THE EFFECT OF EXERCISE ON EXECUTIVE CONTROL IN

OVERWEIGHT CHILDREN

by

CYNTHIA ELISABETH KRAFFT

(Under the Direction of Jennifer E. McDowell)

ABSTRACT

This study investigated the effects of exercise on executive control (EC) in children using antisaccade and Eriksen flanker tasks. Fifty 8-11 year old sedentary and overweight children were randomly assigned to either an exercise or an attention control condition. They participated in their condition for 1 hour/day, 5 days/week, for 8 months. Measures of EC were acquired at pre-test, timepoint 2, timepoint 3, and post-test. While both groups showed EC improvement over time (as observed in percent correct and reaction time measures), the exercise group improved significantly more than the control group on the percent of correct incongruent trials in the flanker task, during which a correct response had to be generated in the face of incorrect distractors. Exercise may improve EC in children, which is a finding that could have important implications for physical education in schools.

INDEX WORDS: executive control, inhibition, saccades, exercise

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CHAPTER 1

INTRODUCTION

Pediatric obesity has been referred to as an epidemic and its prevalence is increasing rapidly (Strauss & Pollack, 2001). In the U.S., currently 35.5% of children who are 6-11 years old are overweight (Ogden, Carroll, Curtin, Lamb, & Flegal, 2010). In addition to the many associated health concerns, children who are overweight are more likely to have below average cognitive abilities (Y. Li, Dai, Jackson, & Zhang, 2008). This includes lower performance on IQ tests (Campos, Sigulem, Moraes, Escrivão, & Fisberg, 1996; X. Li, 1995), poor academic achievement (Taras & Potts-Datema, 2005), and worse performance on tests of executive control (Guxens, et al., 2009). Recent research has sought to determine whether exercise may have cognitive benefits (which could counteract some of these problems).

Most of the previous work in humans that has investigated the benefits of exercise on cognition has been done with adults. Studies with older adults show that long-term regular physical activity improves brain function (Churchill, et al., 2002; S. J. Colcombe, et al., 2004; Larson, et al., 2006; Pereira, et al., 2007; Weuve, et al., 2004). A randomized, controlled experiment conducted with older adults revealed that 6 months of aerobic training led to improved performance on a variety of cognitive tasks (Kramer, et al., 1999). Another study demonstrated an impact of exercise training on brain activity as evaluated by functional magnetic resonance imaging (fMRI) (S. J. Colcombe, et al., 2004). It’s also recently been found that exercise can induce functional plasticity in large-scale brain systems (the Default Mode Network and the Frontal Executive Network) in older adults (Voss, et al., 2010). Cardiovascular fitness has also been associated with better cognitive performance in young adults (Åberg, et al., 2009).

While most studies of exercise have been done with adult participants, there is a multitude of studies that demonstrates the potential impact of early experiences on brain development and function (Brody, 1992; Garlick, 2002; Mackintosh, 1998; Nelson, 1999). Neural networks continue to mature from childhood through young adulthood (Giedd & Rapoport, 2010; Power, Fair, Schlaggar, & Petersen, 2010; Schmithorst & Yuan, 2010) and the pattern of children's neural specialization is determined, in part, by environmental stimulation (Katz & Shatz, 1996; Kolb & Whishaw, 1998). Therefore, the cognitive benefits of exercise may be even greater for children than for adults by impacting the brain at a time when it is developing and is possibly more sensitive to environmental factors. A recent study provided evidence for the beneficial effects of exercise on the cognition of overweight children (Davis, et al., 2007). The impact of physical activity on neurological development and cognitive function also has been reported in numerous animal studies (Collins, et al., 2009; Creer, Romberg, Saksida, van Praag, & Bussey, 2010; Nichol, Parachikova, & Cotman, 2007). Animal studies also show that aerobic training increases brain-derived neurotrophic factor and other growth factors, leading to increased capillary blood supply to the cortex and growth of new neurons and synapses, resulting in better learning and performance (Churchill, et al., 2002; Dishman, et al., 2006; Lu & Chow, 1999; Neeper, Gómez-Pinilla, Choi, & Cotman, 1995; van Praag, Christie, Sejnowski, & Gage, 1999).

Studies utilizing cognitive tasks requiring executive control (EC) have shown particular benefits of exercise and fitness (S. J. Colcombe, et al., 2004; Davis, et al., 2007). In fact, EC may be more sensitive to aerobic exercise training than other aspects of cognition (S. Colcombe & Kramer, 2003). EC constitutes supervisory control of cognitive functions, including inhibition and allocation of attention and memory (Eslinger, 1996).

Studies of the impact of exercise on EC in children are rare, but one previous study investigated the effect of chronic aerobic exercise on EC in children (Davis, et al., *In press*). Children participated in either a high-dose, low-dose or no-exercise condition for 13 weeks. This study found a dose response benefit of exercise on EC as measured by the Planning scale of the Cognitive Assessment System (CAS). There was also a dose response benefit of exercise on mathematics achievement. Changes in brain activity were evidence as well, as fMRI data from this study demonstrated that the exercise group had increased bilateral prefrontal cortex (PFC) activity and decreased activity in bilateral precuneus regions compared to controls. Other studies have also provided evidence that physical activity and play behaviors may have important roles in normal maturation and the emergence of children's EC processes (Johnson, Christie, & Yawkey, 1987; Panksepp, Siviy, & Normansell, 1984).

EC is crucial for adaptive behavior and child development (Lyon & Krasnegor, 1996; Schneider, Schumann-Hengsteler, & Sodian, 2005). The capacity to self-regulate behavior is related to a child's readiness for elementary school (Blair, 2002). Several clinical disorders that are characterized by lack of control of attention and judgment (e.g. ADHD) have been explained in terms of ineffective EC processing (Barkley, 1996; Lyon & Krasnegor, 1996). EC has also been positively related to achievement (St Clair-Thompson & Gathercole, 2006). Specifically, cognitive shifting, inhibition, and working memory are related to math strategies and scores as well as to science scores (Rebecca Bull, Johnston, & Roy, 1999; R. Bull & Scerif, 2001; Espy, et al., 2004; St Clair-Thompson & Gathercole, 2006). One study found that preschoolers high in EC functioning later had higher math scores in kindergarten, controlling for general intelligence, suggesting that EC may play a causal role (Blair & Razza, 2007). This same study found similar results for literacy scores. Another study found a relationship between cognitive shifting, inhibition, and working memory and English scores (St Clair-Thompson & Gathercole, 2006). EC is also related to writing skills (Hooper, Swartz, Wakely, de Kruif, & Montgomery, 2002; St Clair-Thompson & Gathercole, 2006). It has been found that inhibition is related to reading (Gernsbacher, 1993) and vocabulary learning (Dempster & Cooney, 1982). Cognitive inhibition and performance on working memory and shifting/switching tasks improve with age during middle childhood (Brocki & Bohlin, 2004; Klenberg, Korkman, & Lahti-Nuuttila, 2001; Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003; Levin, et al., 1991).

