

# Effect of Acute Exercise on Executive Function in Children with Attention Deficit Hyperactivity Disorder

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## Abstract

This study was conducted to determine the effect of acute aerobic exercise on executive function in children with attention deficit hyperactivity disorder (ADHD). Forty children with ADHD were randomly assigned into exercise or control groups. Participants in the exercise group performed a moderate intensity aerobic exercise for 30 min, whereas the control group watched a running/exercise-related video. Neuropsychological tasks, the Stroop Test and the Wisconsin Card Sorting Test (WCST), were assessed before and after each treatment. The results indicated that acute exercise facilitated performance in the Stroop Test, particularly in the Stroop Color-Word condition. Additionally, children in the exercise group demonstrated improvement in specific WCST performances in Non-perseverative Errors and Categories Completed, whereas no influences were found in those performances in the control group. Tentative explanations for the exercise effect postulate that exercise allocates attention resources, influences the dorsolateral prefrontal cortex, and is implicated in exercise-induced dopamine release. These findings are promising and additional investigations to explore the efficacy of exercise on executive function in children with ADHD are encouraged.

**Keywords:** Physical activity; Executive control; Cognitive function; Mental disorder; Mental health

## Introduction

Attention deficit hyperactivity disorder (ADHD) is recognized as a highly prevalent neurobehavioral childhood disorder that is described by symptoms of inattentive, hyperactive, and/or impulsive behavior based on criteria in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV; American Psychiatric Association, 1994). The rate of ADHD in U.S. children is incredibly high where 8.7% or ~2.4 million school-aged children meet the DSM-IV criteria (Froehlich et al., 2007). The impact of ADHD on society is enormous regarding its financial cost, family life, academic performance, and mental health (Biederman, 2005; Bledsoe, Semrud-Clikeman, & Pliszka, 2010).

Emerging literature has proposed that children with ADHD often exhibit deficiencies in cognitive function, particularly in executive function (Semrud-Clikeman, Pliszka, & Liotti, 2008; Sergeant, Geurts, & Oosterlaan, 2002). Executive function, an umbrella term used to describe “higher or meta-” cognitive function, encompasses broad and multi-faceted constructs (Alvarez & Emory, 2006; Miyake et al., 2000). It also refers to the processes of self-monitoring or self-regulation that are responsible for purposeful and goal-directed behaviors (Gioia, Isquith, & Guy, 2001). Given this multi-faceted concept, a variety of neuropsychological tasks have been proposed to assess general or specific constructs of executive function (e.g., Stroop Test, Wisconsin Card Sorting Test [WCST], Stop-Signal Test, and Tower of Hanoi/London). These neuropsychological tasks have also been applied to investigate the executive function in children with ADHD, where research generally revealed that

ADHD was associated with executive dysfunction assessed by these tasks (Geurts, Verte, Oosterlaan, Roeyers, & Sergeant, 2005; Nyhus & Barcelo, 2009).

Although a definitive pathophysiological model of ADHD has not been fully characterized (Doyle et al., 2005), the linkage between executive dysfunction and ADHD has been tentatively established by prefrontal hypothesis (Seidman, Valera, & Makris, 2005) or by imbalances in the dopaminergic and noradrenergic systems (Pliszka, 2005).

According to the prefrontal hypothesis, prefrontal-related cortices have a potential role linked to executive function and are abnormal in ADHD. Executive function and its related tasks are associated with the frontal cortex (Alvarez & Emory, 2006; Keil & Kaszniak, 2002) and neural networks, including the prefrontal cortex, thalamus, and basal ganglia (Middleton & Strick, 2002; Pennington, 2002). Recent neurochemical and neuroimaging studies have further supported that dysfunctions in the prefrontal cortex, particularly the dorsolateral prefrontal cortex and orbitofrontal cortex (Seidman et al., 2005), and dysfunction in fronto-striatal pathways (Booth et al., 2005; Rubia, Smith, Brammer, & Taylor, 2003) are generally implicated in ADHD.

Another hypothesized mechanism was implicated by imbalances in the dopaminergic and noradrenergic system (Arnsten, 2006). ADHD may result in the dysfunction of attention circuits that are regulated by neurotransmitters such as dopamine and norepinephrine. In fact, stimulant medications (i.e., methylphenidate) that are used commonly to treat ADHD are based on the hypothesis that they act by blocking the reuptake of these neurotransmitters in the prefrontal cortex, thereby reducing ADHD symptoms (Stahl, 2010). Additionally, these stimulants were also linked to increase executive function and neuropsychological performances in adults with and without ADHD (Mehta et al., 2000; Rhodes, Coghill, & Matthews, 2006). Although plausible to treat ADHD and to improve executive function, stimulants may induce multiple side effects, such as decreased appetite, sleep problems, or personality changes (National Institute of Mental Health, 2008). Alternative approaches to impact both executive function and ADHD should be considered.

Exercise is a candidate-behavioral treatment for cognition in ADHD children. A meta-analytic review conducted by Sibley and Etnier (2003) explored the relationship between exercise and cognition in children based on multiple moderators (i.e., experimental design, age, activity design, and types of cognition). Exercise had a significant and positive impact on cognition in children (overall effect size [ES] = 0.32). Additionally, acute exercise had a greater impact (ES = 0.37) when compared with chronic exercise and cross-sectional comparison (ES range from 0.29 to 0.35).

