR% between groups (ADHD: 51.95% HRR, non-ADHD: 53.06% HRR). Regarding cognitive performance at the pre-test, a significant difference

between ADHD and non-ADHD groups was observed for the Stroop Color-Word condition, with shorter completion times by the non-ADHD group ( $p = 0.04$ ). However, although ESs indicated that performance was better for those in the non-ADHD group compared to those in the ADHD group (ES = 0.06–0.24) and that these differences were particularly evident in tasks related to executive function (ES = 0.18–0.23), no significant differences in performance on the TMT (Tasks A and B) or the DS (Forward and Backward) were observed between the two groups (Table 2).

### 3.2. Acute exercise-related cognitive function measures

#### 3.2.1. Stroop Test

Following the acute exercise bout, the Mann–Whitney *U* test revealed significant differences in performance on the Stroop Color and Stroop Color-Word conditions between pre-test and post-test in the non-ADHD group, with completion times significantly longer at post-test in the Color condition but significantly shorter at post-test in the Color-Word condition ( $p < 0.05$ ). In contrast, the Mann–Whitney *U* test revealed significant improvements from pre-test to post-test in both Stroop Color and Stroop Color-Word conditions for the ADHD group, with completion times significantly shorter at post-test ( $p < 0.05$ ) (Table 3).

#### 3.2.2. TMT

Following the acute exercise bout, the Mann–Whitney *U* test revealed a significant improvement in TMT-Part B between pre- and post-test in the non-ADHD group, with significantly shorter completion times at post-test ( $p < 0.05$ ). However, no pre- to post-test differences were found for the TMT-Part A condition. Additionally, there were no significant pre- to post-test differences in either TMT-Part A or Part B conditions in the ADHD group.

Table 2

Cognitive performance at the pre-test in college students with and without ADHD (mean  $\pm$  SD).

Measures	Group		ES
	Non-ADHD ( <i>n</i> = 10)	ADHD ( <i>n</i> = 10)	
Stroop Test (s)			
Color (–)	20.85 ± 2.55	24.43 ± 5.52	0.83
Color-Word (–)	30.94 ± 4.48	37.92 ± 9.37 <sup>a</sup>	0.95
Trail Making Test (s)			
Task A (–)	19.99 ± 6.25	23.76 ± 10.01	0.45
Task B (–)	53.98 ± 10.82	63.61 ± 27.22	0.46
Digit Span (digit)			
Forward (+)	10.70 ± 2.16	11.00 ± 2.49	0.13
Backward (+)	8.40 ± 1.58	9.10 ± 2.18	0.37

Notes: (–) represents that lower values (i.e., for time measures such as are used in the Stroop Task and Trail Making Test) indicate better performance. (+) represents that larger values (i.e., for number correct such as in the Digit Span) indicate better performance. ES represent the difference of magnitude between ADHD and non-ADHD groups in pre-test.

<sup>a</sup>  $p < 0.05$ , compared with non-ADHD group.

Table 3

Cognitive performance and neurotrophic measures induced by acute exercise in college students with and without ADHD (mean  $\pm$  SD).

Measures	Non-ADHD group			ADHD group		
	Pre-test	Post-test	ES	Pre-test	Post-test	ES
Stroop Test (s)						
Color (–)	20.85 $\pm$ 2.55	21.45 $\pm$ 3.49 <sup>a</sup>	0.20	24.43 $\pm$ 5.52	22.60 $\pm$ 4.58 <sup>a</sup>	0.36
Color-Word (–)	30.94 $\pm$ 4.48	27.59 $\pm$ 4.14 <sup>a</sup>	0.78	37.92 $\pm$ 9.37	31.44 $\pm$ 6.06 <sup>a</sup>	0.82
Trail Making Test (s)						
Task A (–)	19.99 $\pm$ 6.25	17.75 $\pm$ 5.62	0.38	23.76 $\pm$ 10.01	22.42 $\pm$ 7.54	0.15
Task B (–)	53.98 $\pm$ 10.82	42.77 $\pm$ 6.74 <sup>a</sup>	1.24	63.61 $\pm$ 27.22	59.33 $\pm$ 30.48	0.15
Digit Span (digit)						
Forward (+)	10.70 $\pm$ 2.16	11.30 $\pm$ 2.31	0.27	11.00 $\pm$ 2.49	11.00 $\pm$ 1.76	0.00
Backward (+)	8.40 $\pm$ 1.58	9.80 $\pm$ 2.70 <sup>a</sup>	0.63	9.10 $\pm$ 2.18	9.10 $\pm$ 2.03	0.00
BDNF (pg/mL)	1005.81 $\pm$ 248.80	967.03 $\pm$ 169.70	0.18	1050.84 $\pm$ 311.12	1065.50 $\pm$ 268.22	0.05

Notes: (–) represents that lower values (i.e., for time measures such as are used in the Stroop Task and Trail Making Test) indicate better performance. (+) represents that larger values (i.e., for number correct such as in the Digit Span) indicate better performance.

