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Classroom-based physical activity, cognition, and academic achievement

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ABSTRACT

Background. There is increasing evidence for the association between physical activity, cardiovascular fitness, fatness, and cognitive function during childhood and adolescence. Evidence also suggests that these variables are linked to academic achievement. Classroom-based physical activity provides a viable approach to improve fitness, body mass index (BMI), cognitive function, and ultimately academic achievement.

Methods. Studies examining the relation between physical activity, fitness, fatness, cognitive function, and academic achievement are described. The results of a large-scale, longitudinal, cluster randomized trial to examine the impact of classroom based physical activity on body mass index and academic achievement will be presented.

Results. Overall, the data support the link between physical activity, cognitive function, and academic achievement. The role of physical activity in the classroom was also supported by the Physical Activity Across the Curriculum (PAAC) project. Physically active academic lessons of moderate intensity improved overall performance on a standardized test of academic achievement by 6% compared to a decrease of 1% for controls ($p<0.02$). Body mass index increased less from baseline to 3 years in students with greater than 75 minutes of PAAC lessons per week (1.8 BMI) compared to students with less than 75 minutes of PAAC per week (2.4 BMI), $p<0.00$.

Conclusions. Future research examining the effects of physically active academic instruction is warranted. The impact of physically active academic lessons of greater intensity may provide larger benefits for body mass index and academic achievement.

Introduction

Physical activity in public schools has steadily declined since the 1970s. During this time, the percentage of children who are overweight has more than doubled, and the rates among adolescents have more than tripled (Hedley et al., 2004). Recent estimates indicate that 25% of children in the US are overweight and 11% are obese (Dehghan, 2005). In parallel fashion, co-morbidities formerly only seen in adults have emerged in children including type 2 diabetes, elevated blood pressure, triglycerides, and low HDL-cholesterol. Metabolic syndrome has been estimated to be at 5% in elementary school children and this percentage increases to 12% and 20% in minority and overweight children, respectively (DuBose et al., 2006), though more data is needed to verify these percentages. It is likely that decreased physical activity is a major factor in the drastic increase in obesity rates, and one third of male and female adolescents fail to meet recommended standards for cardiorespiratory fitness (Pate et al., 2006). Both fitness and fatness appear to be associated with cognitive function (Li et al., 2008; Roberts et al., 2010; Yu, 2010) and academic achievement (Datar et al., 2004; Shore et al., 2008) in children.

Many researchers have made attempts to target child obesity by designing interventions that can be utilized in the public school system. Children are accessible in this setting because the majority of children in the United States spend most of their day at school. However it should be noted that schools promote a sedentary lifestyle. Children spend between 6 and 8 h in academic instruction per day. Paradoxically, physical education classes may detract from physical activity, as children spend less than half of this time engaged in moderate to vigorous physical activity (Levin et al., 2001). The association between physical activity, fitness, fatness and academic achievement (see Fig. 1) provides a unique opportunity to intervene and provide programs that both improve health and academic performance. This review will present evidence for the association of physical activity, fitness, fatness, and academic achievement and describe an intervention designed to increase physical activity in the classroom and in turn impact these variables. The Physical Activity Across the Curriculum (PAAC) project

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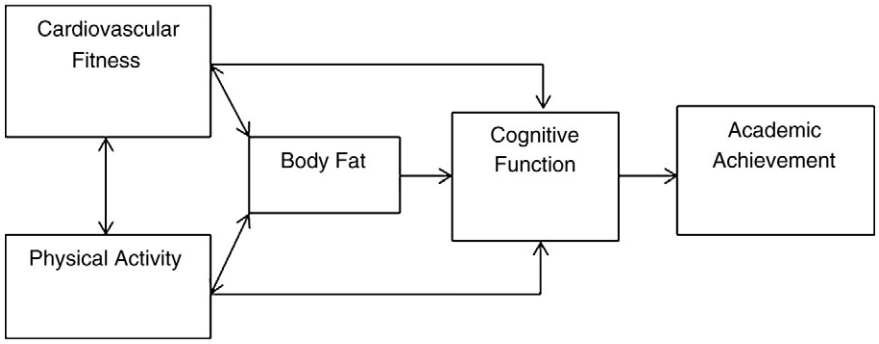

Fig. 1. Model of factors associated with improved academic achievement.

was a 3-year, NIH funded (RO1 061489) intervention that evaluated the impact of physically active academic lessons on BMI and academic achievement (Donnelly et al., 2009).