Targeting children with and without clinical disorders (i.e., ADHD, autism, behavioral disorder, and mental retardation), the Tomporowski (2003a) review concluded that acute exercise generally demonstrated beneficial influences on cognition in both types of children. However, he also noted several methodological limitations within these early studies. For example, three studies investigated the effect of acute exercise on cognition in children with ADHD but demonstrated mixed results. Molloy (1989) found that attention behavior in two children was improved following a 5-min cycling. However, Craft (1983) did not find a cycling effect on cognitive performance measured during exercise for 1, 5, and 10 min. Additionally, with a case study design, Silverstein and Allison (1994) indicated that a 3-year-old boy had worse disruptive behavior after 20-min runs compared with methylphenidate intake. These early studies should be considered with caution given the study limitations, for instance small sample sizes, unappreciated control groups, non-standard cognitive tasks, tasks assessed during exercise, and high-intensity level exercise intervention (i.e., exhaustion) that made the children uncomfortable.

A recent well-controlled study conducted by Gapin and Etnier (2010) indicated positive preliminary findings between exercise level and executive function. Using an accelerometer, a Daily Physical Activity Log, and multiple standard executive function tasks (i.e., Tower of London, Digit Span, and Children's Color Trails Test 1 and 2), the researchers indicated that moderate-to-vigorous intensity physical activity could significantly predict performances on the Tower of London. This activity was also associated with other executive function performances where more exercise participation showed better executive performances, suggesting that exercise positively influences inhibition, planning, working memory, and processing speed in children with ADHD.

Because exercise may benefit executive function by adjusting brain structure and neurotransmitters and these brain functions are particularly relevant to ADHD, Halperin and Healey (2010) recently proposed rationale that potentially connect among exercise, ADHD, and executive function. In rodent models, Petzinger and colleagues (2007) found that treadmill exercise increased motor performance (velocity and balance) as well as striatal tissue dopamine levels, suggesting that exercise influences dopaminergic neurotransmission. Similarly, Foley and Fleshner (2008) indicated that running increased dopamine synthesis as well as reduced D2 autoreceptor-mediated inhibition of dopamine neurons in the substantia nigra pars compacta. The benefits of physical exercise on cognition (attentional capabilities) were recently confirmed by using spontaneously hypertensive/ADHD-like rats (Robinson, Hopkins, & Bucci, 2011). These positive findings have also been extended to human subjects, where McMorris and colleagues proposed that acute exercise-induced neurotransmitter modifications (i.e., plasma concentrations of norepinephrine and dopamine metabolite homovanillic acid) were related to central executive tasks (McMorris, Collard, Corbett, Dicks, & Swain, 2008; McMorris et al., 2009).

Based on the evidence that ADHD patients suffer from the deterioration of executive function, acute exercise positively influences executive function, and the potential mechanisms linking ADHD, acute exercise, and executive function, it seems plausible that exercise could facilitate executive function in ADHD patients. To our knowledge, the effect of acute moderate exercise on executive function measured by neuropsychological tasks in ADHD has not yet been explored. The aim of this study, therefore, was to examine whether a single bout of aerobic exercise could improve executive function in children with ADHD. Specifically, we targeted two types of neuropsychological tasks, the Stroop Test and the WCST, as these tasks have been used frequently to measure executive functions in healthy adults (Alvarez & Emory, 2006; Etnier & Chang, 2009) and ADHD patients (Geurts et al., 2005; Homack & Riccio, 2004; Sergeant et al., 2002; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Given the results of the studies briefly reviewed above, we hypothesized that acute exercise could benefit executive functions measured by the Stroop Test and the WCST. Such a study may be critically important in laying the ground work for both scientific research and clinical application.

## Method

### Participants

Potential participants were initially recruited through posted flyers, referral of patients' parents from local elementary schools, and several orientations introducing the project. The participants were then included only if they met inclusion criteria as follows: (1) children aged between 8 and 15; (2) classified as ADHD diagnosed by a psychiatric physician; (3) reported as being free of intellectual disability, brain injury, and disease; and (4) meeting criteria assessed by the Physical Activity Readiness Questionnaire (PAR-Q) to ensure no potential risk factors while performing a single bout of aerobic exercise, which followed the guidelines of the American College of Sports Medicine (ACSM, 2010).

According to a psychiatric physician, the diagnosis of ADHD was based on DSM-IV with multiple assessments (e.g., observations, questionnaire, etc.). In addition, all types of ADHD (i.e., ADHD-I, a predominantly inattentive subtype; ADHD-HI, a predominantly hyperactive-impulsive subtype; and ADHD-C, a combined hyperactive-impulsive and inattentive subtype) with or without medicine intake were included once the participant met the criteria. At the end of recruiting procedure, 40 children (3 women and 37 men, mean age = 10.43 years, age range: 8–13 years) were finally involved and were randomly assigned into either the exercise group or the control group. Participants as well as their parents completed a written assessment and informed consent that was reviewed and approved by the University's Institutional of Review Board (IRB) prior to the experiment.

### Exercise Manipulation Check

**Heart rate.** Heart rate (HR) was measured with a Polar HR monitor (Mode S 610i; Polar Electro, Finland), a short-range radio telemetry device, during the entire experimental stage. HR data from the HR monitor were recorded at 1-min intervals. Three HR variables were identified, where HR-pre and HR-post represented HRs assessed before and immediately after each treatment. HR-avg. represented average HR assessed during the main exercise stages.

**HR reserve.** HR reserve (HRR) is one of the recommended methods for establishing exercise intensity (ACSM, 2010). HRR was calculated as maximal HR minus resting HR (Karvonen, Kenthla, & Mustala, 1957), where maximal HR was estimated using an indirect formula " $206.9 - (0.67 \times \text{age})$ " (Gellish et al., 2007). The target HR was calculated by a formula as follows: Target HR = [(maximal HR – resting HR-rest)]  $\times$  percentage intensity desired + resting HR.