ES represents the difference of magnitude between pre-test and post-test in each group.

<sup>a</sup>  $p < 0.05$ , compared with pre-test values.

### 3.2.3. DS

Following the acute exercise bout, the Mann–Whitney *U* test revealed a significant pre- to post-test improvement in DS Backward in the non-ADHD group, with participants recalling significantly more numbers correctly at post-test ( $p < 0.05$ ). However, no differences were found for the DS Forward condition. There were no significant pre- to post-test differences in either DS Forward or Backward conditions in the ADHD group.

### 3.3. Neurotrophic measure

A Mann–Whitney *U* test revealed no significant differences in BDNF levels at baseline between ADHD and non-ADHD groups. Additionally, there were no significant changes in the BDNF level from pre- and post-test in either the ADHD group or the non-ADHD group.

## 4. Discussion

The aims of this preliminary study were to examine whether ADHD is associated with specific cognitive functions and whether an acute bout of moderate-intensity aerobic exercise influences cognition and BDNF levels in college students with and without ADHD. The main findings revealed that although ADHD students had impairments for all conditions of the three cognitive tasks, with small to medium effect sizes, only the Color-Word condition of the Stroop Test demonstrated significant differences between the college students with and without ADHD. Additionally, acute exercise significantly improved performance on all three tasks in the students without ADHD but only significantly influenced the cognitive functions assessed by the Stroop Test in the students with ADHD. Finally, no difference in BDNF levels was found between the groups, and BDNF was not significantly increased by acute exercise, regardless of ADHD status.

Previous studies have indicated that individuals with ADHD show impaired cognitive functions, particularly executive dysfunction,<sup>12–15</sup> and our study examined the three main

aspects of executive function proposed by Miyake et al.<sup>10</sup> Although the individuals with ADHD generally exhibited worse performances across all indices of executive function, our results revealed that only performance on the Stroop Color-Word condition was significantly worse in the individuals with ADHD compared with the individuals without ADHD. Given that the three cognitive tasks tested in the present study are believed to reflect inhibition, task switching, and working memory aspects of executive function, our findings suggest that individuals with ADHD may be characterized by impairments in the inhibition aspect of executive function. Previous studies have consistently shown a slower Stroop Color-Word performance in individuals with ADHD, which suggests that ADHD was associated with inhibition deficits,<sup>43–45</sup> and the current study replicated these previous findings. Regarding the observation that no significant differences were found in other aspects of executive functions, it is possible that the tasks associated with working memory and task switching assessed by the current study may not be sufficiently sensitive to reflect these differences in a college population. For example, Gropper and Tannock<sup>12</sup> indicated that subjects with ADHD scored worse on auditory-verbal working memory assessed by an average of the age-adjusted DS scores and the Paced Auditory Serial Addition Test, but not on auditory-verbal working memory assessed by the Letter-Number Sequencing Test or on visual-spatial working memory assessed by the Cambridge Neuropsychological Testing Automated Battery. Likewise, using the Test of Variables of Attention (TOVA), Weyandt et al.<sup>14</sup> observed that younger adults with ADHD only demonstrated worse performance in omission errors on the error index of the TOVA but not on the other indices of the TOVA (e.g., commission errors or correct response time). These mixed findings suggest that further research is warranted, specifically including tasks that reflect multiple aspects of executive function.

The present study observed that acute exercise leads to improvements in executive functions for students without ADHD, regardless of the specific aspects of the executive functions assessed. Although we cannot eliminate the

possibility of learning effects as an explanation of the beneficial effects observed in this study, our findings are consistent with the majority of empirical and review studies in which acute, moderate-intensity exercise for 30 min facilitated executive functions in terms of inhibition,<sup>36,46</sup> switching,<sup>2</sup> and working memory.<sup>47</sup> Interestingly, the observed benefits were only evident on the Stroop Test, but not on the TMT or DS in the group with ADHD, suggesting that the effects of acute exercise on executive function are moderated by the specific aspects of the executive functions being assessed and the diagnosis of ADHD. In terms of the Stroop Test, our findings are similar to those of a recent study conducted by Chang et al.,<sup>25</sup> which indicated a positive effect of acute exercise on executive functions using the Stroop Test in children with ADHD. Although the underlying mechanism remains unclear, studies that have examined neuroelectric approaches have suggested that acute exercise may increase the attentional resources and the speed of stimulus selection, which, in turn, facilitates inhibition performance.<sup>46</sup> This hypothesis was recently confirmed in children with ADHD.<sup>48</sup> However, given that acute effects of exercise on multiple aspects of executive function are unexplored, the interpretation of our findings that acute exercise has effects that specifically involve inhibition, but not switching or working memory, remain uncertain. More studies that simultaneously examine acute exercise, multiple cognitive functions, and ADHD symptoms are necessary to advance understanding in these areas.

