NIH Public Access

Author Manuscript

Prev Med. Author manuscript; available in PMC 2012 June 1.

Published in final edited form as:

Prev Med. 2011 June 1; 52(Suppl 1): S65–S69. doi:10.1016/j.ypmed.2011.01.020.

Fitness, fatness, cognition, behavior, and academic achievement among overweight children: Do cross-sectional associations correspond to exercise trial outcomes?

Catherine L. Davis[a,*] and **Stephanie Cooper**[b]

Stephanie Cooper: slcooper@uga.edu

[a]Georgia Prevention Institute, Department of Pediatrics, Medical College of Georgia, Georgia Health Sciences University, 1499 Walton Way, HS1711, Augusta GA 30912, USA

[b]University of Georgia, Department of Kinesiology, 300 River Road, Athens GA 30602, USA

Abstract

Background—This study examined associations of fitness and fatness with cognitive processes, academic achievement, and behavior, independent of demographic factors, at the baseline of an exercise trial.

Methods—Overweight, sedentary but otherwise healthy 7–11 year olds (N=170) participated in a study of health, cognition and achievement in the Augusta, GA area from 2003–2006. Children underwent evaluations of fatness and fitness, psychological assessments of cognition and academic achievement, and behavior ratings by parents and teachers. Partial correlations examined associations of fitness and fatness with cognitive and achievement scores and behavior ratings, controlling for demographic factors.

Results—Fitness was associated with better cognition, achievement and behavior, and fatness with worse scores. Specifically, executive function, mathematics and reading achievement, and parent ratings of child behavior were related to fitness and fatness. Teacher ratings were related to fitness.

Conclusion—These results extend prior studies by providing reliable, standardized measures of cognitive processes, achievement, and behavior in relation to detailed measures of fitness and fatness. However, cross-sectional associations do not necessarily indicate that improving one factor, such as fatness or fitness, will result in improvements in factors that were associated with it. Thus, randomized clinical trials are necessary to determine the effects of interventions.

Keywords

Academic achievement; Adiposity; Behavior; Child; Cognition; Cross-sectional; Fitness; Obesity; Overweight

Introduction

Childhood overweight and obesity is no longer unusual (Ogden et al., 2010). Despite the known benefits of physical activity (Daniels et al., 2005; Freedman et al., 2009), sedentary

*Corresponding author. Fax: +1 706 721 7150. cadavis@georgiahealth.edu (C.L. Davis).

Conflict of interest statement

There is no conflict of interest.

behavior is very common in children (Eaton et al., 2010). An association of overweight with poor academic performance has been shown in several epidemiological, cross-sectional and longitudinal studies (Datar et al., 2004; Dwyer et al., 2001; Shore et al., 2008; Taras and Potts-Datema, 2005; Welk et al., 2010). Aerobic fitness has also been linked with cognition and academic achievement (Aktop, 2010; Buck et al., 2008; Castelli et al., 2007; Cottrell et al., 2007; Dwyer et al., 2001; Eveland-Sayers et al., 2009; Hillman et al., 2009a, 2005; Keeley and Fox, 2009; Shore et al., 2008; Welk et al., 2010; Wittberg et al., 2010). In one large study, fitness predicted achievement more strongly than did overweight (Roberts et al., 2010).

However, most of these studies have relied on BMI as a measure of adiposity, and few used standardized psychological or educational measures. Perhaps as a result, studies have been inconsistent. For example, Gunstad and colleagues found no association between BMI and cognitive function in a large sample of children (Gunstad et al., 2008), despite several studies demonstrating an executive function disadvantage in healthy but overweight adults (Gunstad et al., 2007; Volkow et al., 2009).

Physical activity, fatness, and fitness may influence achievement by affecting on-task classroom behavior. There is some evidence linking physical activity with better classroom behavior (Dwyer et al., 1996; Grieco et al., 2009; Jarrett et al., 1998; Keays and Allison, 1995; Mahar et al., 2006; Siedentop, 2009). Thus, inactivity may detract from on-task behavior. Obesity is more common than expected in children with ADHD, and vice versa (Chen et al., 2010; Cortese et al., 2008; Waring and Lapane, 2008). Becoming obese has been linked with behavior problems in children (Lumeng et al., 2003). Another study showed cross-sectional links in girls, but not boys, and overweight status did not confer risk of developing behavior problems (Datar et al., 2004). There is little information about associations of aerobic fitness with classroom behavior.

The present study in overweight, sedentary children utilized detailed measures of fitness and fatness, and standardized psychological assessments of cognition, achievement, and behavior to quantify the cross-sectional associations among them after control for demographic factors.