**Rating of perceived exertion.** The rating of perceived exertion (RPE) was developed by Borg (1998) and provides a subjective rating of each individual's perception of effort during exercise. We utilized the original Borg scale, which ranges from 6 to 20; scores from 7 to 11 represent "very, very light to fairly light exertion," scores from 13 to 14 represent "somewhat hard exertion," scores from 15 to 19 represent "hard to very, very hard exertion," and 20 represents "maximal exertion." RPE was recorded at 2-min intervals during the exercise.

### Executive Function Measures

**Stroop Test.** The Stroop Test is a color-naming task developed by Stroop (1935). During the Stroop Test, the participant is instructed to identify the color of ink verbally as quickly as possible based on trials listed in each condition. The Stroop Test consisted of three conditions, including Stroop Word, Stroop Color, and Stroop Color-Word. The Stroop Word condition involved 50 trials with color names (i.e., blue, red, green) written in black ink. The Stroop Color condition involved 50 trials

with color names in same-colored rectangles. Stroop Color-Word involved 50 trials with color names printed in different color ink (i.e., “GREEN” printed in red ink). Trials in each condition were displayed on a sheet of paper, and participants were asked to name the trials from top to bottom (10 trials) and left to right column (5 columns). The Stroop Test was chosen because of evidence that it measures executive function and is sensitive to the effects of acute exercise (Chang & Etnier, 2009a, 2009b; Sibley, Etnier, & Le Masurier, 2006).

*Wisconsin Card Sorting Test.* The WCST is one of the most widely used tasks for executive function (Greve, Stickley, Love, Bianchini, & Stanford, 2005), and it has been linked to measures of strategic planning, updating, shift cognitive set, modulating impulsive responding, and perseveration (Greve et al., 2005; Heaton, Chelune, Talley, Kay, & Curtiss, 2008). The WCST included four stimulus cards and 128 response cards. Respondents were required to sort response cards based on one of three characteristics (i.e., color, form, and number) of the four stimulus cards. The examiner provides “Correct” or “Incorrect” feedback after each response trial, and once the respondent matched the characteristics of the stimulus cards for 10 cards (also known as “nature of category”), the sorting category was changed. The WCST was terminated by either successful completion for 6 categories or at the end of 128 response cards. The WCST of the present study was administered by WCST: Computer Version 4, Research Edition (Heaton, 2008), and six raw scores were included for statistical analysis including Total Correct, Perseverative Responses, Perseverative Errors, Non-perseverative Errors, Conceptual Level Response, and Categories Completed (Greve, Ingram, & Bianchini, 1998).

### *Experimental Protocols and Procedures*

Four stages were involved in the experimental procedure: (1) confirmation, (2) pre-test, (3) treatments, and (4) post-test. During the first stage, each participant and his/her parent visited the lab after school during the fall 2010 semester. They were asked to read and complete the consent form approved by the University’s IRB, the PAR-Q, and a medical history questionnaire. After meeting inclusion criteria, each participant was equipped with an HR monitor and was assigned randomly into either the control group or the exercise group. The study room was set a constant temperature of 25°C and a relative humidity of 65%–70%.

Each participant then entered the pre-test stage, which consisted of measuring the participant’s Stroop Test and WCST. Participants were instructed to verbally perform the Stroop Test under Stroop Word, Stroop Color, and Stroop Color-Word conditions as quickly as possible. The trial error was identified by the examiner, and the participant was required to rename the trial until the correct trial was identified. Stroop Test performance measures were assessed by time duration in each condition. Then, the participant was asked to perform the WCST. In the computer version, four stimulus cards were displayed across the top of the screen, whereas a response card (total = 128) was displayed at the bottom center. Respondents were asked to sort response cards that matched one of the stimulus cards by pressing corresponding bottoms (F, G, H, or J) on the keyboard. After each response trial, the examiner provided feedback of either “Correct” or “Incorrect,” and no other feedback and instruction was provided.

During the treatment, participants in the exercise group were instructed to individually perform a single bout of aerobic exercise. Exercise mode, intensity, and duration were considered in the exercise protocol. Participants were instructed to run on a treadmill (Cybex) for 30 min. The exercise directions included warm up for 5 min, main exercise for 20 min, and cool down for 5 min. The exercise intensity was set at 50%–70% HRR of each participant’s individual HRR. Based on ACSM guidelines (2010), 50%–70% HRR represented moderate intensity. The intensity was selected because of evidence that moderate intense exercise is recommended by ACSM exercise guidelines and is sensitive to effect of acute exercise (Briswalter, Collardeau, & Rene, 2002; Tomporowski, 2003b). RPE (ranging from 12 to 15) was recorded at 2-min intervals to monitor and confirm that each participant experienced this intensity. The speed was further adjusted based on target HRR and PRE. In contrast, participants in the control group were asked to watch a running/exercise-related video for the same duration as the exercise group. The video was made by the experimenter for the purpose of manipulating stable arousal during the control process. The context involved information about the benefits of exercise on health, while some of the clips within the video were presented as cartoons for intriguing the children.

In the post-test, within a minute of the end of treatment, each participant was asked to complete the Stroop Test and the WCST again with the same approach as the pre-test. The HR was assessed with an HR monitor at 2-min intervals over the duration of the experiment. The entire experimental process lasted ~100 min. The participant and his/her parents were informed briefly on the purpose and expectation of the present study after the completion of all four stages.



## Statistical Analysis

A two-way mixed randomized controlled trial design was employed with group and time as independent variables. To ensure homogeneity in potential confounds between the control and exercise groups, an analysis of independent samples using a *t*-test or a  $\chi^2$ -test was applied to compare demographic data in continuous or discrete scales between the two groups, respectively. To test exercise intensity manipulation, a mixed 2 (group: exercise vs. control)  $\times$  3 (time: HR-pre, HR-avg., and HR-post) analysis of variance (ANOVA) was completed. Then, statistical analyses testing the effect of exercise on executive function using the Stroop Task and WCST scores were conducted separately using a 2 (group: exercise vs. control)  $\times$  2 (time: pre-test vs. post-test) mixed ANOVA. For the ANOVAs, significant interaction effects were followed up with tests of simple main effects, whereas significant main effects (when levels  $>3$ , i.e., HRs) were followed up with multiple comparison. Additional Bonferroni adjustments were made to control for the experiment-wise inflation of  $\alpha$ . All analyses satisfied Levene's test of homogeneity.