Cardiovascular fitness, cognitive function, and academic achievement

In a similar fashion as the adult population, researchers have found cross-sectional associations between levels of cardiovascular fitness and cognitive function in children. Hillman and colleagues have shown associations between cardiovascular fitness (Hillman et al., 2005; C. Hillman et al., 2009; C.H. Hillman et al., 2009) and single acute bouts of moderate aerobic exercise (C. Hillman et al., 2009; C.H. Hillman et al., 2009) and cognitive function. Children who are fit perform better on attentional tasks that require greater amounts of cognitive control. This includes a subset of goal directed, self-regulatory processes that include planning, organization, abstract problem-solving, working memory, motor control, and inhibitory control. Castelli et al. (2007) assessed the cross-sectional association between CV fitness (Fitnessgram–PACER) and academic achievement (Illinois State Achievement Test) in 259, 3rd through 5th grade students. There was a positive association between CV fitness and total achievement score ($r = 0.48$), math score ($r = 0.49$) and reading score ($r = 0.45$). Similarly, significant associations between fitness scores and state-wide academic achievement tests in Texas were recently reported by Welk (2010).

A meta-analysis conducted by Sibley and Etnier (2003) suggested that physical activity may be related to cognitive function during development. A positive association was found between physical activity and cognitive function including perceptual skills, intelligence quotient, academic achievement, verbal tests, mathematics tests, developmental level, and academic readiness in school-age children (age 4–18 years). Of the 44 studies included in this review, only nine used a randomized design. For example, in an early study by Ismail (1968), 10–12 year old children were randomized to a normal or "enhanced" physical education program. The author reported increased performance on the Stanford Academic Achievement Test for the students in the enhanced program. McCormick et al. (1968) showed improved reading scores in elementary school children randomized to a 7 week, 2 day/week program of physical education when compared to children randomized to a perceptual-motor training group and a control group.

More recent reviews (Trudeau and Shephard, 2008; Tomporowski et al., 2008) have identified two additional randomized trials of the relation between physical education and academic achievement. Coe et al. (2006) randomly assigned 214 sixth grade students to physical education either during their first or second semester. Academic achievement was assessed from 4 core academic courses (math, science, English, world studies) and a standardized test (Terra Nova). Physical activity outside of school was assessed by 3-day recall. No impact of physical activity on standardized test scores was observed. However, students with higher levels of vigorous physical activity outside of school had significantly higher grades ($p<0.05$) than those who reported no vigorous physical activity. Ahamed et al. (2007) conducted a 16 month cluster randomized trial in 8 elementary schools (6 intervention, 2 usual practice). The goal of the intervention was to provide 150 min/week of physical activity (actual = 139 min/week) by increasing physical activity in several different environments (home, school, etc.). Outcome measures included the amount of leisure time physical activity and academic achievement. Leisure time physical activity was assessed by 7-day self-report administered 5 times across the intervention, and academic achievement was assessed by a standardized test (Canadian achievement test — CAT-3). There was no difference in leisure time physical activity between the intervention and control groups. Furthermore, academic achievement over one academic year did not change as a result of increased physical activity. While the 10 min of additional daily physical activity did not appear to be sufficient in improving academic achievement, the authors noted that dedicating this time to daily physical activity did not compromise children's academic performance.

Overall, the results from cross-sectional studies support the relation between physical activity and academic achievement in elementary school children (for additional discussion of the cross-sectional association between physical activity and academic achievement, please see Davis and Cooper, this issue). However, the results from the few available randomized and non-randomized prospective studies are mixed. This may be partially explained by the limited descriptions of intervention fidelity provided in the older studies, as well as the use of non-standardized tests of academic achievement and limited assessments of daily physical activity and cardiovascular fitness. More recent evidence from a randomized controlled trial (Davis et al., 2007, in press) with highly controlled exercise intervention and a standardized achievement test indicated that physical activity interventions may have selective effects on children's cognition. Aerobic exercise training improved executive function in overweight children between the ages of 7 and 11 years. Scores on the Planning scale of the Cognitive Assessment System (CAS) were significantly higher for the children who performed 40 min of aerobic exercise 5 times per week compared to a control group. The Planning scale of the CAS reflects the ability to organize and control goal-directed actions and is linked to academic achievement. Similar to adults, increasing physical activity in children may produce the greatest improvements in complex mental processing known as executive function, which includes the ability to achieve goal-directed behavior, self-monitoring, and self-control.