Methods

Overweight (BMI-for-age≥85th percentile) and sedentary (≤1 h/week organized physical activity) but otherwise healthy 7–11 year olds (N=170, 56% female, 61% black) provided measures of anthropometry, dual-energy X-ray absorptiometry, and cognition, and parents reported demographic information and behavior ratings of their child at baseline of a randomized clinical trial. For most of these children, a graded treadmill test, MRI scans of abdominal adipose tissue, measures of academic achievement, and teacher ratings of behavior were available (see Table 1). Methods and trial results have been reported (Bassali et al., 2010; Davis and Lambourne, 2009; Davis et al., 2007, in press; Meléndez-Ortega et al., 2010; Petty et al., 2009; Tkacz et al., 2008).

Measures

Primary caregivers provided information on the child’s race, gender, birthdate, health history, and whether the child was enrolled in any regular physical activity program. Education level was self-reported by the child’s primary caregiver using the following scale: 1=less than 7th grade, 2=8th or 9th, 3=10th or 11th, 4=high school graduate, 5=some college, 6=college graduate, and 7=postgraduate.

Anthropometrics

Anthropometrics were measured at least twice until consistent measures were obtained. 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 a BMI z-score (Ogden et al., 2002). Waist circumference was measured in cm with a Gulick fiberglass tape with tension gauge (M-22C, Creative Health Products, Plymouth MI); with the subject standing, feet slightly apart, and abdomen relaxed, a horizontal measure was taken at the narrowest point of the torso above the umbilicus and below the ribcage.

Body fat

Whole-body dual energy X-ray absorptiometry scans were performed (QDR 4500W, Hologic Inc., Bedford, MA). Percent body fat adjusts for body mass (fat mass/total body mass×100).

Visceral and subcutaneous abdominal fat

Visceral abdominal adipose tissue and subcutaneous abdominal adipose tissue volume were quantified in cm^3 via magnetic resonance imaging (five 1 cm transverse slices centered around the L4–L5 disk of the lumbar spine).

Aerobic fitness

Fitness was measured with a graded treadmill test (Modified Balke Protocol for Poorly Fit Children, (American College of Sports Medicine, 2000) preceded by a warm-up (2 min at 2.5 mph, 0% grade; 2 min at 3.0 mph, 3.0% grade). Oxygen uptake was measured with a metabolic cart (Vmax Spectra 29c, SensorMedics, Yorba Linda, CA) and heart rate was recorded with a heart rate monitor which registered values during the last 15 s of each minute (S610i, Polar Electro, Kempele, Finland). 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 standard criteria, or for safety reasons. The indicators of aerobic fitness were peak VO_2 (ml/kg/min) and treadmill time (s), i.e., the duration of each child's treadmill test (Eisenmann et al., 2005). Treadmill time was included in analyses to permit a larger sample than was available for VO_2 measures.

Cognitive and achievement tests

Standardized tests were selected for optimum reliability and clinical interpretability. The Cognitive Assessment System measures children's mental abilities defined on the basis of four interrelated cognitive processes: Planning, Attention, Simultaneous, and Successive (Naglieri and Das, 1997). The Planning scale measures executive function (i.e., strategy generation and application, self-regulation, intentionality, and utilization of knowledge). The Attention scale requires focused, selective cognitive activity and resistance to distraction. The Simultaneous scale taps gestalt processing with spatial and logical questions that contain nonverbal and verbal content. The Successive scale requires analysis or recall of stimuli arranged in sequence, and formation of sounds in order. Children's academic achievement was measured using two interchangeable forms of the Woodcock–Johnson Tests of Achievement III (McGrew and Woodcock, 2001) which were randomly counterbalanced. The Broad Reading and Broad Mathematics clusters were administered. Standard scores are reported.

Behavior ratings

Parent and teacher reports of children's behavior were obtained (Kollins et al., 2004). Classroom behavior was evaluated with the 28-item Conners' Teacher Rating Scales—

Revised: Short (CTRS-R:S) and home behavior with the 27-item Conners' Parent Rating Scales—Revised: Short (CPRS-R:S). These instruments include four subscales: Oppositional Defiance, Cognitive Problems/Inattention, Hyperactivity, and ADHD Index.

Analysis

Partial correlations examined baseline associations of fitness and fatness with cognitive and achievement scores, controlling for race, gender, and primary caregiver's education level. Correlations with the behavior ratings included only race and parental education as covariates because gender was accounted for in the standard scoring method.

Results

After controlling for covariates, fitness measures were positively related to cognition and achievement, and fatness measures negatively related to these outcomes (Table 2). Specifically, the Planning and Attention scales of the CAS, and Broad Math and Broad Reading achievement clusters were related to indices of both fitness and fatness in overweight children. Figure 1 shows partial regression plots illustrating these relations. The Simultaneous scale of the CAS showed relations with fat, but not fitness. The Successive scale was unrelated to fitness or fatness.

For the teacher ratings of children's behavior (CTRS-R:S), only the Cognitive Problems/ Inattention scale showed weak relations with a few health measures. Waist girth was positively related and treadmill time negatively related to cognitive problems. For the parent ratings (CPRS-R:S), the Cognitive Problems/Inattention scale was positively related to several fatness measures and negatively to treadmill time. The ADHD summary scale was positively related to anthropometrics and negatively to treadmill time for the parent, but not the teacher ratings. The Oppositional Defiance and Hyperactivity scales were unrelated to fatness or fitness for both teacher and parent ratings.