ES were calculated using Cohen's *d* (the mean difference of the groups divided by the pooled standard deviation), and a partial eta-square ( $\eta^2$ ) was reported for significant main effects and interactions. The test–retest reliability of the Stroop Test and the WCST were also evaluated for the age group. An  $\alpha$  of 0.05 was used as the level of statistical significance for all statistical analyses, which were conducted using SPSS 17.0.

## Results

### Demographic Analyses

There was no significant difference between the groups in age, weight, height, and body mass index,  $t'(38) > -0.22$ ,  $p > .05$ ; and gender, grade, ADHD type, and medicine intake, for all group,  $\chi^2 > 0.37$ ,  $p > .05$ , suggesting homogeneity between the two groups. The demographic characteristics of participants in both groups are summarized in Table 1.

### Exercise Manipulation Check

Results of the 2  $\times$  3 mixed ANOVA for HR revealed that there were significant main effects for group,  $F(1, 38) = 183.77$ ,  $p < .001$ , partial  $\eta^2 = 0.83$ , time,  $F(2, 76) = 118.12$ ,  $p < .001$ , partial  $\eta^2 = 0.84$ , and interaction of group by time,  $F(2, 76) = 188.75$ ,  $p < .001$ , partial  $\eta^2 = 0.83$ . Because there was a significant interaction effect, a follow-up of simple effects was utilized to decompose the interaction of time by group. The results revealed that there were significant time effects for the exercise group,  $F(2, 38) = 491.16$ ,  $p < .001$ , partial  $\eta^2 = 0.96$ , but the control group,  $F(2, 38) = 0.13$ ,  $p > .05$ . In the exercise group, HR-avg. was significantly higher than HR-post which was also significantly higher than HR-pre. Stated another way, the simple effects showed that the exercise group had a significantly higher HR on HR-avg. and HR-post than the control group,  $F(1, 38) > 47.02$ ,  $p < .001$ . However, no significant differences between groups were observed for HR-pre,  $F(1, 38) = 1.98$ ,

**Table 1.** Participant demographic characteristics

| Variable   | Control ( <i>N</i> = 20) | Exercise ( <i>N</i> = 20) | Total ( <i>N</i> = 40) |
|--|--------------------------|---------------------------|------------------------|
| Gender (M:F; <i>M</i> [ <i>SD</i> ])             | 18:2                     | 19:1                      | —                      |
| Age (years; <i>M</i> [ <i>SD</i> ])              | 10.42 (0.87)             | 10.45 (0.95)              | 10.43 (0.90)           |
| Height (cm; <i>M</i> [ <i>SD</i> ])              | 139.75 (7.80)            | 141.90 (9.98)             | 140.83 (8.91)          |
| Weight (kg; <i>M</i> [ <i>SD</i> ])              | 33.03 (6.56)             | 34.60 (8.56)              | 33.81 (7.57)           |
| BMI (kg/m <sup>2</sup> ; <i>M</i> [ <i>SD</i> ]) | 16.71 (2.16)             | 16.86 (2.60)              | 16.79 (2.36)           |
| Grade ( <i>N</i> [%])                            |                          |                           |                        |
| Third  | 4 (20)                   | 3 (15)                    | 7                      |
| Fourth   | 9 (45)                   | 11 (55)                   | 20                     |
| Fifth  | 3 (15)                   | 3 (3)                     | 6                      |
| Sixth  | 4 (20)                   | 3 (15)                    | 7                      |
| ADHD type ( <i>N</i> [%])                        |                          |                           |                        |
| ADHD-I   | 4 (20)                   | 10 (50)                   | 14                     |
| ADHD-HI  | 3 (15)                   | 2 (10)                    | 5                      |
| ADHD-C   | 13 (65)                  | 8 (40)                    | 21                     |
| Medicine Intake                                  | 10 (50)                  | 10 (50)                   | 20                     |

Notes: BMI = body mass index; ADHD-I = predominantly inattentive subtype; ADHD-HI = predominantly hyperactive-impulsive subtype; ADHD-C = combined hyperactive-impulsive and inattentive subtype; *N* = number of participants; % = percentage in the group.

$p > .05$ . In brief, the exercise group showed that aerobic exercise induced arousal and slight reduced after ceasing exercise, whereas control failed to reveal any arousal differences.

During the exercise, %HRR, RPE, and speed were 58%, 12.65 and 6.52 km/h, respectively. Detailed descriptive data for exercise manipulation checks are summarized in Table 2.

### Effect of Exercise on the Stroop Test

For Stroop Word, a  $2 \times 2$  mixed ANOVA revealed that there was a significant main effect of time,  $F(1, 38) = 7.45, p < .01$ , partial  $\eta^2 = 0.16$ , where shorter times were observed in the post-test. However, main effects for group and the interaction of group by time were not significant,  $F(1, 38) < 0.06, p > .05$ . Similar findings were also observed for Stroop Color, where there was a significant main effect of time,  $F(1, 38) = 14.20, p < .01$ , partial  $\eta^2 = 0.27$ , with shorter durations found in the post-test. However, both main effects for group and the interaction of group by time were not significant,  $F(1, 38) < 0.30, p > .05$ . Means, standard deviations, and ESs for the Stroop Test and WCST performances are presented in Table 3.

