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Effects of Aerobic Exercise on Overweight Children's Cognitive Functioning:

A Randomized Controlled Trial

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Abstract

The study tested the effect of aerobic exercise training on executive function in overweight children. Ninety-four sedentary, overweight but otherwise healthy children (mean age = 9.2 years, body mass index ≥ 85th percentile) were randomized to a low-dose (20 min/day exercise), high-dose (40 min/day exercise), or control condition. Exercise sessions met 5 day/wk for 15 weeks. The Cognitive Assessment System (CAS), a standardized test of cognitive processes, was administered individually before and following intervention. Analysis of covariance on posttest scores revealed effects on executive function. Group differences emerged for the CAS Planning scale ($p = .03$). Planning scores for the high-dose group were significantly greater than those of the control group. Exercise may prove to be a simple, yet important, method of enhancing aspects of children's mental functioning that are central to cognitive and social development.

Keywords

Executive Functioning; Physical Activity; Obesity; Developmental Psychology

Pediatric obesity is an epidemic with major implications (Daniels et al., 2005; Strauss & Pollack, 2001). Besides its well known health sequelae, overweight in children is associated with poor IQ test performance (Campos et al., 1996; Li, 1995) and poor academic achievement

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(Taras & Potts-Datema, 2005). For this reason and because overweight is a marker of a long history of inactivity, overweight, sedentary children may be more likely to benefit from an exercise intervention than their active, normal weight peers.

A recent meta-analytic review of published and unpublished studies conducted with children and adolescents suggests that exercise training is significantly associated with improved cognition in children (effect size d = .32) (Sibley & Etnier, 2003). The authors acknowledge, however, that there is limited evidence that systematic exercise training *causes* improvement in children's cognitive function. Few experiments have been conducted that both involve children in substantial levels of aerobic training and employ sensitive, well-validated measures of cognitive function. Some studies failed to detect effects on cognition (see Tuckman, 1999 for a review). Sibley and Etnier (2003) suggested that controlled intervention studies with adequate statistical power were needed to establish causation. The present study was designed to address these concerns.

The executive function hypothesis (Churchill et al., 2002; Hall, Smith & Keele, 2001; Kramer et al., 1999), which has been developed in gerontology, predicts that the largest improvements in cognition due to exercise will be on executive function (i.e., the ability to plan, initiate, and carry out activity sequences that make up goal-directed behavior, self monitoring, and self-control). Executive function develops from early childhood through adolescence, with its most dynamic phase of development during the elementary school years (Welsh, Friedman, & Spieker, 2006). Since most exercise studies with children have not used measures that are sensitive to executive function (Lezak et al., 2004, pp. 36, 611-612), this hypothesis may explain the mixed findings in children.

Children's cognitive functioning may be particularly sensitive to the influence of physical activity, given the evidence for a relation between children's early experiences, brain development, and cognitive function (S. M. Carlson, 2005; Nelson, 1999). The pattern of children's neural specialization (e.g. pruning of synapses) appears to be determined, in part, by environmental stimulation (Kolb & Whishaw, 1998). Recently, Hillman and colleagues (2005) measured EEG brain activity in high- and low-fit children while they performed a choice-reaction test. High-fit children performed the behavioral task more rapidly and evidenced larger P3 amplitudes, consistent with better executive function, than low-fit children. The cognitive advantage in high-fit vs. low-fit children might be the result of regular, vigorous exercise in the high-fit group.

To address the executive function hypothesis in children, this randomized controlled trial was conducted to determine if an aerobic exercise program will improve sedentary, overweight children's cognitive function and, if so, whether the gains would be seen most clearly on tests that measure executive function. A standardized measure of executive function with excellent psychometric qualities, the Cognitive Assessment System (CAS), was selected. One of the four CAS scales, Planning, measures executive function processes. The remaining scales measure other aspects of cognitive performance, and thus can help determine whether the effects of exercise training in children are stronger for executive function than for other cognitive processes.