There are many tasks that are designed to evaluate EC. Two of them, the antisaccade and flanker tasks, will be particularly important for the following discussion. Antisaccade and flanker tasks are especially useful in studies with children because they are easily explained, use simple visual stimuli, and only require a motor response. Antisaccade tasks tap primarily inhibitory capabilities. During the antisaccade task, the participant fixates on a central target. The target is turned off and a peripheral cue appears on one side or the other. Participants are instructed not to look at the target, but instead to move their eyes to the mirror image location (opposite side, same distance from the center). An initial glance towards the cue constitutes an error, and can be construed as an inhibitory failure. Another type of saccadic task (the prosaccade task) is useful in conjunction with antisaccades in studies of EC because it does not rely on EC (and thus may be useful as a baseline measure). Prosaccades are rapid redirections of gaze to a target. During the prosaccade task, the target moves from the center to one side or the other and participants are instructed to move their eyes to the target as quickly and accurately as possible.

Saccade performance changes during development. For example, Fischer et al. reported decreasing prosaccade reaction times until age 15 or 20 and greatest antisaccade error rates below age 11 (Fischer, Biscaldi, & Gezeck, 1997). Similarly, Munoz et al. showed that the most antisaccade errors were made by children in the 5-8 year old range (around 50% errors) and that the error rates dropped to 10% by 16 years (Munoz, Broughton, Goldring, & Armstrong, 1998). They also found that other saccade metrics (such as peak velocity and duration) were relatively stable across their measured age range (5-79 years).

The peak velocity and duration of the saccade are a function of the properties of the brainstem saccadic pulse generator and are not under voluntary control. The frontal eye fields and the superior colliculus are also involved, providing the major descending input to the saccadic pulse generator (Leigh & Zee, 2006). Constant peak velocity and duration across these ages suggests that the saccadic pulse generator and the nuclei of the extraocular muscle motor neurons remain relatively unchanged across the age groups that they studied. Prefrontal cortex (PFC) is a key area thought to mediate antisaccade performance and antisaccade deficits in psychiatric patients (McDowell, et al., 2002). Lesion studies have shown that damage to the PFC results in greater error rates on the antisaccade task (Pierrot-Deseilligny, Rivaud, Gaymard, & Agid, 1991; Ploner, Gaymard, Rivaud-Péchoux, & Pierrot-Deseilligny, 2005).

That some antisaccade performance measures are variable below age 11 (such as error rate), while others show stability (such as peak velocity) suggests that prefrontal-based circuitry is still developing in children at this age. Studies of myelination also provide evidence for this delayed maturation of PFC (Klingberg, Vaidya, Gabrieli, Moseley, & Hedehus, 1999). If improvements in EC are seen in children who exercise, they could be related to an effect on PFC. Antisaccade error rates are generally stable between multiple measurements in time (Ettinger, et al., 2003). There is also evidence that daily practice may affect performance and that practice may be associated with changes in brain activity (Dyckman, Camchong, Clementz, & McDowell, 2007; Dyckman & McDowell, 2005; Fischer & Hartnegg, 2000). That antisaccade performance changes with intervention (practice) is evidence that this process is malleable and thus may respond to exercise.

Flanker tasks provide simple measures of selective attention and inhibition. Flanker tasks have been used during fMRI studies of exercise-related neural changes (S. J. Colcombe, et al., 2004). Correct performance in the flanker task requires a participant to attend to the central stimulus (which conveys information about the correct response) and ignore the adjacent stimuli that are either congruent (e.g. > > > > >) or incongruent (e.g. < > < < >) in nature. Correct reaction times are longer in the incongruent condition than in the congruent condition (S. J. Colcombe, et al., 2004; Eriksen & Eriksen, 1974), suggesting that subjects experience increased flanker interference in the incongruent condition. Like the antisaccade task, the flanker task also relies in part on PFC circuitry (S. J. Colcombe, et al., 2004; Lee, Han, Lee, & Choi, 2010).

The purpose of the current study is to determine whether aerobic exercise training improves performance on tests of EC in overweight, sedentary children. Fifty participants performed up to 4 sessions each of antisaccade, prosaccade, and flanker tasks in order to assess their cognitive functioning. It was hypothesized that children in an exercise intervention would improve more in measures of EC than children in a control condition, as demonstrated by an a greater increase in the percentage of correct trials (within the context of faster or unchanged reaction times) in both antisaccade and flanker tasks. Performance on the prosaccade task was not expected to change, since this task is likely not as reliant on the PFC-mediated EC processes that were hypothesized to be impacted by exercise (Johnston & Everling, 2006; McDowell, et al., 2002; Pierrot-Deseilligny, et al., 2003; Pierrot-Deseilligny, et al., 1991).

CHAPTER 2

METHODS

Participants

50 healthy, sedentary, and overweight (BMI ≥ 85th percentile for age and sex) (Ogden, et al., 2002) children, age 8-11 years old (mean age = 9.53, SD = 0.92) were recruited during the 2009-2010 school year from public schools in the Augusta, GA area. General exclusion criteria were any medical condition which contraindicates or interferes with participation in testing or vigorous exercise (e.g. orthopedic conditions), any medications that would interfere with research measurements (e.g. antipsychotics, stimulants, sedating antihistamines, seizure medications), or participation in a weight control program or any formal exercise program that meets more than 1 day/week (other than physical education). All participants provided written assent and their parents provided informed consent as per Medical College of Georgia Human Assurance Committee approval (# 02-08-037).

Procedure

Randomization

Participants were randomized to either the aerobic exercise intervention or attention control condition. Randomization was balanced for race, gender, and school (see Table 2.1 for demographic information).

Interventions

Classes took place at the Georgia Prevention Institute (GPI) at the Medical College of Georgia (MCG) after school. Children were transported via school bus between their schools and the GPI. Each child spent 1.5 hours/day at the GPI, including 30 minutes for doing homework.

The children were asked to attend at least 4 times per week over ~8 months (the entire school year). They were provided with healthy snacks. Staff members were rotated between the two conditions to avoid bias.

Exercise intervention

Each session included 40 minutes (two 20-minute bouts) of vigorous aerobic activities and games interspersed with brief rest periods. Children wore heart rate monitors, which transmitted heart rate to wristwatch-like devices. They were awarded points (redeemable for prizes) based on maintenance of an average heart rate > 150 beats per minute.

Attention control group

Each session included 60 minutes of instructor-led, sedentary recreational activities such as videos, board games, art, and music. Points (redeemable for prizes) were awarded based on participation and good behavior. It should be noted that this control group is much more similar to the exercise group than in previous exercise interventions in children (Davis, et al., 2007). In the current study, children in both groups participated in a daily after school program that involved structured activities with adults and their peers, supervised homework time, and healthy snacks.

Behavioral testing

Participants completed three tasks, an antisaccade, a prosaccade, and an Eriksen flanker task. Participants completed these tasks at pre-test, timepoint 2 (8 weeks), timepoint 3 (16 weeks), and at post-test.

Antisaccade task

Eye movements were recorded using an Eyelink II eyetracking system (SR Research, Kanata, Ontario) while participants kept their head positioned on a custom-made padded chinrest that was 64 cm away from the computer monitor that displayed the stimuli. Prior to each saccade task, a calibration trial was run. Based on the calibration, the X coordinate at the center of the participant's pupil were recorded for each sample point. After calibration, eye movements were displayed on a computer monitor so performance could be monitored continuously by the experimenter and data were recorded (sampling rate = 500 Hz) for later analysis.

