A Study of the Effects of Aerobic Exercise on the Executive Cognitive Functioning of Overweight Children

Anne Kimball

University of Georgia

February 27, 2009

Abstract

Evidence suggests that exercise can have a variety of beneficial effects on cognition. This study investigates whether exercise benefits children's executive control (EC). EC constitutes supervisory control of cognitive functions, including inhibition and allocation of attention and memory. The participants were 25 sedentary, overweight (BMI $\geq 85^{th}$ percentile) children ages 8 – 11 years old. Subjects were randomly placed into either an attention control group, which engaged in instructor-led sedentary activities, or an exercise intervention group, which participated in aerobic training for 40 minutes/day, 5 days/week for 4 months. Subjects were tested at the beginning and at 9 weeks into the intervention using behavioral measures of EC. These measures included a) an antisaccade task that involves the inhibition of a prepotent visual response to a cue and the generation of eye movement towards the mirror-image of that cue, and b) an Eriksen flanker task which requires selective attention to a central target and suppression of interfering responses presented in the periphery. Because antisaccade and flanker tasks are relatively well-understood measurements of EC, evaluating changes in task performance over time could provide evidence for an exercise effect on cognition. It is hypothesized that the exercise group will demonstrate increased performance on both antisaccade and flanker tasks as compared to the control group. By providing evidence for the positive effects of exercise on cognition, this study would support the implementation of aerobic exercise programs in schools so that American schoolchildren will be healthier, both physically and mentally.

Introduction

According to the World Health Organization, obesity is one of the most important public health issues, and excess body weight is the sixth most important risk factor contributing to disease worldwide, with about 110 million children now classified as overweight or obese (Cali & Caprio, 2008). Pediatric obesity is an epidemic, and its prevalence is increasing rapidly (Strauss & Pollack, 2001). In the state of Georgia, 61% of children between the ages of 6-11 are overweight, with a Body Mass Index at or above the 85th percentile (Davis et al., 2005). Childhood obesity correlates with many health concerns, including lower performance in IQ tests (Li, 1995) and poor academic achievement (Taras & Potts-Datema, 2005). Experimental evidence has shown that exercise enhances children's mental functioning in ways that are central to cognitive development (Davis et al., 2007).

The current research is designed to evaluate whether aerobic exercise benefits executive cognitive control in overweight children. Executive control (EC) refers to the supervisory control of cognitive functions, including goal-setting, self-monitoring, use of strategies, inhibition, and allocation of attention and memory (Eslinger, 1996). EC is crucial for child development, cognitive development, and adaptive behavior (Lyon et al. 1996). Measures of EC have also been positively related to achievement (St. Clair-Thomson, 2006).

In this study, sedentary, inactive, and overweight children were placed in either an exercise intervention group or an attention control group. Both groups were tested on two behavioral measures of EC in a pre-test and after 9 weeks of the study. The two measures of EC are the antisaccade and flanker tasks.

Antisaccade tasks provide a direct and simple measure of inhibition. During the task, a participant fixates on a central target. This target is then turned off and a peripheral cue is turned on. Participants are instructed not to look at the cue but to look at the opposite side, the same distance from the center. An initial glance towards the cue is an error and is construed as a failure of inhibition. Performance on this task (measured as percent correct responses and reaction time of correct saccades) may be a good indicator of potential exercise-related changes in neural circuitry. Antisaccade error rates are generally stable between multiple measurements in time in adults (Ettinger, 2003); however, performance can be improved by daily purposeful practice (Dyckman, 2005 and Fischer, 2000). Thus, while antisaccade performance in adults is generally stable, performance can change with intervention (practice). This inhibitory process is malleable, and thus may respond to exercise.

Flanker tasks provide measures of selective attention and inhibition. Correct performance in the flanker task requires selective attention to a middle stimulus (that conveys information about the correct response) and ignoring adjacent stimuli that are either congruent (e.g. > > > > >) or incongruent (e.g. < > < < >) in nature. Across numerous versions of flanker tasks, correct reaction times are longer in the incongruent condition (Colcombe, 2004 and Eriksen, 1974), suggesting that subjects experience increased conflict compared with the congruent condition.