Discussion

The present cross-sectional study examined the associations of fitness and fatness with cognition, academic achievement, and behavior in overweight, sedentary children at the baseline of an exercise trial, controlling for demographic factors. Relating fitness with behavior ratings is novel. Fitness was positively related to cognition, achievement, and better behavior, and fatness was negatively related to these outcomes. Specifically, measures of executive function, resistance to distraction, mathematics and reading achievement, and parent ratings of child behavior were related to both fitness and fatness in overweight children. Gestalt processing was related to fatness, but not fitness. Resistance to distraction was more strongly related to fitness than fatness, with only 1 of 5 measures of fatness significantly related. Successive processing was unrelated to fitness or fatness. Fatness was inversely related to cognition, especially executive functioning and gestalt processing, and to both types of achievement. Associations with anthropometric measures were mostly comparable to those with DXA or MRI measures of adiposity, suggesting that simpler anthropometrics are adequate to pick up these relationships, and that special attributes of certain fat depots (e.g. visceral fat vs. subcutaneous) are not important mechanisms for cognition and achievement. These results suggest that children's cognitive ability and school performance may be affected by their general physical condition, and extend prior studies by providing reliable, standardized measures of cognitive processes, behavior, and achievement in relation to detailed measures of both fitness and fatness in a sample including a substantial proportion of minority participants.

These findings are consistent with previous studies, which reported positive associations of fitness (Buck et al., 2008; Castelli et al., 2007; Cottrell et al., 2007; Dwyer et al., 2001; Eveland-Sayers et al., 2009; Hillman et al., 2009a, 2005; Keeley and Fox, 2009; Roberts et al., 2010; Welk et al., 2010; Wittberg et al., 2010) and negative associations of fatness (Castelli et al., 2007; Datar and Sturm, 2004; Datar et al., 2004; Lumeng et al., 2003; Shore et al., 2008; Taras and Potts-Datema, 2005; Welk et al., 2010) with cognition, behavior, and academic achievement. These studies provide support for the hypothesis that physical health coincides with mental health (*mens sana in corpore sano*), and suggest that improving physical health through physical activity might improve mental performance.

Fitness was associated with better teacher ratings of attentiveness, and better parent ratings of attentiveness and ADHD symptoms. Treadmill time was significantly related to behavior ratings while VO_2 was not, despite similar or larger effect sizes, due to a smaller sample size for the more complex physiological measure. Several indices of adiposity were related to worse parent ratings of children's attentiveness and a summary ADHD index. However, these data do not lend support to a link between fatness and poor classroom behavior. Only one measure of fatness, waist girth, was related to a teacher rating subscale. This may be due in part to a larger sample size for parent than for teacher ratings, but effect sizes were also smaller for teacher ratings.

The associations with fatness were slightly larger (though not significantly different, calculations not shown) for mathematics than reading achievement in the present study, suggesting that mathematics achievement might be more vulnerable to deleterious effects of excess adiposity that are independent of aerobic capacity. Every measure of fatness and fitness was related to mathematics achievement. Reading achievement was more strongly related to fitness than fatness. Differing results for mathematics and reading achievement suggest there may be different health mechanisms affecting them. A specific effect on mathematics, but not reading, achievement was observed in the exercise trial with these children (Davis et al., in press). A greater impact on mathematics achievement than other academic subjects was also observed in a trial promoting 90 min/week of brief physical activity bouts as part of the academic curriculum (Donnelly et al., 2009). The consistent strength of impact of physical activity on mathematics achievement in the two trials suggests a particular benefit in this area. In contrast, a trial of enhanced physical education showed a beneficial effect on reading, but not mathematics (Sallis et al., 1999). Future studies may identify the most helpful type of intervention for each academic outcome. For instance, an integrated approach of physical activity with the core academic curriculum may provide more general benefits to academic achievement than aerobic activity in physical education or outside of school (Davis et al., in press; Donnelly et al., 2009; Sallis et al., 1999).

Physical activity is thought to benefit children's cognition and academic achievement (Sallis, 2010), despite a dearth of literature examining associations with physical activity per se (Dwyer et al., 2001; Taras, 2005), and little experimental evidence for effects of physical activity on children's cognition or academic performance (Howie, 2010; Tomporowski et al., 2008). In the cross-sectional literature, fitness is often utilized as a proxy for physical activity (e.g., Buck et al., 2008). This is a reasonable preparatory step to screen hypotheses for possible testing in randomized trials, but because there is substantial genetic influence on fitness and variability in response to physical training (Skinner et al., 2001), fitness and physical activity should not be conflated. Improved aerobic fitness does not appear to be the mechanism driving cognitive benefits of exercise (Etnier et al., 2006). Mechanisms such as vascular and neural growth factors have been identified in animal studies as mediators of exercise benefits to the brain (Dishman et al., 2006).