The antisaccade task consisted of 84 trials, with a 30-second rest period after 30 trials and again after 60 trials (during which participants were told to relax their eyes but not move their heads). Each trial had a 1700 ± 100 millisecond fixation, 200 millisecond gap, and 1200 millisecond cue presentation and response period. The fixation was a 1^{o} blue dot in the middle of the screen. During the gap, a black screen was presented. During the cue presentation and response period, the blue dot moved to one of four pseudorandomly selected peripheral locations (5^{o} right, 5^{o} left, 10^{o} right, or 10^{o} left). The participants were told to move their eyes as quickly and accurately as possible to the opposite side of the screen, the same distance from the center as the peripheral cue. Each trial lasted for 3100 ± 100 milliseconds and each session lasted for approximately 5 minutes and 20 seconds (see Figure 2.1).

Prosaccade task

The prosaccade task consisted of 48 trials, with a 30-second rest period after 30 trials. Each trial had a 1700 ± 100 millisecond fixation, 200 millisecond gap, and 800 millisecond cue presentation and response period. The fixation was a 1^{o} yellow dot in the middle of the screen. During the gap, a black screen was presented. During the response period, the yellow dot moved to one of four pseudorandomly selected peripheral locations (5^{o} right, 5^{o} left, 10^{o} right, or 10^{o} left). The participants were told to follow the dot with their eyes as quickly and accurately as possible. Each trial lasted for 2700 ± 100 milliseconds and each session lasted for approximately

2 minutes and 40 seconds (see Figure 2.2).

Eriksen flanker task

The flanker task consisted of 60 trials, with a 30-second rest period after 30 trials. Each trial had a 900 ± 100 millisecond fixation and 2000 millisecond cue presentation and response period. The fixation was a white cross in the middle of the screen. During the response period, five arrows were displayed across the middle of the screen. The participants were told to pay attention only to the middle arrow and to press a button (according to the direction it was pointing) as quickly and accurately as possible. Button press responses were recorded with the keyboard of the participant's computer. Each trial lasted for 2900 ± 100 milliseconds and each session lasted for approximately 3 minutes and 24 seconds (see Figure 2.3).

Analysis

Behavioral scoring

Eye movements were scored using scripts written in Matlab (Mathworks, Inc., Natick, MA). Eye movements were manually scored for percent correct (i.e., the percent of trials where the first saccade was generated in the correct direction), reaction time, and final eye position. For both saccade tasks, trials with blinks before stimulus presentation or no responses were eliminated. Before analysis, flanker trials without responses or with responses in between the fixation and response period were deleted. Also, any extra responses in a given trial were deleted (only the first responses were included in the analysis).

Variables

Eye movements were scored for 1) the percentage of trials with correct responses and incorrect responses (an initial saccade generated to the incorrect location during the response period), 2) the latency of saccades (time in milliseconds between cue onset and the start of the saccade [>90 milliseconds]) (Fischer et al., 1993), and 3) the final eye position of saccades. The flanker task was analyzed for 1) the percentage of trials with correct responses and incorrect responses overall and for congruent and incongruent trials separately (a button response in the direction corresponding to the direction of the middle arrow), 2) the latency of button responses overall and for correct and incorrect congruent and incongruent trials separately (time in milliseconds between the display of the arrows and the button response [>100 milliseconds]) (Kuhns, Lien, & Ruthruff, 2007), and 3) the interference effect (((incongruent RT – congruent RT)/congruent RT)*100) (S. J. Colcombe, et al., 2004).

Statistical analyses

The scored results were analyzed with scripts written in SAS. Repeated-measures ANOVAs were performed for all variables of interest. Also, a linear regression analysis was performed for each variable to examine possible differences in the slopes or y-intercepts between the two groups.

Table 2.1 Demographic Information
Where applicable, this table displays the mean and standard error in the format M(SE).

Group	N	Age at pre-test (in years)	% male	% African-American	Average CAS Full Scale score
Control	23	9.7(.2)	52%	91%	99.2(2.0)
Exercise	27	9.4(.2)	41%	93%	95.7(2.3)

Antisaccade Task

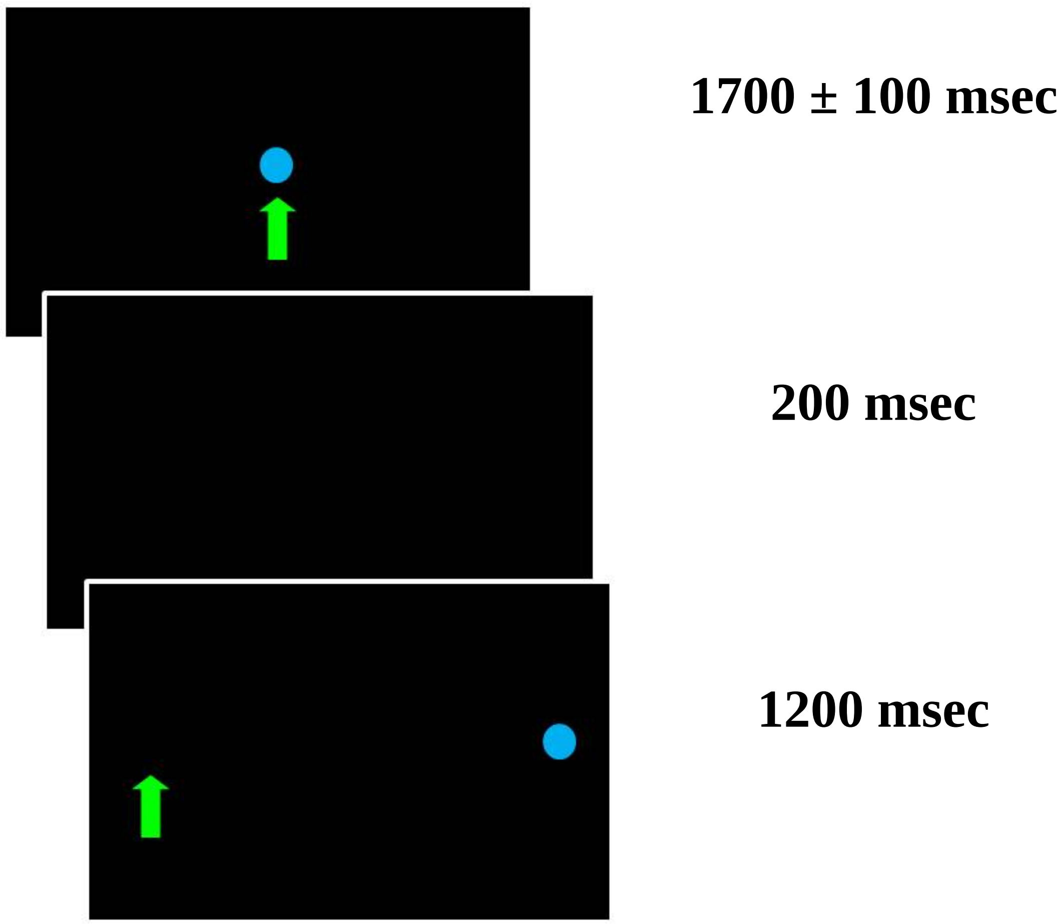


Figure 2.1 Stimuli Presented During the Antisaccade Task
Participants performed 84 trials of antisaccades. When the dot moves to the side, participants should look on the opposite side (the same distance from the center) as quickly and accurately as possible. Green arrows show correct eye position.