Evidence has shown the beneficial impacts of exercise on physical, mental, and cognitive health. Hillman et al. (2008) examined the benefits of aerobic physical activity for cognition and brain function on molecular, cellular, systems, and behavioral levels. A link has been demonstrated between physical activity and reduced cardiovascular disease, colon and breast cancer, obesity, depression, and anxiety. In addition, physical activity is linked to higher scores on cognitive functioning assessments, especially on executive control tasks. While physical activity is shown to be beneficial at all stages of life, this activity during childhood may help to improve and maintain cognitive health and functioning throughout the adult lifespan (Hillman et al., 2008).

Past studies also have shown the beneficial effects of exercise programs on various aspects of cognition in adult populations. One study found that exercise training resulted in improvements in cognitive functioning in elderly adults with dementia and cognitive impairments, highlighting the role of exercise in brain functioning and cognition (Heyn et al., 2004). It has also been demonstrated that aerobic fitness training increases the performance on many cognitive tasks in sedentary older adults, with the most significant benefits on executive control tasks (Colcombe & Kramer, 2003). These studies have shown the beneficial effects of exercise on cognitive functioning in adults with prior cognitive deficits and in adults who live a sedentary lifestyle.

Previous research also has indicated that there is a link between cognition and exercise in children. A meta-analysis found a positive correlation between physical activity and cognition in elementary and middle-school aged children (Sibley & Etnier, 2003). It also has been found that children with greater levels of aerobic fitness performed better on tasks of executive control, suggesting a beneficial effect of exercise on cognition during preadolescent development (Buck et al., 2008). These studies all show the positive relationship between exercise and various measures of cognitive control and executive functioning. Davis et al. (2007) tested the effects of a 15-week multi-level (zero, low, and high doses of aerobic activity) exercise program on the cognition in sedentary, overweight children. Using the Cognitive Assessment System Planning scale, the study reported that the children in the high-dose exercise group had significantly higher planning scores than the control group (Davis et al., 2007). This previous study provided a basis for the current study of overweight children in a high aerobic exercise environment versus an attention control group that spends the same amount of time onsite and with supervisors.

Based on the body of previous research, the following hypotheses were generated. Exercise training will improve executive control in sedentary, overweight (BMI $\geq$ 85th percentile) children. More specifically, the children who have exercise training will show a greater decrease in antisaccade and flanker error rates (within the context of unchanged or even faster reaction times) than those in the attention control group. Performance on the EC tasks was measured at the beginning of the experiment and after 9 weeks of intervention so that changes could be assessed.

Method

Participants

Participants in this study were 25 sedentary, overweight (BMI $\geq$ 85th percentile) male and female children of varying ethnicities between the ages of 8-11 years old. The children were recruited from public elementary schools in Augusta, GA in the 2008-2009 school year, as part of a funded grant on behalf of investigators at the Georgia Prevention

Institute (GPI) at the Medical College of Georgia and at the University of Georgia. Informed consent was given by both the parent/guardian and the participant.

Procedure

Each child spent 60 min/day, 5 days/week at the GPI for 2 months. The exercise intervention group participated in an aerobic training program. Each session included warm-ups and cool-downs and 40 min (two 20-min periods) of aerobic exercises and games (running games, ball games, and jump rope) with brief rests. Games were developed during previous intervention programs conducted at GPI with students of the same ages. Children wore monitors that were strapped around the chest to record heart rate (HR), which is then transmitted to a watch-like device. The device records HR and the children learn to check the device in order to keep their HR high (an average HR >150 bpm must be maintained for the children to earn small prizes).

The attention control group included 60 minutes of instructor-led sedentary activities, such as videos, art, and music to control for the amount of time spent at the GPI. Rewards were given for attendance and good behavior.