In contrast, for Stroop Color-Word, there was a significant main effect of time,  $F(1, 38) = 62.51, p < .01$ , partial  $\eta^2 = 0.62$ , and an interaction of group by time,  $F(1, 38) = 5.24, p < .01$ , partial  $\eta^2 = 0.12$ . Because there was a significant interaction effect, a follow-up of simple main effects was used to decompose the interaction of times by groups, and a significant time effect was found for the exercise group,  $F(1, 38) = 58.27, p < .0001$ , partial  $\eta^2 = 0.75$ , and control groups,  $F(1, 38) = 14.24, p < .001$ , partial  $\eta^2 = 0.43$ . When the group was controlled for, no significance was found in the pre-test,  $F(1, 38) = 0.05, p > .05$ , but near significance was found in the post-test,  $F(1, 38) = 3.30, p = .08$ . The results suggested that although shorter durations of both groups were found in the post-test compared with the pre-test, the post-test of the exercise group had a shorter duration than those in the control group (ES = 0.57; Fig. 1). The test–retest reliabilities of the Stroop Test for the age group was high ( $r = .79-.83$ ).

### Effect of Exercise on the WCST

For Non-perseverative Errors, a  $2 \times 2$  mixed ANOVA revealed that there was a significant main effect of time,  $F(1, 38) = 7.61, p < .05$ , partial  $\eta^2 = 0.17$ , and an interaction of group by time,  $F(1, 38) = 7.48, p < .05$ , partial  $\eta^2 = 0.17$ . Because there was a significant interaction effect, a follow-up of simple main effects was used to decompose the interaction of times by groups. A significant time effect was found for the exercise group,  $F(1, 38) = 9.62, p < .005$ , partial  $\eta^2 = 0.34$ , but not the control group,  $F(1, 38) = 0.01, p > .05$ . When controlling for group, a significance was found in the pre-test,  $F(1, 38) = 4.36, p < .05$ , but not in the post-test,  $F(1, 38) = 0.48, p > .05$ . Similar findings were also revealed in Categories Completed, where a  $2 \times 2$  mixed ANOVA revealed that there was a significant main effect of time,  $F(1, 38) = 7.65, p < .01$ , partial  $\eta^2 = 0.17$ , and an interaction of group by time,  $F(1, 38) = 5.31, p < .05$ , partial  $\eta^2 = 0.27$ . Because there was a significant interaction effect, a follow-up of simple main effects was used to decompose the interaction of times by groups. A significant time effect was found for the exercise group,  $F(1, 38) = 8.24, p < .01$ , partial  $\eta^2 = 0.31$ , but not for the control group,  $F(1, 38) = 0.24, p > .05$ . When controlling for group, a nearly significance was found in the pre-test,  $F(1, 38) = 3.34, p < .05$ , but not in the post-test,  $F(1, 38) = 0.56, p > .05$ .

**Table 2.** Descriptive data for exercise manipulation check

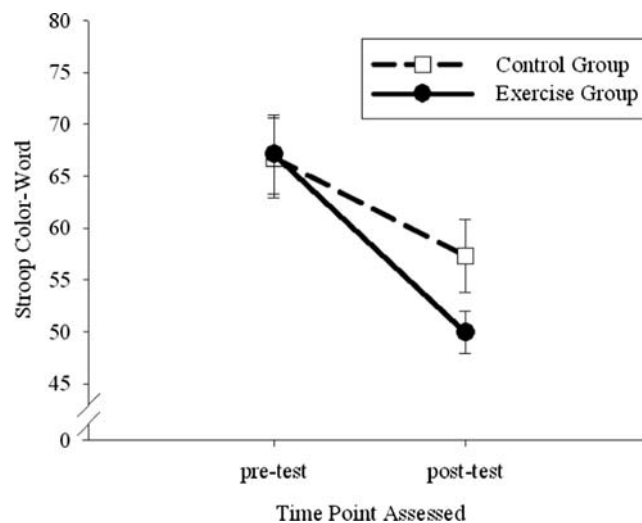
| Variable        | Control ( <i>M</i> [ <i>SD</i> ]) | Exercise ( <i>M</i> [ <i>SD</i> ]) |
|-----------------|-----------------------------------|------------------------------------|
| HR-pre (bpm)    | 78.6 (10.61)                      | 82.55 (9.11)                       |
| HR-avg. (bpm)   | 78.00 (8.61)                      | 150.07 (11.87)                     |
| HR-post (bpm)   | 77.25 (9.64)                      | 99.25 (10.62)                      |
| RPE-warm up     | —                                 | 7.78 (1.39)                        |
| RPE-avg.        | —                                 | 12.65 (1.74)                       |
| RPE-cool down   | —                                 | 11.20 (2.18)                       |
| Speed-warm up   | —                                 | 3.67 (0.48)                        |
| Speed-avg.      | —                                 | 6.52 (0.83)                        |
| Speed-cool down | —                                 | 3.54 (1.00)                        |

Notes: bpm = beats per minute; HR = heart rate; RPE = rating of perceived exertion; -pre = variable assessed before each treatment interventions; -avg. = average variable assessed during the main exercise stage; -post = variable assessed immediately before cognitive task; -warm up = variable assessed during the warm up stage; -cool down = variables assessed during the cool down stage.