Cross-sectional associations do not necessarily indicate that improving one factor, such as fatness or fitness, will result in improvements in factors that were associated with it (Keeley and Fox, 2009). For example, a randomized controlled trial with sedentary overweight children (the same one providing the baseline data presented here) demonstrated improvements in executive function and mathematics achievement due to approximately 3 months of regular aerobic exercise. Resistance to distraction, gestalt processing, reading achievement, and parent and teacher behavior ratings were unaffected by the exercise intervention (Davis and Lambourne, 2009; Davis et al., 2007, in press). Thus in the trial, exercise seemed to have only a selective impact, but this differential was not reflected in the cross-sectional associations that we present here, where relations with fatness and fitness were detected for the nonresponsive measures. Another study where cross-sectional associations were more optimistic than trial results is one by Coe et al. (2006). Students who reported engaging in more vigorous physical activity obtained higher grades, but no link with achievement test scores was observed. Unfortunately the longitudinal aspect of the study had null results: physical education enrollment showed no effect on achievement, perhaps because of the small amount of physical activity performed in those classes (Coe et al., 2006). In that study, like the results presented here, common physiological or social factors may have influenced baseline associations, rather than physical activity or fatness *per se* affecting cognition and achievement indices (Cottrell et al., 2007; Trudeau and Shephard, 2010).

Other controlled intervention studies have provided insufficient evidence that physical activity improves student achievement. A small cluster randomized study reported that adding 30 min of physical activity into the academic curriculum three times per week increased fluid intelligence (the ability to reason quickly and abstractly) and improved performance on the state achievement test in social studies; English/language arts, mathematics and science scores were not affected (Reed et al., 2010). However, no baseline evaluations were available, and the study was confounded by a greater prevalence of overweight in the control group that may explain their poorer cognitive scores. Another recent study (Hillman et al., 2009b) showed a beneficial effect of an acute bout of moderate physical activity vs. rest on children’s academic achievement test results, and counterbalanced the order of sessions within subjects in order to provide a control condition. Performance on a reading achievement test improved after activity; mathematics and spelling performance were unaffected. The qualifications of the achievement test user were unclear. The effects of an acute bout of activity on test results obtained later the same day imply that children perform better when they engage in physical activity just prior to a task, not that regular physical activity benefits learning. Therefore, the conclusion that regular physical activity improves academic achievement remains tentative based on the existing literature.

It is important to demonstrate effectiveness in well-designed randomized trials (Moher et al., 2010) before investing substantial societal resources in a novel strategy such as physical activity, rather than traditional instruction, in order to improve academic performance. On the other hand, the salutary effects of regular physical activity (Strong et al., 2005), along with a good safety profile compared to long-term sedentariness, argue for implementing vigorous physical activity programs for children before overwhelming experimental evidence is available (Hill, 1965). For instance, it is reasonable to make supervised physical activity programs available to children of Native American descent, though the academic benefits of exercise have not yet been experimentally demonstrated in this group. An intriguing possibility is that ethnic differences in fatness and fitness may underlie academic disparities (Roberts et al., 2010). Thus, health promotion efforts to address the childhood obesity epidemic may yield dividends in academic and social domains.

Acknowledgments

This work was supported by NIH R01s DK60692 and DK70922. The authors would like to acknowledge Jerry Allison, Colleen Boyle, Catrina Creech, Mathew Gregoski, Bernard Gutin, Amanda McDougald, Joseph Tkacz, Phillip Tomporowski and other team members for their assistance, and especially the children and families who made the study possible.

References

Aktop A. Socioeconomic status, physical fitness, self-concept, attitude toward physical education, and academic achievement of children. Percept Mot Skills. 2010; 110:531–546. [PubMed: 20499564]

American College of Sports Medicine. ACSM’s Guidelines for Exercise Testing and Prescription. 6. Lippincott Williams & Wilkins; Baltimore: 2000.

Bassali R, Waller JL, Gower B, Allison J, Davis CL. Utility of waist circumference percentile for risk evaluation in obese children. Int J Pediatr Obes. 2010; 5:97–101. [PubMed: 19606372]

Buck SM, Hillman CH, Castelli DM. The relation of aerobic fitness to Stroop task performance in preadolescent children. Med Sci Sports Exerc. 2008; 40:166–172. [PubMed: 18091008]

Castelli DM, Hillman CH, Buck SM, Erwin HE. Physical fitness and academic achievement in third- and fifth-grade students. J Sport Exerc Psychol. 2007; 29:239–252. [PubMed: 17568069]

Chen AY, Kim SE, Houtrow AJ, Newacheck PW. Prevalence of obesity among children with chronic conditions. Obesity (Silver Spring). 2010; 18:210–213. [PubMed: 19521350]