The primary hypothesis was that children assigned to a systematic aerobic exercise training program would evidence greater improvements on a standardized test of cognitive function than children in a non-exercise control condition. The secondary hypothesis was that randomization to a higher dose of exercise training would lead to a greater effect (i.e. dose-response) on cognitive function. Because executive function has shown the greatest response to training in prior studies, we expected to detect gains only on executive function (i.e. CAS Planning).

Method

Participants

Ninety-four children ranging from 7 to 11 years of age (*M* = 9.2 years, *SD* = 0.84) participated in the experiment and completed evaluations at posttest. Cohorts of 30-40 children were recruited from local elementary schools in the Augusta, Georgia area. The study was advertised via presentations and flyers distributed at elementary schools. Children were eligible if they were overweight (≥85th percentile body mass index, BMI, for age and sex; Ogden et al., 2002), inactive (did not participate in a regular physical activity program more than one hour per week), had no medical condition that would affect study results or limit physical activity, and were not taking medication that would affect study results (e.g. antipsychotics). Children taking medication for attention-deficit disorder were included to maximize generalizability of results. They took their usual medication when cognitive testing was conducted. Five children were taking medications for attention-deficit disorder: three on methylphenidate preparations, two on amphetamine mixed salts, and one on atomoxetine. Fifty-six girls and 38 boys (75% African American and 25% Caucasian) participated in the ongoing study. The children's average BMI was 25.8, SD = 4.0, and their average age- and sex-adjusted BMI z-score was 2.1, SD = 0.4. Children and parents completed written informed consent/assent. The study was reviewed and approved by the Human Assurance Committee of the Medical College of Georgia. The study was conducted in concert with a larger study that is evaluating the effects of exercise training on physical function and metabolism of overweight children (NIH R01 DK60692).

Procedure

Children in each cohort were assigned randomly either to a low-dose exercise treatment, which consisted of 20 min of aerobic exercise per session, a high-dose exercise treatment, which consisted of 40 min of exercise, or a no-exercise control condition. The exercise conditions were equivalent in intensity, and differed only in duration (volume) of daily exercise. Children assigned to exercise treatments attended programs, which met 5 days per week for 15 weeks. Each cohort of children was recruited from neighboring elementary schools. Three cohorts participated successively in the study over 2 years to allow a larger sample size than could be accommodated at one time.

Exercise intervention—The exercise sessions were conducted after school during a school semester. Children were transported by bus to a gymnasium located at the Georgia Prevention Institute. The exercise intervention was modeled on a program previously shown to decrease adiposity and to enhance children's aerobic fitness (Gutin et al., 1999). Instructors included a master's level physical educator, bachelor's level exercise scientists, and other trained research staff who had at least some college education, with a student:teacher ratio of about 9:1. The emphasis was on intensity, enjoyment and safety, not competition nor the enhancement of skills; therefore, activities were selected based on ease of comprehension, fun, and ability to elicit a heart rate greater than 150 bpm. The exercise program handbook is available on request. Heart rate monitors (S610i; Polar Electro, Oy, Finland) were used to motivate children to adhere, and to monitor the exercise dose. Each child's average heart rate (using a 30 sec epoch) during the exercise sessions was recorded daily and points were awarded for maintaining an average heart rate >150 bpm. Nearly every child achieved this goal nearly every day. Points were redeemed for weekly prizes. An additional manipulation check was provided by instructors' periodic checks on the children's heart rate readings during each 20-min bout. If below 150 bpm, the children were encouraged to engage in more vigorous activity such as jump rope or a lap around the gym. Activities included running games, tag games, jump rope, and modified basketball and soccer (Gutin et al., 1999; Hinson, 1995; Turner & Turner, 2000). The 5 minute daily warm-up included moderate cardiovascular activity (brisk walking, up to 10 jumping jacks) and static and dynamic stretching (toe touches, lunges). Sessions ended with a water break, light cool-down cardiovascular activity (slow walking), and static stretching. Children assigned to the high-dose exercise condition completed two 20-min exercise bouts each day. Children who participated in the low-dose exercise condition completed one 20-min bout in the gymnasium and a 20-min period in an adjoining room where they were permitted to do homework or other quiet activities. No tutoring was provided during this period. Children remained at the gymnasium for approximately 75 min each day due to time required for changing, water breaks, and the like. Children were transported back to their neighborhoods each afternoon. Children assigned to the control condition were not provided any after-school program or transportation but were asked to continue their usual activities. All families enrolled in the study were offered monthly lifestyle education classes designed by a dietician and a psychologist that addressed topics such as healthy diet, physical activity, and stress management.