Executive control was assessed with antisaccade and flanker tasks at the beginning of the intervention (Time 1) and at the 9-week period (Time 2). Antisaccades require suppression of a prepotent response and generation of a voluntary saccade towards an unmarked location (Fig. 1). An antisaccade error is a saccade towards the cue instead of away from it and is construed as an error of inhibition. Antisaccade error rate (error trials/total trials) and reaction time for correct responses (time in msec from the onset of the stimulus to the beginning of the eye movement) were measured. Antisaccade data were analyzed using programs written in Matlab to score eye position as well as reaction times of error and correct saccades.

The flanker task requires response selection and suppression of interfering responses (Fig. 2). This task requires selective attention to a central target and inhibition of attention to distracting stimuli. The stimuli are made up of a central target and distracting cues that are either congruent (< < < < <) or incongruent (< < > < >). The subject responds by pressing a response button according to the direction indicated by the central target. Error rates (error trials/total trials) and correct response reaction times were calculated for congruent and incongruent trials. The interference effect [(average incongruent response time – congruent response time)/congruent response time] was also calculated and reflects the greater reaction time required for the incongruent trials when accounting for congruent reaction time.

Figures:

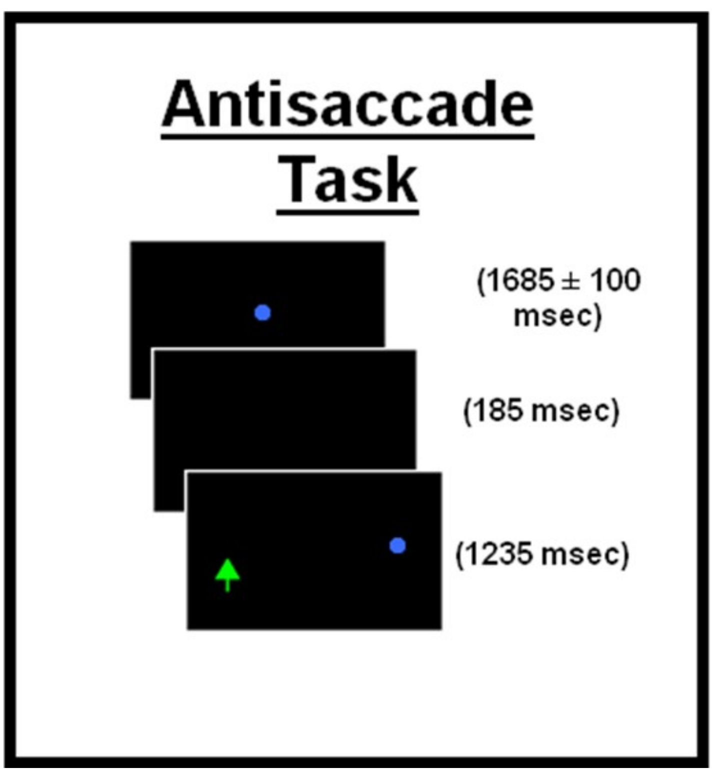


Fig. 1 The blue dot in the middle indicates the fixation period. When the blue dot moves to the side, the participant looks to the mirror image location, as shown by the green arrow.