Coe DP, Pivarnik JM, Womack CJ, Reeves MJ, Malina RM. Effect of physical education and activity levels on academic achievement in children. Med Sci Sports Exerc. 2006; 38:1515–1519. [PubMed: 16888468]

Cortese S, Angriman M, Maffeis C, Isnard P, Konofal E, Lecendreux M, Purper-Ouakil D, Vincenzi B, Bernardina BD, Mouren MC. Attention-deficit/hyperactivity disorder (ADHD) and obesity: a systematic review of the literature. Crit Rev Food Sci Nutr. 2008; 48:524–537. [PubMed: 18568858]

Cottrell LA, Northrup K, Wittberg R. The extended relationship between child cardiovascular risks and academic performance measures. Obesity (Silver Spring). 2007; 15:3170–3177. [PubMed: 18198328]

Daniels SR, Arnett DK, Eckel RH, Gidding SS, Hayman LL, Kumanyika S, Robinson TN, Scott BJ, St Jeor S, Williams CL. Overweight in children and adolescents: pathophysiology, consequences, prevention, and treatment. Circulation. 2005; 111:1999–2012. [PubMed: 15837955]

Datar A, Sturm R. Childhood overweight and parent- and teacher-reported behavior problems: evidence from a prospective study of kindergartners. Arch Pediatr Adolesc Med. 2004; 158:804–810. [PubMed: 15289255]

Datar A, Sturm R, Magnabosco JL. Childhood overweight and academic performance: national study of kindergartners and first-graders. Obes Res. 2004; 12:58–68. [PubMed: 14742843]

Davis, CL.; Lambourne, K. Exercise and cognition in children. In: McMorris, T.; Audiffren, M.; Tomporowski, PD., editors. Exercise and Cognitive Function. Wiley and Son; Hoboken, NJ: 2009. p. 249-267.

Davis CL, Tomporowski PD, Boyle CA, Waller JL, Miller PH, Naglieri JA, Gregoski M. Effects of aerobic exercise on overweight children’s cognitive functioning: a randomized controlled trial. Res Q Exerc Sport. 2007; 78:510–519. [PubMed: 18274222]

Davis CL, Tomporowski PD, McDowell JE, Austin BP, Miller PH, Yanasak N, Allison J, Naglieri JA. Exercise improves executive function and achievement and alters brain activation in overweight children: a randomized controlled trial. Health Psychol. in press. NIHMS 245691.

Dishman RK, Berthoud HR, Booth FW, Cotman CW, Edgerton VR, Fleshner MR, Gandevia SC, Gomez-Pinilla F, Greenwood BN, Hillman CH, Kramer AF, Levin BE, Moran TH, Russo-Neustadt AA, Salamone JD, Van Hoomissen JD, Wade CE, York DA, Zigmond MJ. Neurobiology of exercise. Obesity (Silver Spring). 2006; 14:345–356. [PubMed: 16648603]

Donnelly JE, Greene JL, Gibson CA, Smith BK, Washburn RA, Sullivan DK, DuBose K, Mayo MS, Schmelzle H, Ryan JJ, Jacobsen DJ, Williams SL. Physical Activity Across the Curriculum

(PAAC): a randomized controlled trial to promote physical activity and diminish overweight and obesity in elementary school children. Prev Med. 2009; 49:336–341. [PubMed: 19665037]

Dwyer T, Blizzard L, Dean K. Physical activity and performance in children. Nutr Rev. 1996; 54:S27–S31. [PubMed: 8700449]

Dwyer T, Sallis JF, Blizzard L, Lazarus R, Dean K. Relation of academic performance to physical activity and fitness in children. Pediatr Exerc Sci. 2001; 13:225–237.

Eaton DK, Kann L, Kinchen S, Shanklin S, Ross J, Hawkins J, Harris WA, Lowry R, McManus T, Chyen D, Lim C, Whittle L, Brener ND, Wechsler H. Youth risk behavior surveillance — United States, 2009. MMWR Surveill Summ. 2010; 59:1–142. [PubMed: 20520591]

Eisenmann JC, Wickel EE, Welk GJ, Blair SN. Relationship between adolescent fitness and fatness and cardiovascular disease risk factors in adulthood: the Aerobics Center Longitudinal Study. Am Heart J. 2005; 149:46–53. [PubMed: 15660033]

Etnier JL, Nowell PM, Landers DM, Sibley BA. A meta-regression to examine the relationship between aerobic fitness and cognitive performance. Brain Res Brain Res Rev. 2006; 52:119–130.