Children's average attendance during the exercise intervention was 85% (SD = 11.5) and was similar between the low- and high-dose conditions. There was one serious adverse event (a fracture) in the low-dose group; as a result, this child attended only 56% of sessions. Children's average heart rate during exercise (mean of each child's mean daily values across the intervention period, averaged across children) was 166 (SD = 8.2) bpm and was similar between the low- and high-dose conditions. Post intervention scheduling of physiological and cognitive tests resulted in children receiving an average of 12.6 weeks (range = 10-15 weeks) of the exercise intervention. The duration of the intervention period was similar for low- and high-dose conditions (M = 12.9, SD = 1.6 vs. M = 12.3, SD = 1.5 weeks, $t(1,63) = 1.5$, $p > .1$). The time interval between pre- and posttest was also similar across control, low- and high-dose conditions (M = 17.0, SD = 2.2 vs. M = 16.8, SD = 2.1 vs. M = 16.5, SD = 2.2 weeks, $F(2,91) = 0.4$, $p > .5$).

Fatness, fitness and physical activity measures—Measures were completed at pretest and posttest. Body weight (in shorts and t-shirt) and height (without shoes) were measured with an electronic scale (Detecto, Web City, MO) and stadiometer (Tanita, Arlington Heights, IL) and converted to BMI and a BMI z-score (Epi Info, Centers for Disease Control and Prevention, Atlanta, 2003). BMI z-score reflects the number of standard deviations above or below the average value for a child's age and sex based on the current childhood norms (Ogden et al., 2002). Fitness was measured with the aerobic fitness treadmill test (Modified Balke Protocol for Poorly Fit Children; American College of Sports Medicine, 2000). Prior to beginning the test, participants were asked to do a 4 minute warm-up (2 min at 4.0 km/h, 0% grade; 2 min at 4.8 km/h, 3.0% grade). The test was done on a Monark treadmill with a metabolic cart and computer hardware (SensorMedics Corporation, Yorba Linda, CA). Children were encouraged to walk as long as they could. Instructors stopped the test when children signaled they could not continue, when children had reached maximum according to the modified Balke protocol, or for safety reasons. All but two treadmill tests were terminated on the basis of children's reports of physical discomfort, difficulty breathing, or tiredness. The duration of each child's treadmill test (treadmill time) was the indicator of his or her aerobic fitness. After study enrollment, questions 80 and 81 from the 2001 Youth Risk Behavior Survey assessed children's self-reported moderate (i.e. at least 30 min that did not make you sweat or breathe hard) and vigorous (i.e. at least 20 min that made you sweat and breathe hard) physical activity over the past week (Centers for Disease Control and Prevention, n.d.). One child in the control group did not complete these measures at posttest.

Cognition measure—Children's cognitive performance was assessed prior to and following the exercise intervention via the CAS (Naglieri & Das, 1997). The CAS is grounded in the Planning, Attention, Simultaneous and Successive (PASS) theory of cognitive function (Das, Naglieri, & Kirby, 1994; Naglieri, 1999). The PASS theory is based on the views of Luria, whose insights linking brain anatomy and function are fundamental to neuropsychology (Luria, 1976). The CAS is a standardized test that measures children's mental abilities defined on the basis of four interrelated cognitive processes: Planning, Attention, Simultaneous, and Successive (PASS). Each of the four PASS scales is comprised of three subtests. These composite scales yield standard scores set at a normative mean of 100 and standard deviation of 15. As mentioned earlier, the Planning scale (internal reliability = .88) assesses executive function processes (i.e., strategy generation and application, self-regulation, intentionality, and utilization of knowledge). The Attention scale (internal reliability = .88) subtests require focused, selective cognitive activity and resistance to distraction. The Simultaneous scale (internal reliability = .93) subtests involve spatial and logical questions that contain nonverbal and verbal content. The Successive scale (internal reliability = .93) subtests require the analysis or recall of stimuli arranged in sequence and the formation of sounds in order. According to PASS theory, only the Planning scale reflects executive function (i.e. prefrontal activity, Luria's 3rd functional unit; Das, 1999).