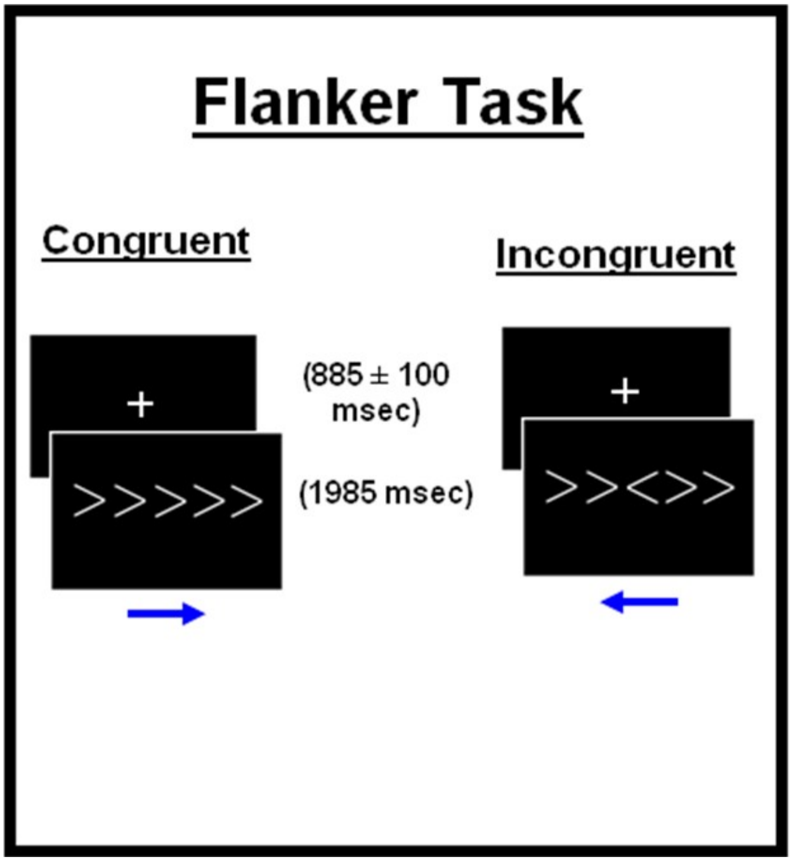
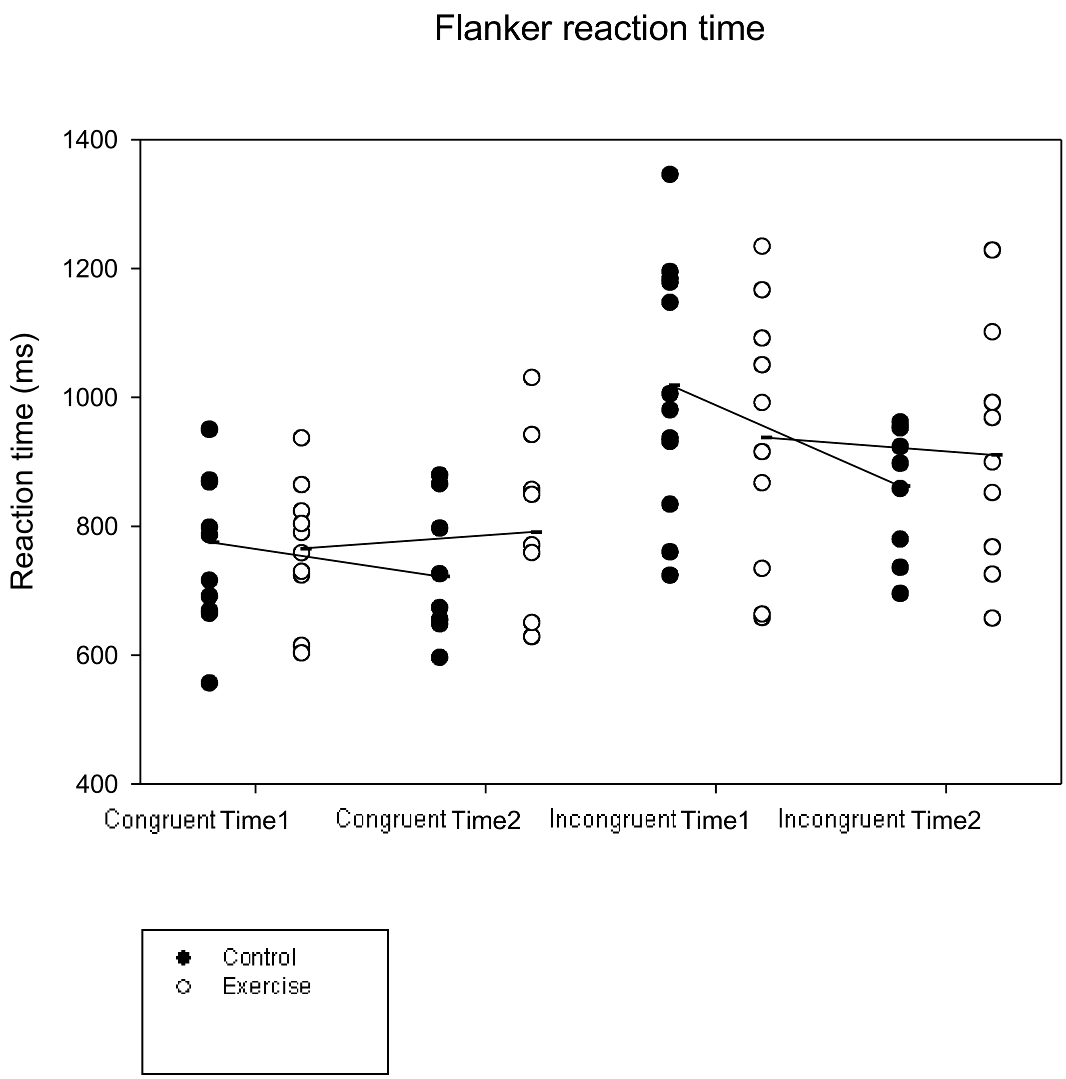