Eveland-Sayers BM, Farley RS, Fuller DK, Morgan DW, Caputo JL. Physicalfitness and academic achievement in elementary school children. J Phys Act Health. 2009; 6:99–104. [PubMed: 19211963]

Freedman DS, Katzmarzyk PT, Dietz WH, Srinivasan SR, Berenson GS. Relation of body mass index and skinfold thicknesses to cardiovascular disease risk factors in children: the Bogalusa Heart Study. Am J Clin Nutr. 2009; 90:210–216. [PubMed: 19420092]

Grieco LA, Jowers E, Bartholomew JB. Physically active academic lessons and time on task: the moderating effect of body mass index. Med Sci Sports Exerc. 2009; 41:1921–1926. [PubMed: 19727020]

Gunstad J, Paul RH, Cohen RA, Tate DF, Spitznagel MB, Gordon E. Elevated body mass index is associated with executive dysfunction in otherwise healthy adults. Compr Psychiatry. 2007; 48:57–61. [PubMed: 17145283]

Gunstad J, Spitznagel MB, Paul RH, Cohen RA, Kohn M, Luyster FS, Clark R, Williams LM, Gordon E. Body mass index and neuropsychological function in healthy children and adolescents. Appetite. 2008; 50:246–251. [PubMed: 17761359]

Hill AB. The environment and disease: association or causation? Proc R Soc Med. 1965; 58:295–300. [PubMed: 14283879]

Hillman CH, Castelli DM, Buck SM. Aerobic fitness and neurocognitive function in healthy preadolescent children. Med Sci Sports Exerc. 2005; 37:1967–1974. [PubMed: 16286868]

Hillman CH, Buck SM, Themanson JR, Pontifex MB, Castelli DM. Aerobic fitness andcognitive development: event-related brainpotential andtask performance indices of executive control in preadolescent children. Dev Psychol. 2009a; 45:114–129. [PubMed: 19209995]

Hillman CH, Pontifex MB, Raine LB, Castelli DM, Hall EE, Kramer AF. The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. Neuroscience. 2009b; 159:1044–1054. [PubMed: 19356688]

Howie EK. Physical activity and academics. J Pediatr. 2010; 157:867–868. (author reply 868–869). [PubMed: 20801460]

Jarrett OS, Maxwell DM, Dickerson C, Hoge P, Davies G, Yetley A. The impact of recess on classroom behavior: group effects and individual differences. J Educ Res. 1998; 92:121–126.

Keays JJ, Allison KR. The effects of regular moderate to vigorous physical activity on student outcomes. Can J Public Health. 1995; 86:62–65. [PubMed: 7728720]

Keeley TJH, Fox KR. The impact of physical activity and fitness on academic achievement and cognitive performance in children. Int Rev Sport Exerc Psychol. 2009; 2:198–214.

Kollins, SH.; Epstein, JN.; Conners, CK. Conners rating scale — revised. In: Maruish, ME., editor. The Use of Psychological Testing for Treatment Planning and Outcomes Assessment. 3. Lawrence Erlbaum Associates; Mahwah, NJ: 2004. p. 215-233.

Lumeng JC, Gannon K, Cabral HJ, Frank DA, Zuckerman B. Association between clinically meaningful behavior problems and overweight in children. Pediatrics. 2003; 112:1138–1145. [PubMed: 14595059]

Mahar MT, Murphy SK, Rowe DA, Golden J, Shields AT, Raedeke TD. Effects of a classroom-based program on physical activity and on-task behavior. Med Sci Sports Exerc. 2006; 38:2086–2094. [PubMed: 17146314]

McGrew, KS.; Woodcock, RW. Woodcock–Johnson III: Technical Manual. Riverside Publishing; Itasca, IL: 2001.

Meléndez-Ortega A, Davis CL, Barbeau P, Boyle CA. Oxygen uptake of overweight and obese children at different stages of a progressive treadmill test. Rev Int Cienc Deporte [Int J Sport Sci]. 2010; 18:74–90.

Moher D, Hopewell S, Schulz KF, Montori V, Gotzsche PC, Devereaux PJ, Elbourne D, Egger M, Altman DG. CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. BMJ. 2010; 340:c869. [PubMed: 20332511]

Naglieri, JA.; Das, JP. Cognitive Assessment System: Interpretive Handbook. Riverside Publishing; Itasca, IL: 1997.

Ogden CL, Kuczmarski RJ, Flegal KM, Mei Z, Guo S, Wei R, Grummer-Strawn LM, Curtin LR, Roche AF, Johnson CL. Centers for Disease Control and Prevention 2000 growth charts for the United States: improvements to the 1977 National Center for Health Statistics version. Pediatrics. 2002; 109:45–60. [PubMed: 11773541]

Ogden CL, Carroll MD, Curtin LR, Lamb MM, Flegal KM. Prevalence of high body mass index in US children and adolescents, 2007–2008. JAMA. 2010; 303:242–249. [PubMed: 20071470]

Petty KH, Davis CL, Tkacz J, Young-Hyman D, Waller JL. Exercise effects on depressive symptoms and self-worth in overweight children: a randomized controlled trial. J Pediatr Psychol. 2009; 34:929–939. [PubMed: 19223278]