The CAS was standardized on a large representative sample of children aged 5-17 years who closely match the U.S. population on a number of demographic variables (e.g., age, race, Hispanic origin, region, community setting, educational classification, and parental education). The test was selected for several reasons. First, it measures processes which are more likely to show sensitivity to changes in cognitive functioning than traditional IQ based on general intelligence. Second, unlike traditional IQ tests, CAS yields small race and ethnic differences, making it more appropriate for assessment of minorities (Naglieri, Rojahn, Aquilino, & Matto, 2005). Third, the CAS is strongly correlated with academic achievement ($r = .71$) (Naglieri & Rojahn, 2004). Fourth, consistent with PASS theory, CAS scores are responsive to educational interventions (Carlson & Das, 1997; Naglieri & Gottling, 1997; Naglieri & Johnson, 2000). Finally, because the CAS Planning scale measures executive processing and the CAS includes other processes besides executive function, this single measure provides an efficient way to assess the possible differential effects exercise may have on this group of cognitive processes. The CAS was administered by a school psychologist or a trained psychology graduate student. Ninety-seven percent of children were evaluated by the same tester, at the same time of day, and in the same room prior to and following treatment. The test administrators were blinded to the child's assigned experimental condition. Each child required approximately 60-90 min to complete the test. The test was scored via software designed by the test creators (CAS Rapid Score 1.0, Naglieri, 2002).

Statistical Analyses

Analysis of covariance (ANCOVA) was used to examine differences in posttest scores of various cognitive scales among activity groups (control, low- and high-dose exercise) controlling for cohort and pretest score (Huck & McLean, 1975). The CAS Planning, Simultaneous Processes, Attention, and Successive scales, as well as BMI z-score, treadmill time, and physical activity were examined as outcomes in intent-to-treat analyses. Statistical analyses were performed using SAS 9.1.3 and SPSS 13.0, and statistical significance was assessed using an alpha level of .05. An estimate of the effect size for activity group, partial eta squared (η^2), was calculated for each dependent variable. Differences between activity groups' adjusted means were examined using unadjusted multiple comparisons (t-tests). In an experiment with three groups, this procedure maximizes power while maintaining the familywise error rate at alpha = .05 (Howell, 1992, p. 356). A contrast to compare the control group to the exercise groups was performed if the overall F value was significant. Significant analyses were repeated excluding the five children taking medications for attention-deficit disorder.

Results

The means for PASS standard scores for the three groups provided in Table 1 suggest that the sample achieved scores that fall in the normal range (Naglieri & Das, 1997). Table 2 presents the results of the ANCOVA models controlling for cohort and pretest score, including partial η^2 and observed power. As predicted, a statistically significant effect was seen for group assignment on the CAS Planning posttest score. Group comparisons showed that the control group had a significantly lower posttest score than the high-dose exercise group, $t(88) = -2.55$, $p = .01$, and, while they were not statistically different, the low-dose group had a lower posttest score than the high-dose group, $t(88) = -1.98$, $p = .05$. The control and low-dose groups did not differ, $t(88) = -0.6$, $p = .52$. The contrast comparing the control group to both exercise groups together on Planning scores was not statistically significant, $t(88) = -1.84$, $p = .07$. ANCOVA analyses revealed no significant group differences among scores on the CAS Attention, Simultaneous, or Successive scales, or on BMI z-score or physical activity. Group differences were noted on treadmill time, where each exercise group had a higher treadmill time at posttest than the control group (high-dose vs. control, $t(87) = -2.5$, $p = .015$; low-dose vs. control, $t(87) = -2.4$, $p = .02$). The low- and high-dose groups did not differ, $t(87) = -0.2$, $p = .86$. The contrast showed that significantly greater improvements in treadmill time were observed in the exercise groups than the control group, $t(87) = -2.8$, $p = .007$. The results were very similar with the five children taking medications for attention-deficit disorder excluded (group effect on Planning posttest score, $p = .02$).