**Table 3.** Means, standard deviations, and ESs for the Stroop Test and the Wisconsin Card Sorting Test

| Variable                           | Control group                      |                                     |       | Exercise group                     |                                     |       |
|------------------------------------|------------------------------------|-------------------------------------|-------|------------------------------------|-------------------------------------|-------|
|                                    | Pre-test ( <i>M</i> [ <i>SD</i> ]) | Post-test ( <i>M</i> [ <i>SD</i> ]) | ES    | Pre-test ( <i>M</i> [ <i>SD</i> ]) | Post-test ( <i>M</i> [ <i>SD</i> ]) | ES    |
| <b>Stroop Test</b>                 |                                    |                                     |       |                                    |                                     |       |
| Stroop Word (–)                    | 26.38 (6.65)                       | 24.59 (7.08)                        | –0.26 | 26.80 (6.37)                       | 25.10 (5.57)                        | –0.28 |
| Stroop Color (–)                   | 36.76 (11.31)                      | 34.00 (8.80)                        | –0.27 | 36.94 (7.80)                       | 33.24 (7.82)                        | –0.47 |
| Stroop Color-Word (–)              | 66.76 (17.13)                      | 57.30 (15.64)                       | –0.58 | 67.13 (16.98)                      | 49.94 (9.15)                        | –1.26 |
| <b>Wisconsin Card Sorting Test</b> |                                    |                                     |       |                                    |                                     |       |
| Total Correct (+)                  | 68.60 (11.37)                      | 76.40 (10.70)                       | 0.71  | 68.05 (15.53)                      | 72.85 (12.33)                       | 0.34  |
| Perseverative Responses (–)        | 23.60 (13.53)                      | 14.10 (7.82)                        | –0.86 | 25.90 (13.14)                      | 18.35 (13.77)                       | –0.56 |
| Perseverative Errors (–)           | 20.65 (15.50)                      | 13.45 (7.04)                        | –0.60 | 23.15 (10.91)                      | 16.95 (12.31)                       | –0.53 |
| Non-perseverative Errors (–)       | 18.95 (14.53)                      | 18.90 (15.90)                       | 0.00  | 29.55 (17.12)                      | 17.85 (14.52)                       | –0.74 |
| Conceptual Level Response (+)      | 59.30 (15.27)                      | 68.05 (16.23)                       | 0.56  | 52.80 (21.87)                      | 62.60 (19.37)                       | 0.47  |
| Categories Completed (+)           | 4.75 (1.77)                        | 4.85 (1.92)                         | 0.05  | 3.60 (2.16)                        | 4.70 (2.07)                         | 0.52  |

Notes: Effect size (ES) is calculated by Cohen's *d*; (+) = higher scores represent better performance; (–) = lower scores represent better performance

**Fig. 1.** The Stroop Color-Word score is a function of time and group.

In summary, the results of Non-perseverative Errors and Categories Completed revealed that post-test WCST performances were improved in the exercise group compared with pre-test performances, while no difference was found between post-tests and pre-tests in the control group (Fig. 2a and b).

In contrast, a  $2 \times 2$  mixed ANOVA for Total Correct revealed that there was a significant main effect of time,  $F(1, 38) = 7.72$ ,  $p < .01$ , partial  $\eta^2 = 0.17$ , where more improvement was found in the post-test. However, the main effect for group and the interaction of group by time were not significant,  $F(1, 38) < 0.44$ ,  $p > .05$ . Similar findings were also observed for Perseverative Responses, Perseverative Errors, and Conceptual Level Response, where there was a significant main effect of time,  $F(1, 38) > 6.21$ ,  $p < .01$ , partial  $\eta^2 > 0.14$ , and better performances were found in the post-test compared with the pre-test. However, both main effects for group and the interaction of group by time were not significant,  $F(1, 38) < 2.50$ ,  $p > .05$ . The test–retest reliabilities of the WCST for the age group was moderate to high ( $r = .36-.74$ ).

## Discussion

The present study examined the effect of acute bout of aerobic exercise on executive function in children with ADHD. With appropriate manipulation of moderate exercise intensity via confirmation in HR and RPE, the main findings revealed that acute exercise facilitated performance in the Stroop Color-Word condition. Additionally, children with ADHD in the exercise group demonstrated the improvements of specific WCST performances in Non-perseverative Errors and Categories Completed, whereas no influences were found in those performances in the control group. Although significant time effects were also

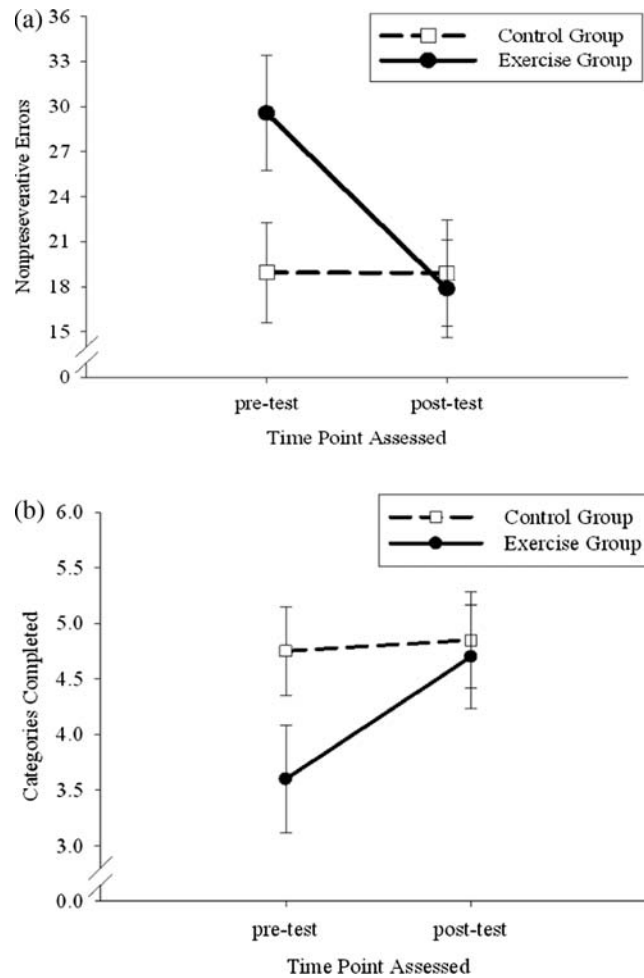


Fig. 2. WCST scores as functions of time and group on (a) Non-perseverative Errors and (b) Categories Completed.

revealed in other sub-indexes of executive function performances (i.e., Stroop Word, Stroop Color, Total Correct, Perseverative Responses, Perseverative Errors, and Conceptual Level Response), no exercise effects were found, suggesting that acute exercise sensitivity was limited on these aspects.