Reed JA, Einstein G, Hahn E, Hooker SP, Gross VP, Kravitz J. Examining the impact of integrating physical activity on fluid intelligence and academic performance in an elementary school setting: a preliminary investigation. J Phys Act Health. 2010; 7:343–351. [PubMed: 20551490]

Roberts CK, Freed B, McCarthy WJ. Low aerobic fitness and obesity are associated with lower standardized test scores in children. J Pediatr. 2010; 156(5):711–718. 718.e1. [PubMed: 20097353]

Sallis JF. We do not have to sacrifice children's health to achieve academic goals. J Pediatr. 2010; 156:696–697. [PubMed: 20304427]

Sallis JF, McKenzie TL, Kolody B, Lewis M, Marshall S, Rosengard P. Effects of health-related physical education on academic achievement: Project SPARK. Res Q Exerc Sport. 1999; 70:127–134. [PubMed: 10380244]

Shore SM, Sachs ML, Lidicker JR, Brett SN, Wright AR, Libonati JR. Decreased scholastic achievement in overweight middle school students. Obesity (Silver Spring). 2008; 16:1535–1538. [PubMed: 18451772]

Siedentop DL. National plan for physical activity: education sector. J Phys Act Health. 2009; 6 (Suppl 2):S168–S180. [PubMed: 20120126]

Skinner JS, Jaskolski A, Jaskolska A, Krasnoff J, Gagnon J, Leon AS, Rao DC, Wilmore JH, Bouchard C. Age, sex, race, initial fitness, and response to training: the HERITAGE Family Study. J Appl Physiol. 2001; 90:1770–1776. [PubMed: 11299267]

Strong WB, Malina RM, Blimkie CJ, Daniels SR, Dishman RK, Gutin B, Hergenroeder AC, Must A, Nixon PA, Pivarnik JM, Rowland T, Trost S, Trudeau F. Evidence based physical activity for school-age youth. J Pediatr. 2005; 146:732–737. [PubMed: 15973308]

Taras H. Physical activity and student performance at school. J Sch Health. 2005; 75:214–218. [PubMed: 16014127]

Taras H, Potts-Datema W. Obesity and student performance at school. J Sch Health. 2005; 75:291–295. [PubMed: 16179079]

Tkacz J, Young-Hyman D, Boyle CA, Davis CL. Aerobic exercise program reduces anger expression among overweight children. Pediatr Exerc Sci. 2008; 20:390–401. [PubMed: 19168916]

Tomporowski PD, Davis CL, Miller PH, Naglieri J. Exercise and children's intelligence, cognition, and academic achievement. Educ Psychol Rev. 2008; 20:111–131. [PubMed: 19777141]

Trudeau F, Shephard RJ. Relationships of physical activity to brain health and the academic performance of schoolchildren. Am J Lifestyle Med. 2010; 4:138–150.

Volkow ND, Wang GJ, Telang F, Fowler JS, Goldstein RZ, Alia-Klein N, Logan J, Wong C, Thanos PK, Ma Y, Pradhan K. Inverse association between BMI and prefrontal metabolic activity in healthy adults. Obesity (Silver Spring). 2009; 17:60–65. [PubMed: 18948965]

Waring ME, Lapane KL. Overweight in children and adolescents in relation to attention-deficit/hyperactivity disorder: results from a national sample. Pediatrics. 2008; 122:e1–e6. [PubMed: 18595954]

Welk GJ, Jackson AW, Morrow JR Jr, Haskell WH, Meredith MD, Cooper KH. The association of health-related fitness with indicators of academic performance in Texas schools. Res Q Exerc Sport. 2010; 81:S16–S23. [PubMed: 21049834]

Wittberg R, Cottrell LA, Davis CL, Northrup K. Aerobic fitness thresholds associated with fifth grade academic achievement. Am J Health Educ. 2010; 41:284–291.