Discussion

These results provide evidence for a direct relation between a substantial dose of regular, vigorous exercise and improvement in children’s executive function. Empirical support for the hypothesis that exercise has a positive influence on executive function has been lacking in research with children. Our primary hypothesis was supported, in that one scale of the CAS, Planning (a measure of executive function) responded to exercise training. Our secondary hypothesis predicting a dose-response relation was not supported. Rather, the significant effect of exercise on cognition was observed only between the no-exercise control and the high-dose exercise conditions, suggesting a threshold effect. The low- and high-dose exercise groups exercised at a similar intensity (average HR > 150 bpm), but for different lengths of time (20 vs. 40 min/day), therefore eliciting energy expenditure in the high-dose group approximately double that in the low-dose group. The children who received the high-dose exercise program increased their standard scores for Planning by about one-third of the standard deviation of standard scores in the normative population.

Executive function plays a pivotal role in planning, organizing, and controlling goal-directed actions (Churchill et al., 2002; Lezak et al., 2004, pp. 35-36). The “executive” allocates and directs the basic cognitive processes toward achievement of a goal. The self-monitoring aspect of executive function allows one to make adjustments to selected strategies if the expected results are not obtained. Recent reviews have integrated the executive function literature with related concepts in developmental cognition (Rueda, Posner, & Rothbart, 2005; Welsh et al., 2006). Executive function, particularly the elements of inhibition and self-monitoring, is crucial to the development during the school-age years of the capacity to delay gratification (Eslinger, 1996; Mischel et al., 1989). The ability to self-regulate behavior via executive function is purported to underlie children’s capacities to develop imagination, experience empathy, act creatively, and to self-evaluate thoughts and actions (Barkley, 1996). This capacity to self-regulate behavior is important for a child’s readiness to function adequately in elementary school (C. Blair, 2002).

The present findings are consistent with reviews that suggest aerobic exercise training has its strongest cognitive effects on executive function in older adults (Churchill et al., 2002; Colcombe et al., 2004b). A meta-analysis concluded that exercise training leads to improvements in older adults' cognitive processing, and that the greatest gains are made in executive processing (Colcombe & Kramer, 2003). Since that publication, an experiment with sedentary 55-77 yr olds showed that a 6-month aerobic training program (walking 3 times per week) altered prefrontal brain activation and led to improvements on a laboratory test of executive function, providing the strongest evidence to date in support of the executive function hypothesis (Colcombe et al., 2004a).

There are reasons to expect that the cognitive benefits of exercise may be even greater for children, who are developing central nervous system structures, than for older adults, whose brain structures and neuronal systems are in a state of dedifferentiation (Cabeza, 2001). Physical activity may be necessary for healthy neural development. Chronic inactivity, which is now typical among children, may put them at a disadvantage for cognitive as well as physical health (Booth et al., 2000). There may be critical or sensitive periods during childhood where exercise has limited windows to promote optimal neural development and leave a lasting impact (Chugani, 1998; Knudsen, 2004). Alternatively, the neural benefits of regular exercise may be like that of aerobic fitness and associated health benefits, which progressively improve with exercise but are lost with a period of inactivity (Ferguson et al., 1999; Mikines et al., 1991). Future studies could address the minimum duration of a program of regular exercise needed to achieve an effect. It may be that most of the benefit accrues in the first few bouts of exercise, rather than accruing in linear fashion over several months. Additional dose comparisons on amount or intensity of daily exercise, or maintenance of the daily exercise program for a longer period may shed additional light on this exercise-cognition effect. For instance, it may be that 20 min of daily aerobic exercise would improve executive function if undertaken for a full year rather than just a few months.