Body fat and cognitive function

Like fitness, fatness may also be associated with cognitive function and academic achievement. Li et al. (2008) reported findings from 2519 children aged 8–16 who completed a neuropsychological battery and measures of height and weight as part of NHANES III. Visuospatial organization and general mental ability were negatively associated with increased body weight. Taras and Potts-Datema (2005) reviewed 7 studies (4 cross-sectional–3 non-randomized prospective) on the

association of BMI and academic achievement. Assessment methods for BMI (self-report vs. measured) and academic achievement (standardized tests, school grades, failure to progress in school) were variable across studies. Results for 6 of 7 studies indicated higher BMI was associated with lower academic achievement. Roberts et al. (2010) reported on 1989 ethnically diverse 5th, 7th, and 9th graders who completed a 1-mile walk/run fitness test, BMI, and California standardized academic achievement tests. Children who exceeded CDC sex and age specific BMI standards scored lower for math, reading, and language tests compared to students with desirable BMI status even after controlling for parent education. In a cross-sectional sample of 6346 adolescents (age 14–15 years), Kristjansson et al. (2008) showed a negative association between self-reported BMI and academic achievement. On balance, Gunstad et al. (2008) found no relation between BMI and cognitive test performance in a sample of 478 children and adolescents. The authors suggested that the relation between BMI and cognitive function differed from that of adults because elevated BMI was not associated with cognitive performance in healthy children and adolescents.

There is some evidence that the association between BMI and academic achievement is confounded by participant characteristics and psychosocial variables. For example, Datar et al. (2004) observed an association between overweight status (BMI greater than the 95th percentile) and academic achievement measured by standardized tests of reading and math in a sample of 11,192 kindergarteners. Achievement scores were significantly lower in overweight compared with non-overweight children. However, this association was no longer significant after adjustment for race/ethnicity and socioeconomic status. Psychosocial variables have also been shown to influence the relation between BMI and academic achievement. Krukowski et al. (2009) showed that weight-based teasing mediated the relation between weight category and school performance. Crosnoe and Muller (2004) showed that the association between elevated BMI and decreased academic achievement was dependent on the extent to which obesity was stigmatized in the school.

Practical application: impacting fitness, fatness and academic achievement in elementary school children

The relation between fitness, fatness, and academic achievement provides a unique opportunity to use physical activity as an intervention that may impact the health and academic achievement of children simultaneously. Although it may be intuitive to consider physical education class as the logical target for increased physical activity, time allocated to physical education has steadily declined and teachers are often faced with overcrowded conditions and limited equipment. This often results in little time actually spent in physical activity during physical education (Simons-Morton et al., 1994). The evidence for significant increases in academic achievement in response to increases in physical activity during physical education class is not convincing (Ahamed et al., 2007; Carlson et al., 2008). However, several studies (Coe et al., 2006; Dwyer et al., 2001; Sallis et al., 1999) have indicated that increased time devoted to physical education does not decrease academic achievement. In addition, physical education in elementary school is generally restricted to 2 or 3 days/week for 30 min duration (National Center for Education Statistics, 2005). Thus, if physical activity is to be increased in elementary schools, venues other than physical education need to be developed and evaluated.

An alternative to physical education for increased physical activity is the regular classroom where students spend the majority of their time. The classroom may be the ideal setting to combine physical activity with academic instruction. If regular classroom teachers provided physically active academic lessons, this may impact fitness and fatness while preserving the time allotted to academic instruction. In turn, improvements for cognitive function and academic achievement will likely follow. (See Kibbe et al., this issue, for additional discussion of the role of classroom based physical activity in academic achievement).