The Stroop Test, in particular the Stroop Color-Word condition, is a measure of selective attention as well as cognitive inhibition or inhibition of a dominant response in favor of completing a required unusual task (Miyake et al., 2000; Schwartz & Verhaeghen, 2008). Homack and Riccio (2004) determined that the Stroop Test is an appropriate neuropsychological task with moderate sensitivity to distinguish children with ADHD from normal children (ES range from  $-0.52$  to  $-0.75$ ). Compared with controls, in the present study, the exercise group presented a marginal better performance in Stroop Color-Word rather than Stroop Color and Stroop Word condition following acute exercise. While primarily measuring the basic reading rate and motor speed ability in Stroop Color and Stroop Word, Stroop Color-Word reflects the ability to inhibit the over-learned response during conflicting stimulus, which is generally believed to confer inhibition or interference of executive function (Homack & Riccio, 2004). Therefore, the results suggested that acute exercise particularly benefitted inhibition-related executive function in the ADHD population.

The general relationship observed for acute exercise and Stroop Color-Word has been supported by previous studies that focused on healthy adults (Chang & Etnier, 2009a; Sibley et al., 2006). Sibley and colleagues (2006) found that the acute bout of exercise improved Stroop Color-Word in college-aged adults and suggested that it was beneficial in interference involved in maintaining goal-oriented processes. Alternatively, Chang and Etnier (2009a, 2009b) applied acute resistance



exercise in several neuropsychological tasks and proposed that the type of exercise facilitate all Stroop Test conditions with moderate to large effects.

Although the mechanisms among acute exercise, inhibition, and ADHD have yet to be fully understood, the exercise benefit in inhibition may result in an individual's neuroelectric adjustment. Hillman, Snook, and Jerome (2003) examined acute aerobic exercise on cognition using the Eriksen flanker task as well as event-related potential. Results indicated that following 30 min of treadmill exercise, college students showed a larger P3 amplitude and shorter P3 latency in incongruent stimulus compared with baseline and congruent stimulus. Because the amplitude and latency of P3 reflect the amounts of attention resources allocated and speed of stimulus evaluation and recognition processes, respectively, the results proposed that acute exercise that improves inhibition may be accompanied by changes in attention resource allocation and increased stimulus evaluation and recognition. These positive behavioral and neurocognitive findings also appeared in the study focused on pre-adolescent children (Hillman et al., 2009). They indicated that moderate intense exercise resulted in better performance during incongruent stimulus tasks, larger P3 amplitudes, and higher academic achievements (i.e., reading, spelling and arithmetic), suggesting the benefits and mechanism of acute exercise could extend to children.

The WCST is one of most extensively used tests for assessing executive function and prefrontal function (Nyhus & Barcelo, 2009). Although the WCST can assess multiple executive processes, including conceptual problem-solving ability, use of feedback, cognitive flexibility, inhibition, and response maintenance, it has frequently been utilized to measure set shifting, a major distinctive component within executive function (Miyake et al., 2000; Sergeant et al., 2002). The WCST may be able to differentiate between ADHD patients and controls (Sergeant et al., 2002), and ADHD patients exhibited significant impairment ( $ES = 0.46$ ) in set shifting measured by the WCST (Willcutt et al., 2005).

We found that performances of the post-test in Categories Completed and Non-perseverative Errors rather than Total Correct, Perseverative Responses, Perseverative Errors, and Conceptual Level Response were improved following acute moderate intense exercise relative to the pre-test. With factor analysis, Greve and colleagues (1998) indicted that at least two distinguishing factors could be involved in the variety of scores measured in the WCST. The first factor, including Categories Completed, Total Correct, Perseverative Errors, Perseverative Responses, and Conceptual Level Response, is concept formation/perseveration and reflects the ability to shift correct sorting principle. The second factor includes only Non-perseverative Errors, is labeled as itself (Non-perseverative Errors), and reflects inefficient or unsuccessful problem-solving, where an incorrect sorting response is constantly shifting. As mentioned previously, ADHD patients have revealed dysfunction in the dorsolateral prefrontal cortex and the orbitofrontal cortex of the prefrontal cortex (Seidman et al., 2005), and these cortices have been linked to executive function, including the ability to maintain and set shifting measured by WCST (Alvarez & Emory, 2006). Indeed, with neuroimaging techniques (i.e., functional magnetic resonance imaging and positron emission tomography), numerous studies have found increased activation in dorsolateral prefrontal cortex while performing the WCST, although some studies have also found similar activations in the ventromedial cortex and the orbitofrontal cortex (Konishi et al., 1998; Mentzel et al., 1998; Nagahama et al., 1998; Tien, Schlaepfer, Orr, & Pearson, 1998). Nyhus and Barcelo (2009) further indicated that set shifting seemed to be a central cognitive ability underlying the WCST, and the dorsolateral prefrontal cortex may be a main region during operating set shifting. Because the present study found that acute exercise could partially improve correct set shifting indexed by Categories Completed and enhanced efficiency of incorrect set shifting indexed by Non-perseverative Errors in children with ADHD and because there is evidence that links set shifting and the dorsolateral prefrontal cortex, acute exercise could impact set shifting positively and may be accompanied by an influencing activation in the dorsolateral prefrontal cortex. While acute exercise has limited influence on other correct set shifting indexes, more research still need further exploration to clarify the view.