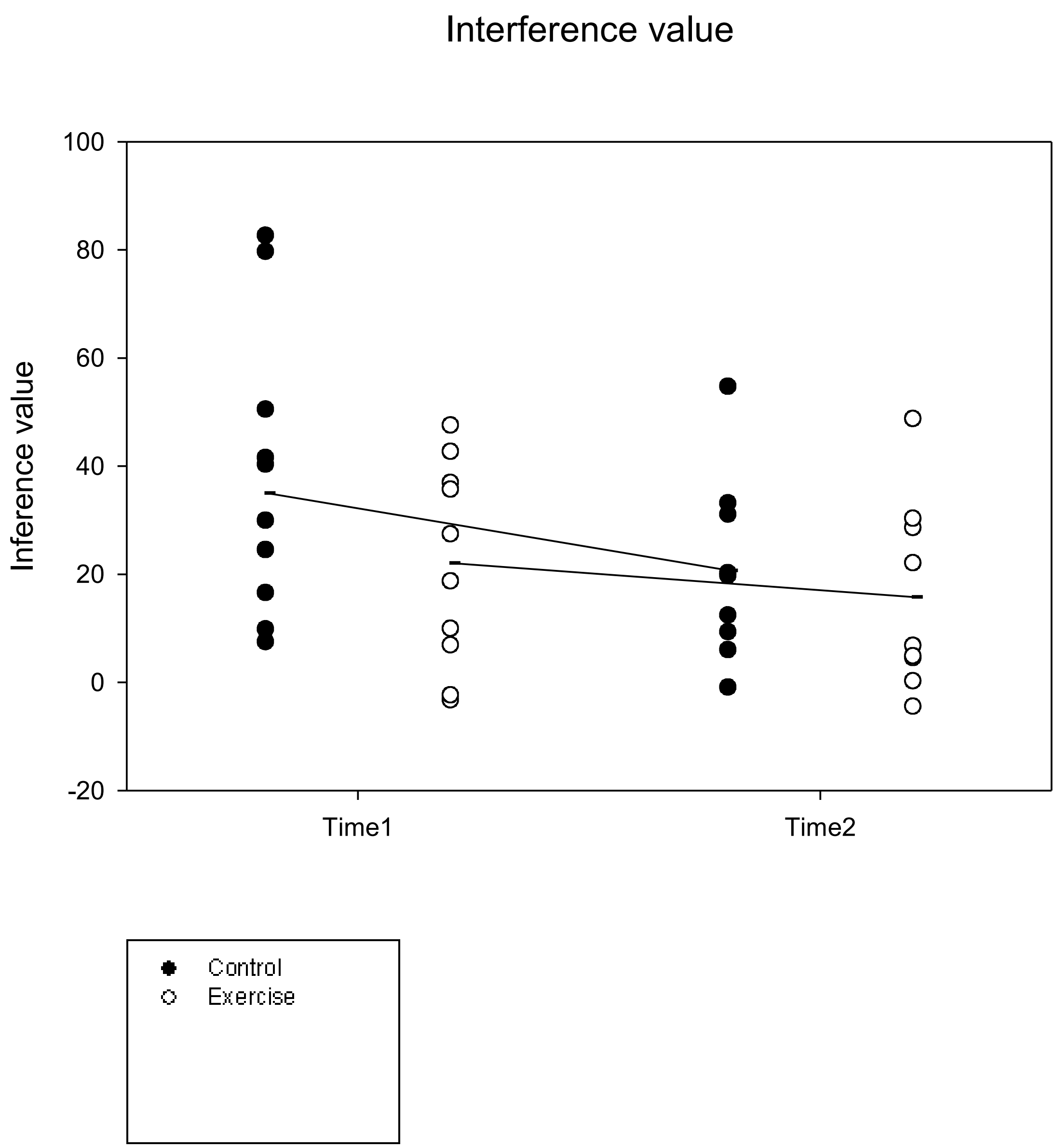