Prosaccade Task

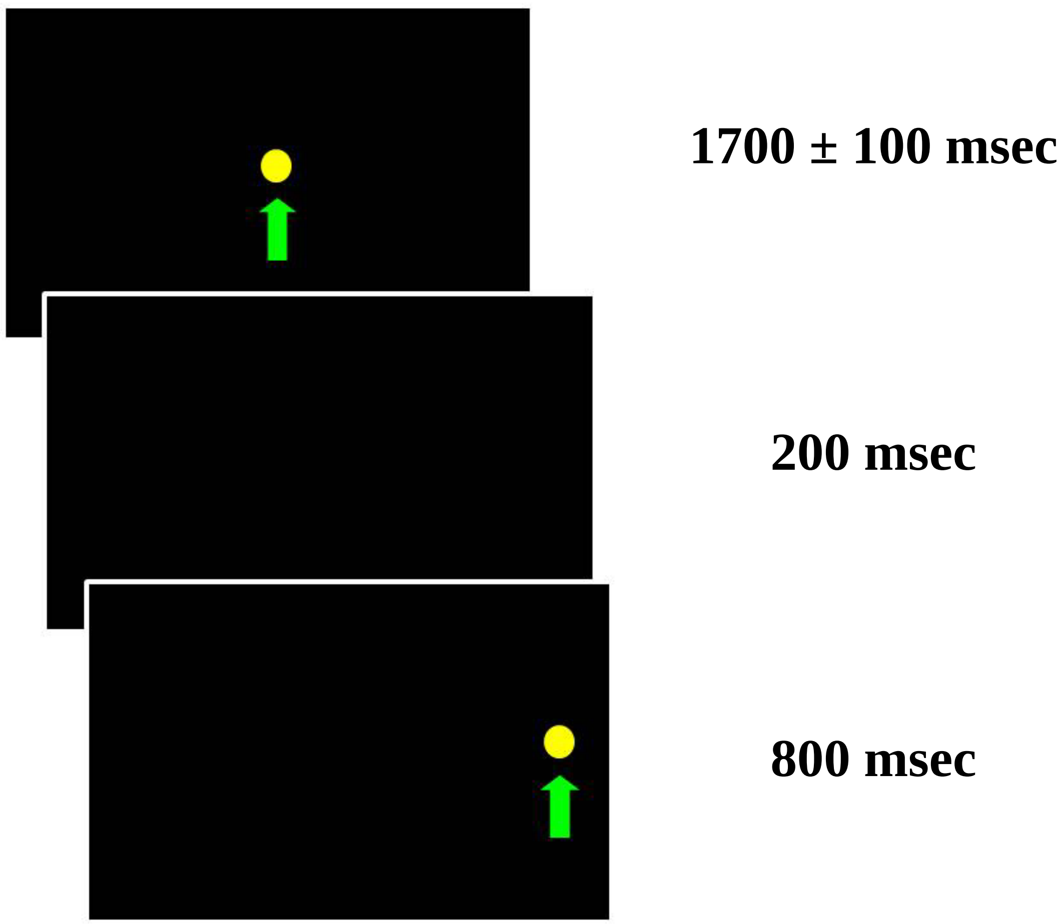


Figure 2.2 Stimuli Presented During the Prosaccade Task
Participants performed 48 trials of prosaccades. When the dot moves to the side, participants should follow it with their eyes as quickly and accurately as possible. Green arrows show correct eye position.

Flanker Task

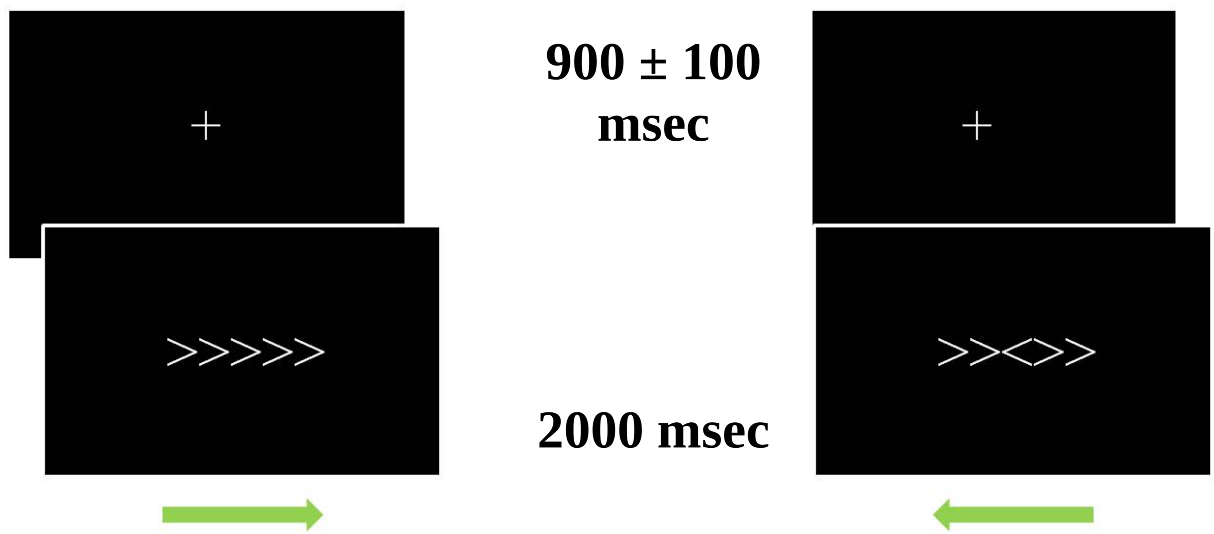


Figure 2.3 Stimuli Presented During the Flanker Task
Participants performed 60 trials of the flanker task. Participants should only pay attention to the arrow in the middle. They should press a button in the direction that this central target arrow is pointing as quickly and accurately as possible. Green arrows show the correct button press response.

CHAPTER 3

RESULTS

Groups did not significantly differ in gender (χ^2(1, N=50) = .654, p = >.4), race (χ^2(1, N=50) = .028, p = >.6), age (t(48) = 1.112, p > .5), or average CAS Full Scale score (t(48) = 1.074, p > .2).

Antisaccade Task

Data were available for 45 participants for pre-test, 17 participants for timepoint 2, 35 participants for timepoint 3, and 32 participants for post-test. Missing data were due to withdrawal from the study, refusal to participate in the testing sessions, or technical problems.

Repeated-measures ANOVAs revealed a significant main effect of time for the percentage of correct trials, F(3,21) = 4.98, p < .01 (see Figure 3.1), meaning that both the exercise and control group had a greater percentage of correct responses over the four timepoints. There were no significant group x time differences in percentage of correct trials, saccade latencies, or final eye position (see Table 3.1). Regression analyses also revealed no significant differences between the groups.