There are numerous approaches to the measurement of executive function in children (C. Blair et al., 2005; Hughes & Graham, 2002). The advantage of using the CAS and PASS theory is that the cognitive processes are carefully defined, and the tests used to measure each process are theoretically based and empirically supported. Therefore these results provide strong evidence of a medium effect size (8% of variance explained; Cohen, 1988, p. 287) of exercise on overweight children's executive function. The Planning scale of the CAS is linked to achievement, indicating that these results may have important implications for children's academic success (Naglieri & Rojahn, 2004). There may be smaller effects of exercise on other aspects of cognition that may be detectable in a larger study or with a larger dose of exercise.

The children in both the low- and high-dose groups improved similarly on a treadmill test of endurance, by about 100 sec relative to controls. There is reason to suspect that the incremental dose of intervention after 20 min/day would make much less difference on children's fitness than those initial 20 min, a diminishing return as fitness increases from an initially very low level of activity and then asymptotes (S. N. Blair et al., 2001). Daily attendance and heart-rate monitoring during intervention support the fidelity of the low- and high-dose conditions. No effect of exercise without dietary intervention was found on BMI z-score, consistent with adult studies, which show that exercise without dietary restriction in obese adults improves health and fitness without any weight loss (Lee et al., 2005).

Whether it is the sympathetic nervous system arousal induced by aerobic exercise, the cortical stimulation resulting from organized motor activity and social interaction, metabolic adaptations resulting from exercise training, or some other mechanism that is responsible for the current finding of improved cognition resulting from regular exercise remains to be determined. However, the lack of change in degree of overweight and the similar improvements in endurance in both exercise groups, in conjunction with the finding that only the high-dose group improved on cognition, argue against the role of overweight and fitness in this causal chain. A recent meta-analysis found no support for aerobic fitness as a mediator of the effect of physical activity on cognition (Etnier et al., 2006). The animal literature suggests a more direct role of neural stimulation by physical activity. The results obtained in the present study may be attributable to proposed mechanisms linking the cognitive benefits of physical activity to physiological brain changes in animals (Dishman et al., 2006). Cognitive gain due to exercise in older adults has been attributed to growth of brain tissue (Colcombe et al., 2004a). Animal studies show that aerobic activity increases capillary blood supply to the cortex, and promotes the growth of new neurons and synapses, resulting in better learning and performance (Churchill et al., 2002; Lu & Chow, 1999; Neeper, 1995; van Praag et al., 1999; van Praag et al., 2005).

This study has some limitations. First, the sample was limited to overweight sedentary children, who might be more responsive to exercise than their leaner, more active peers. However, the overweight children in our sample now represent approximately one-third of the national population, and closer to one-half of our local population of children (Davis et al., 2005; Ogden et al., 2006); therefore these results are quite pertinent to a major public health challenge. This was a community sample rather than a convenience or clinical sample, implying less bias. Another limitation common to behavioral clinical trials was that children were not blinded to their group assignment, nor were interventionists blind to condition or the hypotheses of the study. Nonetheless, evaluators were blinded to group assignment in order to obtain unbiased assessment of cognitive outcomes. Because the two exercise groups came to the same gymnasium each day, there was potential for contamination; however, the fidelity of the distinct doses were maintained through supervision and daily monitoring of heart rates. Finally, rather than a no-intervention control condition, the use of an attention control group which received interaction and intervention time equal to the exercise groups would have provided additional evidence that it was the exercise, rather than other aspects of the intervention, that caused the improvements in cognition.

The current childhood obesity and inactivity epidemic and its behavioral antecedents (excessive calorie consumption, inactivity) may be affecting intellectual potential and school performance (Coe et al., 2006; Campos et al., 1996; Li, 1995; Sigfúsdóttir, Kristjánsson, & Allegrante, 2006; Taras & Potts-Datema, 2005). These results show that an exercise program that delivers 40 min/day of vigorous aerobic exercise results in improved planning abilities among overweight children. This improved executive function may enable children to learn more readily in the short term. It may enable them to better control their behavior in the classroom and other settings. Given that children's brains continue to develop during the school years, it may even promote their ultimate neural development potential and thereby improve their long-term abilities and achievements.