Fig. 2 The 885msec indicates the fixation period, followed by the response period. The blue arrow shows the correct response, indicated by the target.

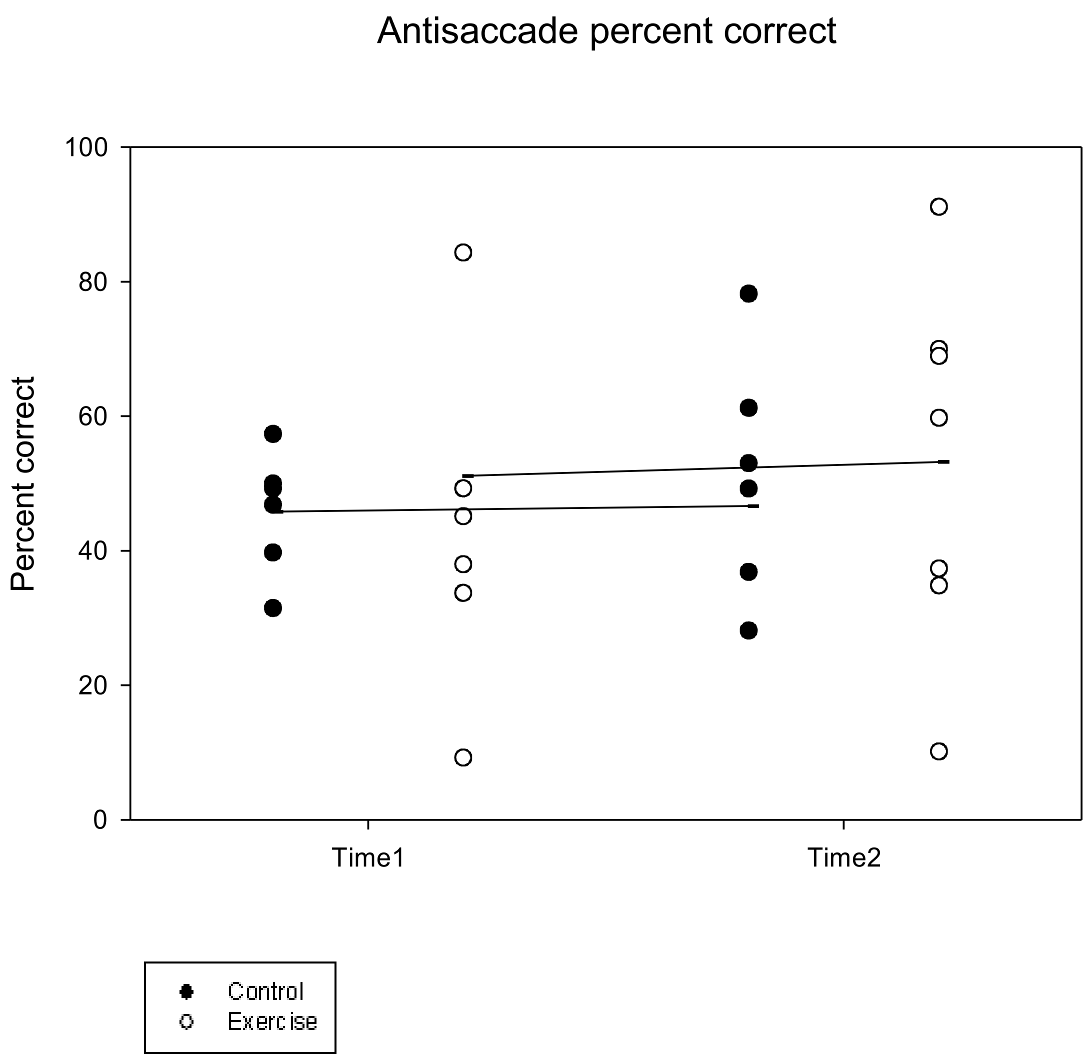
Results