An alternative perspective to link ADHD, exercise, and set shifting is exercise-induced dopamine release. Dysfunction of attention circuits in ADHD have been linked to dopamine activation (Arnsten, 2006). Dopamine, a type of neurotransmitter, regulates brain processes for movement, pleasurable responses, arousal, emotions, and cognitive functions. It is often active in brain areas related to cognition and emotions, including the dorsolateral prefrontal cortex, anterior cingulate cortex, hippocampus, basal ganglia, parietal lobe, and limbic system (Artiges, Salamé, & Recasens, 2000; Barbas, 2000; Jahanshahi, Dirnberger, Fuller, & Frith, 2000). Through animal experiments, Sutoo and Akiyama (2003) showed that exercise could enhance brain dopamine synthesis. Although one may notice that other research argued against increased dopamine during exercise (Wang et al., 2000), numerous studies have supported the relationship between exercise and dopamine in studies of animal and human subjects (Foley & Fleshner, 2008; McMorris et al., 2008; Petzinger et al., 2007). Tantilillo, Kesick, Hynd, and Dishman (2002) provided the first study linking exercise, children with ADHD, and dopamine measured by dopaminergic-like responses. They determined that exercise was possibly beneficial for children with ADHD through changes in dopamine, but that gender and sex may also interact in the relationship.

### Limitations and Future Research

Although the present study has yielded findings that establish positive links among exercise, executive function, and ADHD, its design is not without flaws. First, although these two groups have shown homogeneity in age, grade, type of ADHD, as well as initial Stroop Test performances, some WCST indices were different initially between groups. These findings might be attributed to small sample sizes as well as to the confounders that covary with executive functions, including intelligence, perception, memory, subtype and heterogeneity of ADHD, the amount of regular exercise, and even medications intake, which were not quantified in the present study. In addition, although improved WCST performances were found in the exercise group rather than the control group, group differences in the post-test were not demonstrated. These confounders and limitations are desirable for consideration in future studies. Furthermore, while some clips of the video were presented as cartoons for intriguing the children, it is possible that the children experienced low motivation or boredom during the intervention compared with those in the exercise intervention; therefore, additional observational data should prove quite beneficial, which future research might need to consider.

In addition, while it is appropriate to assess inhibition using the Stroop Test (Bush, 2010; Miyake et al., 2000), some argue its face validity as a measure of inhibition from interference (Sergeant et al., 2002). Inhibition, specifically behavior inhibition, accounts for suppressing overt behaviors and is often assessed by the Stop-single paradigm; however, interference, often measured by the Stroop Test or Dual-Task paradigms, is responsible for reducing performance under conditions that use multiple stimuli or processes, which may not require involvement of active suppression (Kipp, 2005). Willcutt and colleagues (2005) proposed that inhibition assessed by Stop-Single and Continuous Performance Tests had larger effects compared with interference control assessed by the Stroop Test in the ADHD population. Therefore, further research is encouraged to emphasize inhibition, which is the main symptom of ADHD patients. Regarding inhibition, other research has further distinguished “behavioral inhibition” and “resistance to interference” from “cognitive inhibition,” an active suppression of cognitive content that is currently executed in working memory (Kipp, 2005; Sibley et al., 2006), and the researchers highlighted future investigation of the “specific inhibition” rather than “global inhibition” in the ADHD population (Kipp, 2005). Given the multiple modes of inhibition and dysfunction in ADHD, future research is therefore required to verify the concern.

It is intriguing that Tucha and colleagues (2010) have seen exercise broadly as motor activity and have investigated the effects of gum chewing exercise on cognitive performance in children with ADHD. Inconsistent with our study, Tucha and colleagues (2010) indicated an adverse vigilance effect and no sustained attention impact during gum chewing in the children with ADHD. The conflicting results might be attributed to the differences regarding types of exercise (whole body activity vs. localized activity), exercise intensity (moderate vs. light), time assessment (after vs. during exercise), or types of cognitive assessments. Given that gum chewing has facilitative effects on certain aspects of cognition (Tanzer, von Fintel, & Eikermann, 2009) and could be considered as an alternative type of exercise modality, future research is attractive.

Last but not the least, in the ground work to build exercise prescriptions, research related to acute exercise and cognition in healthy adults has been substantially developed with multiple directions including exercise intensity, types of exercise modality, dose–response relationships, potential moderators (i.e., physical fitness), and time delay effects (Barella, Etnier, & Chang, 2010; Chang & Etnier, 2009a, 2009b; Chang, Etnier, & Barella, 2009; Chang, Nien, Tasi, & Etnier, 2010; Davranche, Hall, & McMorris, 2009; McMorris et al., 2009). However, it is questionable to apply adult exercise designs/prescriptions to children and adolescents (Tomprowski, 2003a), let alone populations with mental disorders. Therefore, for advancing the knowledge in theoretical perspectives and building an exercise prescription, we believe that much more research is still needed to explore the relationship between exercise design, executive function, and the ADHD population.

### Conclusion

The present study highlights the positive effect of acute exercise on executive function in children with ADHD. Specifically, the results assessed utilizing the Stroop Test and the WCST suggested that moderate intense aerobic exercise facilitated inhibition as well as set shifting, functions that are responsible for the main executive dysfunctions in ADHD. The tentative explanations for the exercise effect may be the allocation of attention resources, influences of dorsolateral prefrontal cortex, and induction of exercise-induced dopamine release. Although more research is needed to address exercise effects, these findings appear promising for additional investigations to replicate and explore exercise efficacy on executive function in children with ADHD.

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## Conflict of Interest

None declared.

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