Practicality of classroom-based physical activity

Classroom-based physical activity generally takes the form of short breaks from academic instruction where some type of physical activity occurs. Classroom physical activity is either linked to an established curriculum (Stewart et al., 2004) or physical activity is coupled with the teachers' existing lessons (Donnelly et al., 2009). Evidence suggests that physical activity breaks improve classroom behavior such as increased time-on-task (Gabbard and Barton, 1979; Jarrett et al., 1998; Barros et al., 2009; Mahar et al., 2006), reduced fidgeting (Jarrett et al., 1998) and better concentration (McNaughten and Gabbard, 1993). Attention-to-task has recently been shown to improve in response to intermittent PA in elementary school children (Mahar et al., 2006). Attention-to-task is fundamental to learning (Manly et al., 2001) and impacts other components of classroom management such as discipline.

It is challenging to provide activities that do not require reconfiguration of the classroom yet provide adequate intensity and energy expenditure to impact fitness and fatness. Furthermore, Howe et al. (2010) note the importance of precisely estimating the energy expenditure of physical activity interventions for children if we are to successfully target excessive weight gain. For these reasons, Honas et al. (2008) used portable indirect calorimetry to measure the energy expenditure of classroom physical activity in 38 elementary school children. Results indicated average values for classroom physical activity were 3.1 ± 1.0 kcal min^{-1} (3.4 METS). According to the guidelines set forth by the Department of Health and Human Services (2008), moderate intensity physical activity is between 3 and 6 METS; therefore, the activities measured by Honas et al. (2008) would be at the lower level of moderate to vigorous. The energy expenditure of classroom physical activity is rarely measured and this makes it difficult to evaluate the potential of the intervention to impact fitness and fatness. Likewise, it makes it difficult to conclude what exercise dose is required to impact cognitive function and academic achievement.

Effectiveness of classroom-based physical activity

Donnelly and colleagues completed a 3-year cluster randomized, controlled trial of 24 elementary schools to compare changes in fitness and fatness with changes in academic achievement in schools that received PAAC (N = 14) or served as controls (N = 10). Examples of a traditional academic class environment and a PAAC classroom are provided in Fig. 2. PAAC promoted 90 min/week of moderate to vigorous physically active academic lessons (3.0 to 6.0 METS, ~10 min each) delivered intermittently throughout the school day. Lessons were usually delivered in the classroom, but were also delivered in alternate school sites such as hallways and outdoors.

PAAC lessons were used in a variety of academic areas including math, language arts, geography, history, spelling, science, and health. As an example, a math lesson may consist of learning fractions by dividing the classroom into designated sections and asking the students to solve a problem by running and placing themselves in a section so that the correct answer is demonstrated by the number of students per section. In this scenario, if the teacher indicated the fraction of 2/5ths, students would run to spaces designated for either 2 or 5 students. Another math example might be students hop and skip across the room and count their own "laps" as well as add laps of groups of children (i.e. 5 children × 5 laps each = 25). Geometry may be taught by having the students form different shapes such as squares or triangles while walking or skipping on an outside playfield. Geography (north, south, east, west) can be taught by having children run to the appropriate area designated for one of the directions. For example, if Texas is called, students will run or skip to the south space.

Fig. 2. Example of a sedentary classroom versus a PAAC classroom.

A floor mat with alphabet letters printed on it could be used to teach spelling, where the children spell out words by hopping onto the letters (see Fig. 3). The scope of physically active lessons is virtually limitless.

The conceptual framework for PAAC includes no additional teacher preparation time, use of existing academic lessons, no additional costs, and lessons that are fun for both student and teacher. Additionally, PAAC promoted the concept that physical activity can occur at many times and places without the need to report to a special place (gymnasium) and change into special clothes (gym clothes). Participants were 665 boys and 677 girls initially in grades 2 and 3 and who progressed to grades 4 and 5. Participants were 77.4% Caucasian, 6.2% African American, 10.1% Hispanic, 1.6% Native American, 1.2% Asian, and 3.6% multi-ethnic. Forty three percent of the participants qualified for free or reduced lunch.

The primary outcome for PAAC was change in BMI from year 1 to year 3. Secondary outcomes were measured in a sub-sample of 191 boys and 261 girls and included fitness, blood chemistry, blood pressure, waist circumference, daily physical activity, and academic achievement. Details for many of these outcomes have been previously published (DuBose et al., 2006, 2007, 2008; Eisenmann et al., 2007; Gibson et al., 2008).