Another unique component of the present study was that it preliminarily examined the differences in BDNF relative to ADHD and also in response to exercise. In contrast to our hypothesis, no differences in BDNF were observed between the students with and without ADHD. It should be noted that the role of BDNF in ADHD human studies has only recently been examined and mixed results have been reported. For example, BDNF has been found to positively correlated with attentional symptoms in ADHD patients;<sup>49</sup> however, some studies indicated that BDNF may only be associated with the type of ADHD, but not differences between ADHD and non-ADHD subjects.<sup>50</sup> Our finding is in accordance with recent studies that demonstrated no difference in the concentrations of BDNF when children diagnosed with ADHD were compared with their non-ADHD counterparts.<sup>50,51</sup> Although future studies are needed to replicate these findings, our results extend the knowledge from children to college students by suggesting that the presence of BDNF may be not be a primary factor in distinguishing the ADHD population.

Intriguingly, alterations of BDNF were not observed as a result of acute exercise in either group. Thus, our findings failed to offer even preliminary support for BDNF as a potential mediator of the relationship between acute exercise and cognition. Although several human studies have found that exercise increases BDNF levels, the level of BDNF has been speculated to be dependent upon the exercise load. For example, in a comparison of acute exercise bouts of high (10% above ventilatory threshold; VT) and low (20% below VT) intensity, Ferris et al.<sup>52</sup> reported increased serum BDNF levels only following the high-intensity exercise condition. Increased

BDNF levels following lower-intensity exercise (10%–15% below the lactate threshold) were reported in a study by Rasmussen et al.;<sup>53</sup> however, these changes only emerged following a 4-h bout of exercise on a rowing ergometer and had not yet emerged at a midpoint assessment 2 h into the exercise bout. Our findings that moderate-intensity exercise for 30 min failed to impact BDNF levels supports previous research findings that acute exercise protocols must employ high intensities or very long durations to reliably elicit an elevation of BDNF.

Several factors warrant a cautious interpretation of these results. The small sample size limits the statistical power of the present study as well as limiting our ability to eliminate any confounding variables that may have impacted the results, such as ADHD subtype, intelligence quotients, and amount of regular exercise; however, the interpretations of the current findings were based on significant *non-parametric* statistical values, which are appropriately applied to small samples without a normal distribution. An additional consideration is the lack of a non-exercise control group, which made it impossible to parse out a learning effect from an effect resulting from exercise. Although acute exercise has been reasonably well established to have a generally beneficial effect on cognitive function following the cessation of exercise and the present study applied exercise protocols that have been previously identified as the most likely to improve cognition,<sup>18,19</sup> future studies should consider adding a control group. Additionally, examining the additive effects of exercise and stimulant medications in individuals with ADHD is important. In the present study, almost all participants with ADHD were currently taking medications to treat their disorder. Whether exercise enhances the effects of these medications or whether exercise is as effective as medication in tempering the negative conditions of ADHD remains unclear. Future research should explore the role of exercise in conjunction with medication use or in the absence of medication to further our understanding of the potential effects of acute exercise on cognitive performance by persons with ADHD. Finally, although still inconclusive, substantial research focused on the exercise–cognition relationship has been devoted to elucidating the optimal duration, intensity, and modality of exercise in individuals without ADHD to establish the foundations for exercise as a treatment.<sup>34,54</sup> Similar attention is warranted for individuals with ADHD, in which the optimal dose of exercise has yet to be quantified.

To the best of our knowledge, this study is the first to examine the effects of acute exercise on multiple cognitive functions in college students with ADHD. Pharmacotherapy treatments, particularly stimulant medications, are the primary form of treatment used by college students with ADHD;<sup>55</sup> however, few studies exist that have examined the effects of medications on executive functions. Other issues with pharmaceutical treatments include student reports of adverse physical and psychological side effects and limited perceived effectiveness,<sup>56</sup> fear of becoming dependent on the medication, or personal beliefs that lead students to be unsure about using medications as a treatment, which results in persistent

“pharmaceutical ambivalence” in college students with ADHD.<sup>57</sup> As a result, young adults may be increasingly willing and motivated to explore alternative or adjuvant treatments for ADHD. In addition to having fewer side effects, being easily accessible, and holding numerous health benefits that medications alone will not provide, our study provides preliminary evidence that supports the use of exercise as an alternative treatment for improving cognitive function in college students with ADHD.

## 5. Conclusion

College students with ADHD may experience executive dysfunctions, and deficits in the inhibition aspect of executive functions were evident in this study. Additionally, although acute exercise leads to improvements in multiple aspects of executive function in college students without ADHD, its effects particularly benefit the inhibition aspect of executive functions in individuals with ADHD. These results also indicated BDNF did not differ as a function of ADHD nor did it change in response to exercise. Although these results must be considered as chiefly exploratory in nature, mainly due to methodological issues, this preliminary study provides important implications for the potential use of exercise to positively influence select measures of executive functions in college students with and without ADHD.

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