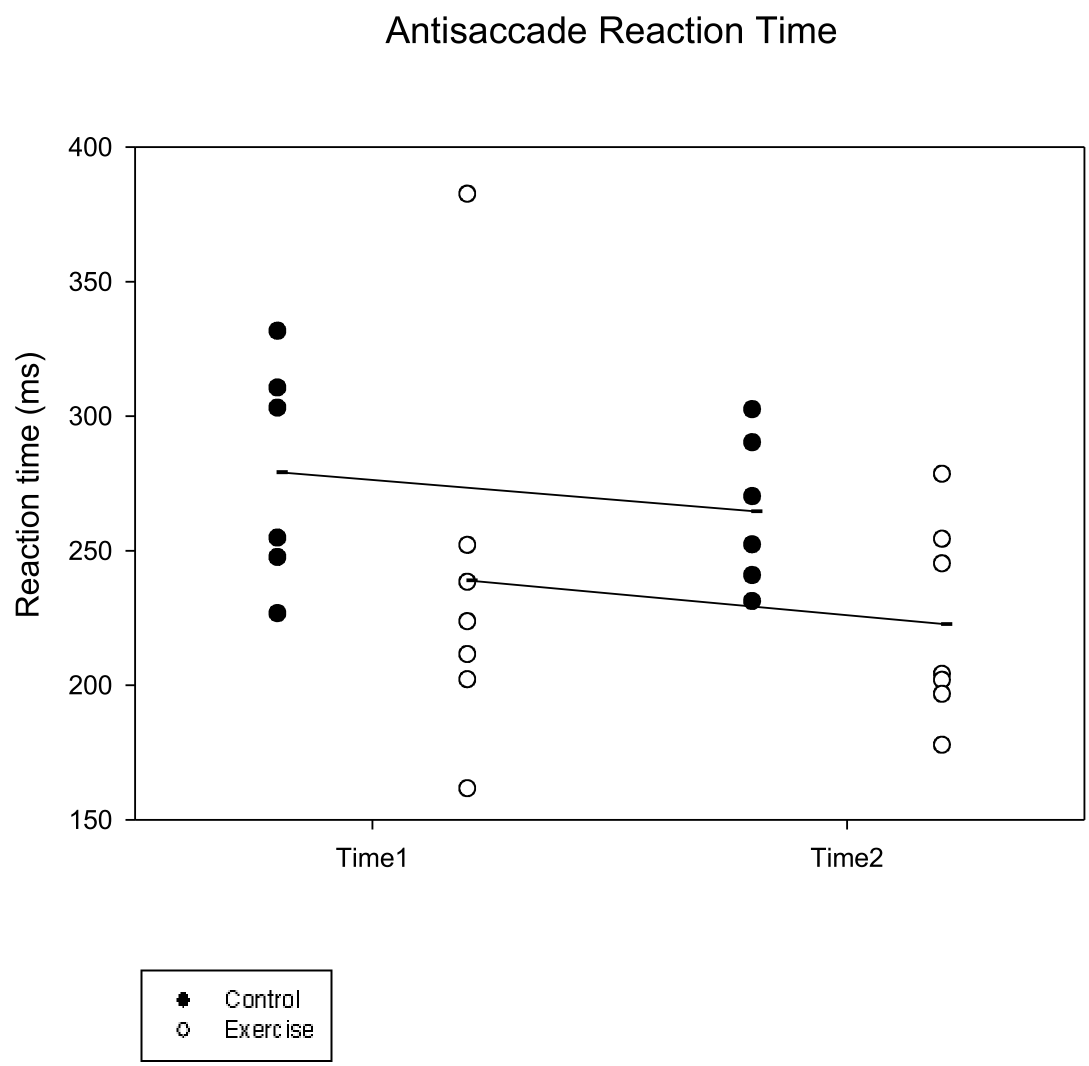
This graph shows the reaction times for the congruent and incongruent flanker tasks between Time 1 and Time 2 for both groups. The changes from Time 1 to Time 2 are not statistically significant.