Prosaccade Task

Data were available for 45 participants for pre-test, 19 participants for timepoint 2, 35 participants for timepoint 3, and 30 participants for post-test. Repeated-measures ANOVAs revealed no significant main effects or group x time differences in percentage of correct trials, saccade latencies, or final eye position (see Table 3.2). Regression analyses revealed no significant differences between the groups.

Eriksen Flanker Task

Data were available for 47 participants for pre-test, 37 participants for timepoint 2, 35 participants for timepoint 3, and 39 participants for post-test. Repeated-measures ANOVAs revealed significant main effects of time for the percentage of incongruent correct trials ($F(3,42) = 4.411$, $p < .01$) and for correct incongruent reaction times ($F(3,42) = 22.651$, $p < .001$) (see Figures 3.2 and 3.3). In other words, both the control and exercise group improved significantly on these two measures over the four timepoints. There were no significant group x time differences in percentage of correct trials, reaction times, or interference effect (see Table 3.3). Regression analyses revealed a significant difference between the groups in the slope ($t(39) = -1.86$, $p < .05$) and y-intercept ($t(39) = -1.81$, $p < .05$) of the percent of incongruent trials correct (see Figure 3.4). The exercise group improved at a faster rate on the percent of incongruent trials correct than the control group.

<u>Table 3.1</u> Antisaccade Results
This table shows the mean and standard error [in the format M(SE)] for each variable in the antisaccade task. Differences are calculated between pre-test and post-test for each individual and then averaged across the group. Results are shown for the control and exercise group.

Antisaccade Task									
Group	**% correct at pre-test**	**% correct at post-test**	**Difference in % correct**	**Correct reaction time (ms) at pre-test**	**Correct RT at post-test**	**Difference in correct RT**	**Error reaction time (ms) at pre-test**	**Error RT at post-test**	**Difference in error RT**
Control	41.1(5.0)	52.2(4.6)	14.6(6.0)*	338(21)	288(17)	-24(17)	208(8)	197(6)	-3(12)
Exercise	27.7(3.5)	41.9(6.3)	17.0(5.5)*	349(20)	323(16)	-10(22)	208(7)	205(7)	-11(9)

* Significant main effect of time

<u>Table 3.2</u> Prosaccade Results
This table shows the mean and standard error [in the format M(SE)] for each variable in the prosaccade task. Differences are calculated between pre-test and post-test for each individual and then averaged across the group. Results are shown for the control and exercise group.

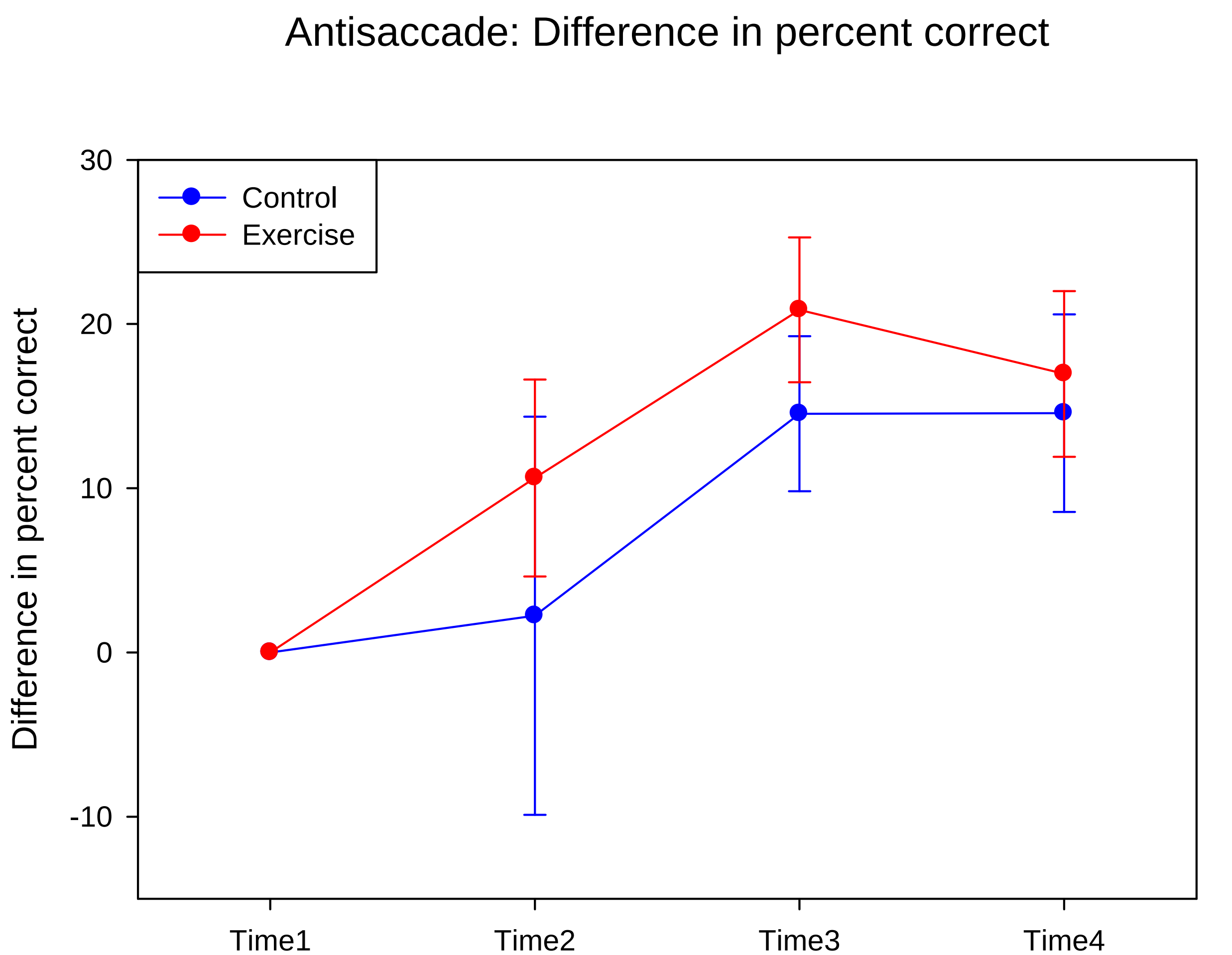
Prosaccade Task						
Group	**% correct at pre-test**	**% correct at post-test**	**Difference in % correct**	**Correct reaction time (ms) at pre-test**	**Correct RT at post-test**	**Difference in correct RT**
Control	97.6(1.5)	99.2(.4)	0.4 (.9)	171(8)	156(8)	-5(6)
Exercise	97.5(.6)	99.3(.4)	1.1(.5)	167(5)	158(6)	-13(7)

<u>Table 3.3</u> Flanker Results
This table shows the mean and standard error [in the format M(SE)] for each variable in the flanker task. Differences are calculated between pre-test and post-test for each individual and then averaged across the group. Results are shown for the control and exercise group.