Even before passage of the No Child Left Behind act, only eight percent of elementary schools provided daily physical education classes (Burgeson et al., 2001). Due to the passage of this act, educators are now under increased pressure to elicit high standardized test scores from their pupils. This pressure, along with a common belief that physical education is of less value in education than academic work, has resulted in the reduction or elimination of physical education and recess in many school systems (Allegrante, 2004). Perhaps if children routinely had opportunities for supervised physical activity during and after the school day, they would be better able to learn information presented in their academic classes. If randomized trials show that physical activity promotes cognitive function and academic achievement in school children, school officials and legislators may reconsider their policies. However, the null result obtained with 20 min/day of aerobic exercise suggests that more than an active daily physical education program may be needed to elicit measurable cognitive gains in children. This study presents a challenge to the strategy of devoting all school time to sedentary classwork rather than incorporating a healthy dose of vigorous physical activity during and after school. Rather than the *status quo* of devoting all school time to sedentary classwork, this study suggests that it may be helpful to include a healthy dose of vigorous physical activity.

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Table 1

Cognitive Assessment System, fatness, fitness, and physical activity unadjusted group means (SE) at pre and post, and adjusted means at post

	Control n = 29		Group Low-dose[a] n = 33		High-dose[b] n = 32	
	M	SE	M	SE	M	SE
Cognitive Assessment System scales (Standard scores):						
Planning						
Pre	95.9	2.05	95.9	1.92	100.5	2.29
Post	99.0	2.64	100.2	2.22	108.4	2.00
Adjusted Post	100.1	1.58	101.4	1.47	105.6[c]	1.51
Attention						
Pre	96.1	2.18	97.4	1.90	101.8	2.51
Post	105.7	2.24	104.0	2.04	108.5	2.68
Adjusted Post	107.6	1.55	104.9	1.43	105.8	1.47
Simultaneous						
Pre	101.0	2.56	100.4	2.48	105.6	1.83
Post	103.5	2.27	106.9	1.95	109.4	2.21
Adjusted Post	104.3	1.66	108.0	1.55	107.5	1.58
Successive						
Pre	100.4	2.38	98.7	2.16	101.8	2.18
Post	101.8	1.96	103.6	1.60	106.5	2.14
Adjusted Post	101.9	1.23	104.7	1.15	105.6	1.17
Body mass index z-score[d]						
Pre	2.19	0.08	2.13	0.06	1.98	0.07
Post	2.16	0.08	2.07	0.07	1.91	0.08
Adjusted Post	2.07	0.03	2.03	0.03	2.03	0.03
Treadmill time (sec)[d]						
Pre	452	28	471	33	498	31
Post	432	35	548	35	573	36
Adjusted Post	458	31	555	28	561	28
Vigorous physical activity (d/wk)[d]						

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	Group					
	Control		Low-dose[a]		High-dose[b]	
	n = 29		n = 33		n = 32	
Pre	3.0	0.43	3.6	0.46	3.1	0.39
Post	4.2	0.35	4.6	0.37	4.6	0.40
Adjusted Post	4.2	0.40	4.6	0.37	4.6	0.37
Moderate physical activity (d/wk)[d]						
Pre	1.8	0.41	1.9	0.39	2.0	0.37
Post	1.9	0.35	2.8	0.36	2.9	0.44
Adjusted Post	1.9	0.41	2.8	0.38	2.9	0.38

[a] Low-dose = 20 min/day aerobic exercise

[b] High-dose = 40 min/day aerobic exercise

[c] Differs from control group, $p = 0.01$

[d] Control group $n = 28$ at post

Table 2

Results of ANCOVA examining group effect on posttest Cognitive Assessment System scales, fatness, fitness, and physical activity, adjusting for cohort and pretest scores

Variable	F(2, 88)	Partial η^2	p
Cognitive Assessment System Scales			
Planning	3.56	.08	.03
Attention	0.84	.02	.44
Simultaneous	1.56	.03	.22
Successive	2.56	.06	.08
Fatness, fitness, and physical activity[a]			
Body mass index z-score	0.58	.01	.56
Treadmill time	3.81	.08	.03
Vigorous physical activity	0.29	.01	.75
Moderate physical activity	1.85	.04	.16

[a] df error = 87