This graph shows the Interference value (((incongruent reaction time – congruent reaction time)/congruent reaction time)*100) for the flanker task. The differences are not statistically significant.



This graph shows the average percent correct for each group on the antisaccade task from Time 1 to Time 2. These differences are not statistically significant.



This graph shows the average reaction time for each group on the antisaccade task from Time 1 to Time 2. These differences are not statistically significant.

A repeated measures analysis of variance (ANOVA) showed no main effect of group (exercise, control; $F(1,24)=.03$, $p>.8$), no main effect of time (time 1, time 2; $F(1,24)=.08$, $p>.8$) and no group by time interaction for the antisaccade task.

Discussion

Contrary to the hypotheses, changes were not observed across time in either the exercise or control group. No statistically significant improvements were observed in either group.

Previous studies have shown that engaging in exercise programs improves measures of executive control in many different populations. Adults showed an improvement in measures of executive control with participation in an exercise intervention program (Colcombe & Kramer, 2003). This improvement is expected for the children in this study, but the hypothesized results have not occurred in the first nine weeks. During childhood, the prefrontal cortex (PFC) is still developing, as measured by synaptic pruning (Huttenlocher, 1979), myelination of prefrontal fibers (Yakovlev & Lecours, 1967), and imaging methods (Klingberg et al., 1999). Inhibitory processes have been associated with the dorsolateral PFC (Colcombe et al., 2004). Since children's PFCs are not yet fully developed, there is reason to believe that any changes in the brain due to exercise may take longer in children than in the brains of adults. It also may be the case that the processes necessary to invoke changed performance in children rely on the development of new synapses, which could take on the order of months instead of weeks. In order to further test this hypothesis, these children will continue through two more 9 week testing periods and the end study will be comprised of 4 testing periods instead of only the two reported to date. If performance continues unchanged, it may reflect structural limitations in the, as of yet, not fully developed PFC. If changes are observed in latter testing dates, it may indicative of synaptogenesis occurring after months of training.

Attendance proved to be a limitation in this study. Some children periodically missed sessions for personal and family reasons that could not have been controlled. The activities that the children engaged in when not at the controlled sessions could have produced confounding variables in the testing. Additionally, some children showed higher scores than others during the pre-test (Time 1), which leaves smaller room for improvement at Time 2.

While these preliminary results did not support the hypothesis, testing will continue for two more time periods. Previous research suggests that the exercise training group may show more of an improvement over the course of the study. Given the evidence in adults that exercise improves EC, it is important to understand the extent to which these studies may apply to children. Studies assessing the neural bases of cognitive control may be important for guiding future policies on recess and physical education.

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