Changes in BMI from baseline to year 3 are shown in Table 1. The overall change for PAAC schools compared to control schools was not significantly different and was not influenced by gender. However, change in BMI from baseline to 3 years was significantly influenced by exposure to PAAC. As minutes of exposure increased (as determined using the System for Observing Fitness Instruction Time [SOFIT] and teacher self-report), the change in BMI decreased (Fig. 4). Schools ($N=9$) with ≥ 75 min of PAAC/week showed significantly less increase in BMI at 3 years compared to schools ($N=5$) with <75 min of PAAC/week (1.8 ± 1.8 vs. 2.4 ± 2.0; $p=0.02$).

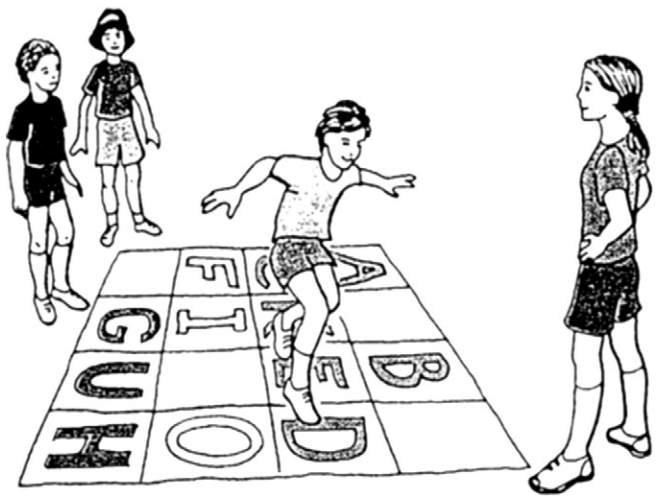

Fig. 3. An illustration of how physical activity can be applied to the academic curriculum.

PAAC results: daily physical activity

Due to the number of available accelerometers (ActiGraph 7164, ActiGraph LLC, Pensacola, FL), daily physical activity was measured in 77 PAAC and 90 control students each spring of the 3-year intervention. Accelerometers were used four consecutive days including 2 weekend days. The main outcome variable was the average ActiGraph counts/minute over the total 4-day period, and average counts/minute on weekdays and weekend days. Additionally, average counts/minute was calculated for moderate to vigorous physical activity (3–6 METS). Results (Table 2) indicated that on average over the 3 year intervention, children in PAAC schools had greater physical activity (by 13%) compared to children in control schools. Children in PAAC schools had significantly greater levels of physical activity during the school day (by 12%) and on weekends (by 17%, all $p<0.05$) compared to children in control schools. Children in PAAC schools also exhibited 27% greater levels of moderate to vigorous physical activity (3–6 METS) compared to children in control schools.

Academic achievement was measured by a third party using trained psychologists blinded to condition. The Wechsler Individual Achievement Test-2nd Edition (WIAT II; The Psychological Corporation, 2001) was individually administered during a 30 min period, and assessed reading, writing, mathematics, spelling, oral language skills and provided individual test scores and an overall composite score. Significant improvements in academic achievement from baseline to 3 years were shown in the PAAC compared to the control schools for the composite, reading, math, and spelling scores (Fig. 5).

Teacher reports of the number of minutes of physical activity performed each week ranged from an average of 45 min to 75 min per week. Nine of 14 PAAC schools averaged ≥ 75 min per week. The average number of minutes for physical activity were lowest at the beginning of each semester and increased significantly within each year, and across years from baseline to the end of year 3 ($p<0.0001$). Focus group discussion following the intervention revealed that teachers improved with practice and became more comfortable with

Table 1
BMI change from baseline (University of Kansas, 2003–2006).

Semester	Control	n	PAAC	N	P-value
Fall 2003	18.0 (3.7)	713	17.9 (3.1)	814	
Spring 2006	20.0 (4.6)	698	19.9 (4.1)	792	
Change from baseline	2.0 (1.9)		2.0 (1.9)		0.83

Values are mean (SD).