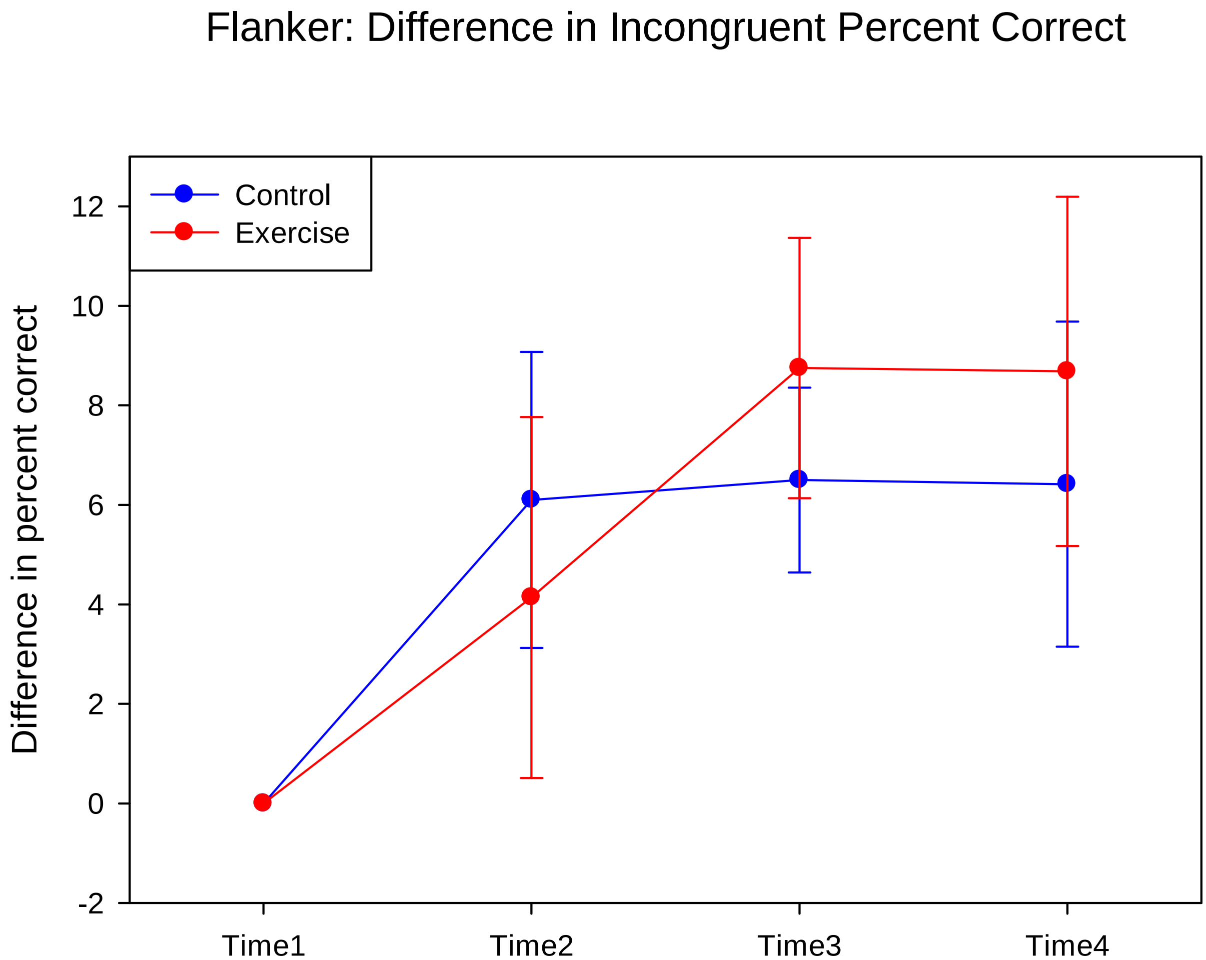
Flanker Task									
Group	**Incongruent % correct at pre-test**	**Incon % correct at post-test**	**Difference in incon % correct**	**Incon correct RT (ms) at pre-test**	**Incon correct RT at post-test**	**Difference in incon correct RT**	**Congruent % correct at pre-test**	**Con % correct at post-test**	**Difference in con % correct**
Control	82.3(5.6)	94.9(1.2)	6.4(3.3)*	951(42)	819(33)	-133(31)*	88.7(6.0)	97.2(.9)	0.2(1.7)
Exercise	69.6(5.2)	90.4(3.6)	8.7(3.5)*	1066(38)	976(41)	-179(96)*	91.2(4.2)	97.5(.7)	2.9(3.3)

Flanker Task (continued)						
Group	**Congruent correct RT (ms) at pre-test**	**Con correct RT at post-test**	**Difference in con correct RT**	**Interference at pre-test**	**Interference at post-test**	**Difference in interference**
Control	794(34)	706(33)	-84(21)	20(3)	17(3)	-4(3)
Exercise	888(30)	819(34)	-78(65)	23(3)	20(3)	-9(6)