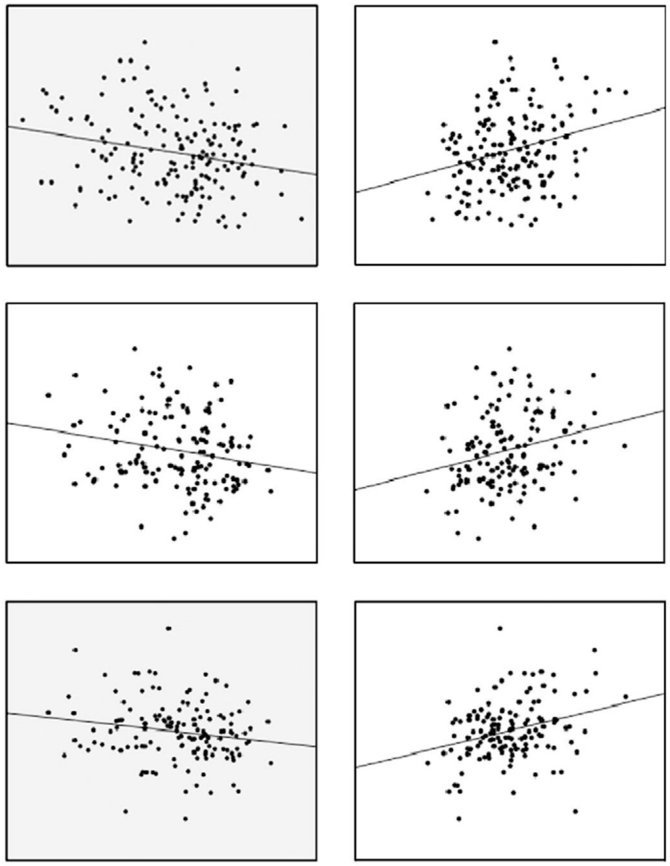

Fig. 1.
Partial regression plots of adiposity (body fat percentage, x-axis) with Planning, Broad Math, and Broad Reading (y-axes in descending order). Points represent residuals of each variable adjusted for race, gender, and parent education (Augusta, GA area, 2003–2006). Partial regression plots of aerobic fitness (peak VO_2, x-axis) with Planning, Broad Math, and Broad Reading (y-axes in descending order). Points represent residuals of each variable adjusted for race, gender, and parent education (Augusta, GA area, 2003–2006).

Table 1

Characteristics of the sample (Augusta, GA area, 2003–2006).

	n	Mean	(SD)
Age (years)	170	9.3	(1.0)
Parent education	170	5.0	(1.1)
BMI z-score	170	2.08	(0.43)
Waist girth (cm)	170	76.7	(10.0)
Body fat (%)	170	40.0	(6.4)
Visceral fat (cm^3)	162	31.6	(16.2)
Subcutaneous abdominal fat (cm^3)	162	271.7	(92.2)
VO_2 peak (ml/kg/min)	161	27.8	(5.6)
Treadmill time (s)	168	460	(199)
Cognitive Assessment System	170		
Planning		99.6	(12.3)
Attention		97.9	(12.2)
Simultaneous		102.8	(12.5)
Successive		100.6	(12.1)
Woodcock–Johnson Tests of Achievement III	140		
Broad Math		104.4	(11.9)
Broad Reading		100.3	(10.9)
Conners' Teacher Rating Scale	145		
Oppositional Defiance		51.7	(9.6)
Cognitive Problems/Inattention		53.2	(10.5)
Hyperactivity		51.9	(9.1)
ADHD Index		53.9	(11.5)
Conners' Parent Rating Scale	170		
Oppositional Defiance		49.2	(9.1)
Cognitive Problems/Inattention		53.1	(11.0)
Hyperactivity		53.4	(10.0)
ADHD Index		53.7	(10.0)

Table 2

Partial correlations among cognitive, achievement, behavior, fatness, and fitness measures (Augusta, GA area, 2003–2006).

	BMI z-score	Waist girth	Body fat	Visceral fat	Subcutaneous abdominal fat	Peak VO_2	Treadmill time
Cognitive Assessment System							
Planning	−0.14	−0.16*	−0.22**	−0.19*	−0.19*	0.26**	0.23**
Attention	−0.11	−0.11	−0.16*	−0.10	−0.13	0.22**	0.24**
Simultaneous	−0.19*	−0.25**	−0.15	−0.18*	−0.24**	0.15	0.14
Successive	−0.11	−0.14	−0.11	−0.13	−0.13	−0.02	0.01
Woodcock–Johnson Tests of Achievement III							
Broad Math	−0.23**	−0.28**	−0.23**	−0.20*	−0.31***	0.25**	0.21*
Broad Reading	−0.20*	−0.21*	−0.20*	−0.17	−0.22*	0.29**	0.28**
Conners' Teacher Rating Scale							
Oppositional Defiance	−0.03	−0.02	−0.06	−0.07	−0.02	0.06	0.11
Cognitive Problems/Inattention	0.13	0.16*	0.11	0.07	0.16	−0.18	−0.18*
Hyperactivity	−0.04	0.01	−0.03	−0.02	−0.02	−0.02	0.01
ADHD Index	0.04	0.08	0.06	0.00	0.14	−0.14	−0.10
Conners' Parent Rating Scale							
Oppositional Defiance	0.07	0.13	0.06	0.09	0.10	0.01	0.00
Cognitive Problems/Inattention	0.16*	0.19**	0.14	0.14	0.17*	−0.25	−0.20**
Hyperactivity	0.07	0.11	−0.02	0.04	0.09	−0.08	−0.01
ADHD Index	0.15*	0.16*	0.15*	0.15	0.07	−0.26	−0.21**

Note. The number of subjects per analysis varied from 170 (CAS and anthropometrics) to 132 (VO_2 and achievement scores) due to missing data. Correlations with the Cognitive Assessment System and Woodcock–Johnson Tests of Achievement III were partialled for race, gender, and parental education. Correlations with the Conners' Rating Scales were partialled for race and parental education.

* $p<.05$.

** $p<.01$.

*** $p<.001$.