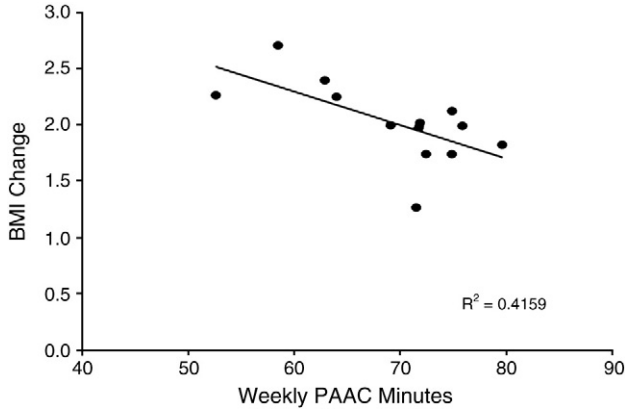

Fig. 4. Correlation between BMI change and the average weekly PAAC minutes reported by each elementary school in northeast Kansas (2003–2006).

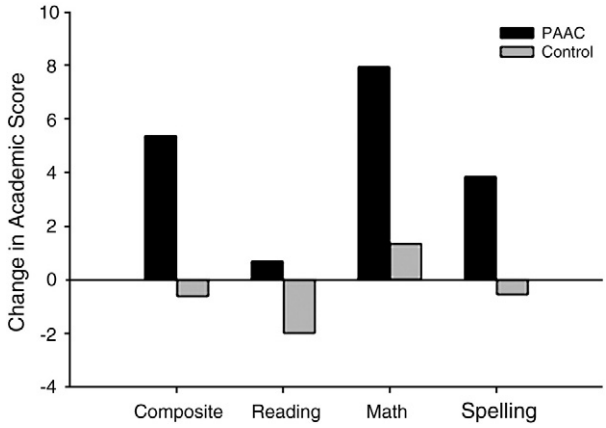

Fig. 5. Change in academic score baseline to 3 years in elementary schools in northeast Kansas (2003–2006). All between group differences were significant ($p<0.01$). PAAC ($n=117$). Control ($n=86$).

the PAAC lessons as the year progressed. Teacher participation in classroom physical activity was directly related to children's physical activity levels measured using SOFIT, an instrument designed to measure variables associated with students' physical activity levels during physical education. SOFIT involves recording student physical activity levels, curriculum context variables, and teacher behavior during direct observation (McKenzie et al., 1992). Teachers who themselves were more physically active had students who were also more physically active ($p<0.001$).

No teachers or schools terminated their participation in PAAC and PAAC was perpetuated subsequent to the end of the intervention. A post intervention survey was administered to PAAC teachers ~9 months after completion of PAAC and without any contact from our staff over the 9 month period. Ninety-five percent of teachers indicated they were using PAAC lessons 1 day/week or greater. Fifty-five percent of teachers indicated they were using PAAC 2–4 days/week, ~35% were using PAAC on most days or every day, and only 5% were not using PAAC lessons. This illustrates the acceptance by administrators, teachers, and students of lessons delivered through physical activity.

PAAC was a well-received intervention that produced some favorable changes in BMI and was successful in improving academic achievement. Changes in BMI were associated with exposure to PAAC and this suggests that if implemented as intended, PAAC and similar programs that provide physical activity in the classroom may be capable of diminishing the trend of increasing BMI in elementary school children. Moreover, the improvements in academic achievement are paramount since this is the chief mission of schools. It is important to recognize that PAAC was a 3-year study that provided longitudinal data from a well-respected measure of academic achievement (WIAT II) obtained by a third party blinded to condition. The WIAT II is independent of teacher bias and has been extensively used and validated (The Psychological Corporation, 2001).

Table 2
Mean accelerometer counts/min (University of Kansas, 2003–2006).

Accelerometer periods	Control (n=90)	PAAC (n=77)	P*
4-day average	744 (183)	851 (233)	0.007
Weekday	738 (192)	800 (222)	NS
Weekend day	750 (219)	901 (279)	0.001
During school (8 AM–2:59 PM)	606 (205)	688 (199)	0.01
After school (3 PM–5:59 PM)	946 (332)	1017 (365)	NS
Evening (6 PM–11 PM)	812 (349)	891 (361)	NS
Minutes of MVPA (≥4 METs)	72 (36.5)	98 (42.7)	0.001

Values are means (SD) taken from 4 day averages. NS, non-significant. MVPA, moderate–vigorous physical activity. MET, metabolic equivalent. *Controlling for gender, race, ethnicity, cohort.