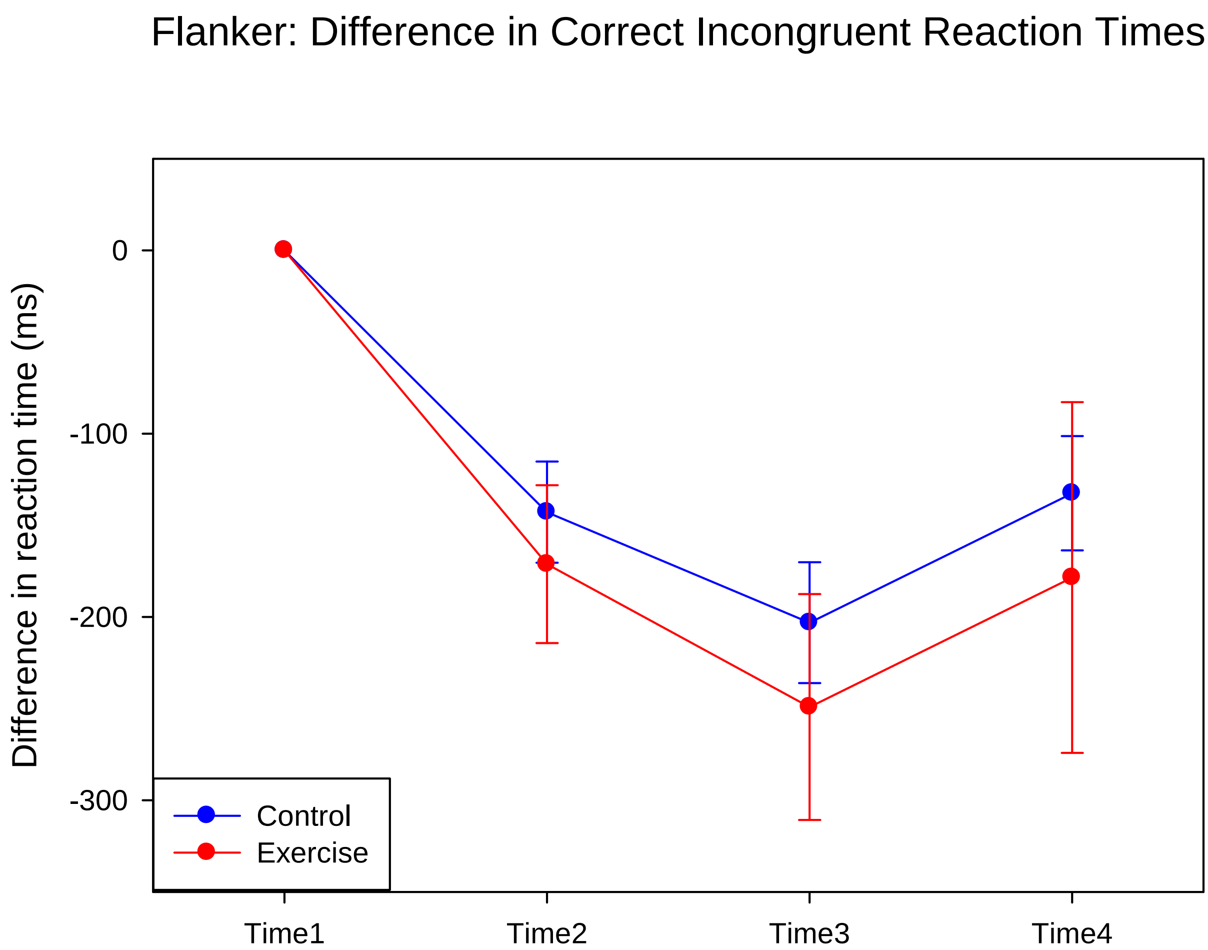
* Significant main effect of time



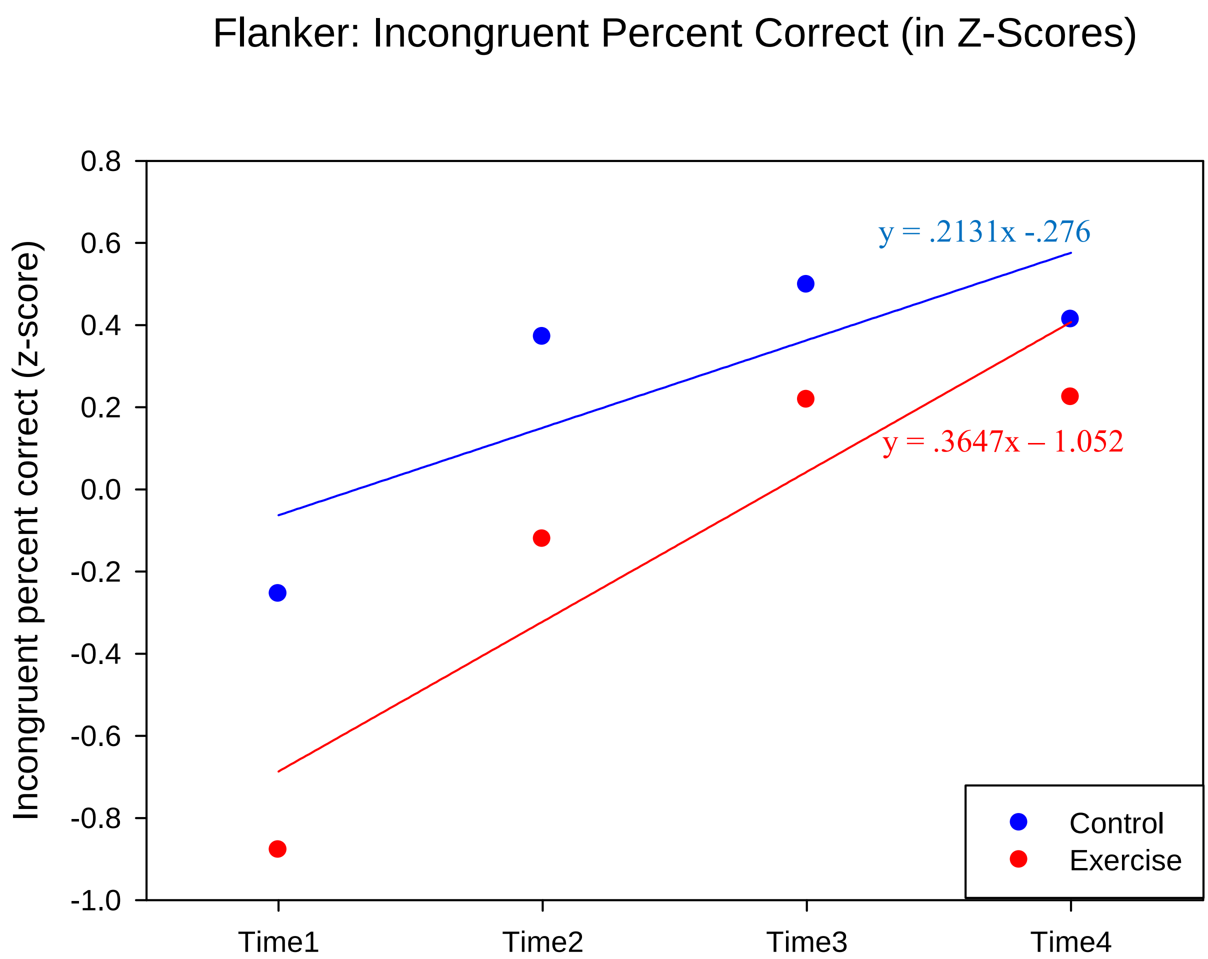
<u>Figure 3.1</u> Antisaccade: Difference in Percent Correct



<u>Figure 3.2</u> Flanker: Difference in Incongruent Percent Correct



<u>Figure 3.3</u> Flanker: Difference in Correct Incongruent Reaction Time



<u>Figure 3.4</u> Flanker: Incongruent Percent Correct (in Z-Scores)

CHAPTER 4

DISCUSSION

The present study investigated the effects of exercise on executive control (EC) in overweight and sedentary children using antisaccade and flanker tasks. It was hypothesized that children in an exercise intervention would show improved performance on both tasks compared to a control group by having a greater increase in percent correct than the control group within the context of unchanged or even faster reaction times. Increased EC was observed across time, although generally in both the exercise and attention control group. The only effects specific to the exercise group were the greater slope of the regression line and the lower y-intercept for incongruent percent correct. There were improvements in antisaccade performance. Both the exercise and the control group improved on the percent of correct trials over time. Both groups also improved on flanker performance, both in terms of the percent of incongruent correct trials and in terms of faster correct reaction times on incongruent trials.

Although there was no group controlling for simply the developmental process (i.e. a group with no intervention), the differences that are seen across time on the percent of trials correct in the antisaccade task may be greater than those that are expected due to development alone. Previous research has shown that between ages 8-9 and ages 10-11, children generally improve by 10 percent correct (on average) on the antisaccade task (Luna, Garver, Urban, Lazar, & Sweeney, 2004). The participants in our study improved by 16 percent correct on the antisaccade task. This difference might not be related to practice effects, as several studies in adults have found that practice effects on the antisaccade task are very small-to-nonexistent between testing sessions for healthy controls (Fischer & Weber, 1992; Larrison-Faucher, Matorin, & Sereno, 2004). However, another study in adults found that the percent correct can increase with practice by 4.5% by practice even 2 months after the initial testing session (Ettinger, et al., 2003). It is not clear whether practice effects in children are the same as those in adults, but it is possible that the improvement in antisaccade percent correct can be accounted for by a combination of development and practice effects.