The finding for improved academic achievement for PAAC compared to control schools is supported by the recent publication from The Centers for Disease Control, "The Association Between School-Based Physical Activity, Including Physical Education, and Academic Performance" (2010). The report covered a total of 50 studies of school-based physical education, recess, classroom-based physical activity, and extracurricular physical activity. Nine of these studies explored physical activity in the classroom separate from physical education classes and recess. The studies were designed to examine how short physical activity breaks enhance learning. In some studies, students were provided with a pure physical activity break. In other studies, these breaks were intended to promote learning through physical activity. Outcome measures included student attitudes, academic behaviors such as time on-task, and cognitive skills such as attention and memory. Academic achievement was also examined in several of the studies and standardized test scores, reading literacy scores, or math fluency scores were evaluated.

Five of the nine studies included in this report employed breaks in classroom work consisting of physical activity only (Ahamed et al., 2007; Lowden et al., 2001; Maeda, 2003; Molloy, 1989; Norlander et al., 2004). The results of these studies showed positive changes in classroom behavior, concentration, and performance solving arithmetic problems. However, this type of intervention did not improve standardized test scores, attention span, or stress level. Three of the nine studies utilized interventions that combined physical activity and academic lessons to enhance academic performance or cognitive skill performance such as reasoning and perception (Della Valle et al., 1986; Fredericks et al., 2006; Mahar et al., 2006). Improvements in on-task behavior, word recognition, and spatial, reading, and math aptitude were observed; no differences were seen on the Aptitude Test for School Beginners that measured perception, reasoning, coordination, memory, and verbal comprehension.

Summary

Schools have reduced the time allotted to physical education and providing adequate amounts of physical activity in physical education classes is challenging. The classroom is where students spend the majority of their time and this provides a viable location for interventions designed to increase physical activity. Increased physical activity has the potential to improve fitness and fatness, both of which impact academic achievement. Physically active academic lessons are cost effective, do not require additional teacher preparation time, are enjoyable for teacher and student, and result in improved academic achievement scores.

One important finding of the PAAC study was the influence of teacher behavior on intervention outcomes. Approaches to changing behavior from a social cognitive perspective must include components that emphasize the interaction of the interpersonal environment, the physical environment, and the individual (Bandura, 1971, 1989). Teacher's influence may be used to actively engage students and reinforce physical activity within the classroom setting. Teachers who actively participate in A + PAAC lessons can be especially effective in demonstrating and inducing their students to try new behaviors. Guided participation by the teacher further enhances the change process by providing opportunities to practice new behaviors with social support and encouragement.

The PAAC intervention has been renewed by the National Institutes of Health (NIH) for an additional 5 years as A + PAAC (RO1 85317). It will focus on academic achievement as the primary aim, and will use the WIAT II, Kansas State standard academic achievement tests, several tests of cognitive function, and measures of attention-to-task. Health outcomes including BMI, cardiovascular fitness, blood pressure, blood chemistry, and anthropometry are now secondary aims. To enhance the impact of A + PAAC on BMI and fitness, classroom activities were developed that are more intense than those from the original PAAC and these activities are on the order of ≥5 METS.

A + PAAC does not compete for time allocated for academic instruction and provides an inexpensive, easily implemented and sustainable approach that may allow elementary schools to meet the competing demands of improving student health while also improving academic achievement. The secondary aims will provide information regarding potential mediators of the change in physical activity and academic achievement. Each variable has been selected based on literature suggesting a potential link to academic achievement and/or cognitive function and may help us understand how learning academic lessons through the use of moderate to vigorous physical activity (i.e. A + PAAC) influences academic achievement.

On the basis of randomized, controlled trials such as PAAC and other similarly designed studies described in this article, the literature supports the relation between physical activity, cognition, and academic performance. On the contrary, there is no evidence to support the argument that increasing the time allotted to physical activity during the school day results in decreased academic performance. Schools may be able to address several health issues in conjunction with improving academic performance by delivering academic lessons using physical activity in the classroom.

Conflict of interest statement

The authors declare there is no conflict of interest.

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