There were similar findings for the Eriksen flanker task. Both groups improved on incongruent percent correct and had faster reaction times on correct incongruent trials. The differences that were seen across time in the incongruent percent correct on the flanker task might also be greater than expected due to development alone. One study has found that the difference in incongruent percent correct between 8-9 year olds and 10-11 year olds is about 2.1%, while we found a 7.55% improvement (Waszak, Li, & Hommel, 2010). That same study also found that the difference in incongruent reaction times between those same age groups was 91 milliseconds, while we found a difference over time of 149 milliseconds. The magnitude and duration of practice effects in the Eriksen flanker task are unclear in the literature.

The finding that the groups differed over time in flanker performance but not in antisaccade performance was unexpected. The flanker task may not require as much EC as the antisaccade task. Flanker tasks can be performed by children as young as 4 years old with above 80 percent accuracy (McDermott, Pérez-Edgar, & Fox, 2007; Rueda, Posner, Rothbart, & Davis-Stober, 2004). However, even 8-9 year old children generally only have as high as 45-55 percent correct on the antisaccade task (Luna, et al., 2004; Velanova, Wheeler, & Luna, 2009). This indicates that the antisaccade task may be more difficult for children than the flanker task, possibly requiring more PFC involvement (or further PFC development). Also, a recent study in children demonstrated an association between aerobic fitness, the volume of both the dorsal striatum and the globus pallidus, and flanker task performance (Chaddock, et al., 2010). It is possible that the exercise intervention is affecting additional EC-related brain regions besides PFC and that changes in these regions could be related to an improvement in flanker performance. Improved antisaccade performance due to exercise could be smaller by comparison due to its higher reliance on PFC. Based on previous studies involving exercise interventions (Davis, et al., *In press*; S. J. Colcombe, et al., 2004), it is likely that PFC is affected, but it may be less affected by the intervention in comparison to other brain regions, or it may require more of an impact before larger behavioral changes can be observed in the antisaccade task.

It is possible that with an increased sample size from the upcoming two cohorts (from 2010-2012), additional group by time differences will emerge. This study, while consisting of a sample that is extremely rare in the literature, currently has a relatively small sample size. Another feature of this study is the choice of control condition. It is also possible that the control condition is robust enough that group by time differences will be smaller than if we had had a less intensive control condition. A previous study found an effect of exercise on cognition in children as compared to a control group (Davis, et al., 2007). The control group in the current study was more structured than the control group in this previous study. Previously, children assigned to the control condition were not provided any after-school program or transportation but were asked to continue their usual activities. Their families were offered the same monthly lifestyle education classes as the exercise groups, which were designed by a dietician and a psychologist and which addressed topics such as healthy diet, physical activity, and stress management. In the current study, many of the previously uncontrolled variables were addressed by having a more similar control group. Children in the control group came to the GPI for the same amount of time every day, had the same healthy snacks and supervised homework time, and had structured activities with their peers and with the same instructors as children in the exercise group. It may be that participation in either intervention helps children improve their EC. Importantly, children in the control condition of the current study are encouraged to participate in various play activities. Play may influence learning in children (Samuelsson & Johansson, 2006). Therefore, the activities in the control condition may benefit cognition, although it is not clear whether potential benefits would be specific to EC.

There were several limitations in this study. First, children in the exercise group were withdrawn from the exercise group to participate in the tasks at timepoints 2 and 3. Because they were exercising immediately prior to testing, they may have been experiencing fatigue, increased heart rate, or other effects which may have impacted their performance. Several studies have found that acute exercise can affect performance on cognitive tasks (Córdova, Silva, Moraes, Simões, & Nóbrega, 2009; Hillman, et al., 2009; Kashihara, Maruyama, Murota, & Nakahara, 2009). Also, children in both groups participated in these tasks near the end of a day-long battery of cognitive and physical tests at the pre-test and post-test. Due to the times at which they participated in these tasks, children may have been experiencing fatigue, which could have resulted in performance that was worse than would otherwise be expected. Another limitation in this study could have been attendance. Children were expected to participate at least four days per week but some attended less frequently than others due to transportation problems or other conflicting activities. However, there was no significant difference between the groups in terms of the number of days attended, $t(44) = -.117$, $p > .9$. Also, the groups began the intervention with different performance on some measures. For example, the exercise group began the intervention with a lower percent of incongruent trials correct on the flanker task than the control group. Therefore, the greater slope of the regression line in the exercise group could be attributed to the group making up some of the difference and not necessarily improving due to the exercise intervention. Finally, a possible limitation is that children tend to have higher variability on some cognitive tasks (including saccadic tasks) in comparison to adults (Yang, Bucci, & Kapoula, 2002). In order to examine whether this impacted internal consistency in the tasks, Cronbach's alpha was calculated for each of the task variables (see Table 4.1). There was generally acceptable internal consistency [i.e. the participants were not highly variable within testing sessions (George & Mallery, 2003)].

This study will have two additional cohorts of participants to in an effort to clarify possible effects of the interventions on EC. Future studies in of exercise in children may attempt to clarify the effects of acute (as opposed to chronic) exercise. There is evidence for different effects of each type of exercise, although what those effects are remains unclear. If this were clarified, it could impact the timing of physical education during the school day. Also, EC is a broad construct and the definitions vary in the literature. It has been defined as encompassing planning, conflict resolution, set-shifting, working memory, and inhibition, among other processes (Camchong, Dyckman, Austin, Clementz, & McDowell, 2008; Davis, et al., *In press;* McGuire & Botvinick, 2010; Slagter, et al., 2006). Thus, future research may aim to clarify whether certain aspects of EC are more affected by exercise than others.

Conclusions

The current study used antisaccade, prosaccade, and Eriksen flanker tasks to investigate a possible effect of exercise on executive control in overweight, sedentary children. The only effects specific to the exercise group were the greater slope of the regression line and the lower y-intercept for incongruent percent correct in the flanker task. Improvements were also observed over time in both the exercise and the control group in flanker incongruent percent correct and correct reaction times. Also, there were improvements in antisaccade performance. Both groups improved on the percent of correct trials over time. It is possible that both the exercise intervention and the attention control condition may be helping to improve performance beyond what would otherwise be expected due to development or practice effects. Two additional cohorts will participate in this study in an attempt to clarify any potential effects of the interventions.

Table 4.1 Internal Consistency Results
This table shows the value of Cronbach's alpha calculated for several variables of interest. Due to missing data, the value could not be calculated on individual trials and small blocks of trials had to be used. The block sizes were 6 trials for both saccade tasks and 5 trials for the flanker task.

Internal consistency				
Variable	Antisaccade % correct	Antisaccade correct RT	Prosaccade correct RT	Flanker incongruent % correct
Alpha	0.86	0.92	0.81	.71

Internal consistency (continued)			
Variable	Flanker congruent correct RT	Flanker incongruent correct RT	Flanker interference effect
Alpha	.90	.91	.54

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