STATE OF THE ART
REVIEWS

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Relationships of Physical Activity to Brain Health and the Academic Performance of Schoolchildren

Abstract: *This review examines possible relationships between academic performance and participation in sports, physical education, and other forms of physical activity. Recent fundamental research has reignited interest in the effects of physical activity on cognitive processes. Experimental studies of potential mediating variables point to physiological influences such as greater arousal and an increased secretion of neurotrophins and psychosocial influences such as increased self-esteem and connectedness to schools. In the specific case of sports, experimental studies are limited to demonstrations of greater attention and acute gains of mental performance immediately following such activity. Several quasi-experimental studies of other types of physical activity have been completed, mainly in primary school students; these have found no decrease in academic performance despite a curtailing of the time allocated to the teaching of academic subjects. Indeed, in some cases, experimental students undertaking more physical activity have outperformed control students. Many investigators have looked at cross-sectional associations between participation in sport or other forms of physical activity and academic performance. Despite difficulties in allowing for confounding variables, particularly socioeconomic status, the overall conclusion has been of a weak positive association. From the practical point of view, it can be concluded that the physical activity needed for healthy child development can be incorporated into the school curriculum without detriment to academic achievement.*

Keywords: children; learning; physical activity; physical education

The topic assigned for this invited review is physical activity participation and cognitive performance. Research results from the early 2000s, largely echoed in the media, suggest a positive impact of regular physical activity on learning and memory at all ages. It seems fairly well accepted that such activity is associated with the maintenance of cognitive functions and brain health in older adults.[1] Leisure time physical activity has even been shown to offer some protection against Alzheimer disease.[2,3] Furthermore, the Nun study demonstrates the importance of early stimulation of brain structures to cognitive function in later life.[4] It has been suggested that early stimulation increases the reserves of brain function, as characterized by both the number of neurons and the extent of their interconnections. There is also growing evidence that physical activity can make an important contribution to this increase of brain reserve.

Physical activity is here defined as all form of movement associated with an increase of energy expenditure. It includes spontaneous physical activity and organized noncompetitive forms of physical activity including exercise, physical education classes, and sport. In Europe, the term *sport* was once used to describe all forms of vigorous physical activity,[5] but we have followed the recommendation of an international consensus conference[6] and restrict this term to physical activities performed individually or in teams and involving some form of competition.

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Academic achievement has commonly been assessed by the student's grade point average or standing in provincial, statewide, or national examinations, although occasional studies have accepted subjective assessments of learning or self-reports of students or teachers. One assumption commonly made in reviewing findings has been that various forms of physical activity provide a similar stimulus to the learning process; however, this seems unlikely to be the case. A second assumption underlying most investigations has been that athletes and sedentary students receive comparable instruction, although this again seems inherently unlikely. In the school system, the introduction of a physical activity program for a particular class may allow the academic teachers who are involved a greater amount of free time to prepare their courses. At the university level, athletes often receive substantial scholarship support and additional academic coaching, both of which help them to achieve good grades. If reliance is placed on classroom assessments of scholastic performance, findings may be biased further by the attitudes of academic teachers toward the sports program[7] and (particularly at the university level) by the special pleading of coaches for the upward adjustment of marginal grades assigned to athletes in their care.[7] Finally, the direction of any associations has usually been assumed from physical activity to academic excellence, although directionality cannot be inferred from correlational studies, and there are several potential factors influencing associations. Students who strive for academic achievement are often regarded as "uncool" or "nerds." Thus, a desire for academic excellence can sometimes motivate a student to vigorous sports participation. Sir Roger Bannister once told one of us that the reason he became involved in sport was so that his fellow students would allow him opportunity to study. Furthermore, those who are intrinsic high achievers or strongly motivated by their parents may excel in both their academic work and in sport. Such issues are difficult to disentangle other than by experimental or quasi-experimental studies. The present review will focus primarily on the practical issue of whether participation in physical activity influences academic achievement. This question is still the subject of heated debate among schools, universities, school boards, and parent-teacher associations. If teaching time is diverted from academic work to sport, will learning suffer? And given an exponential increase in the volume of knowledge to be transmitted, should sport programs be curtailed to allow a greater amount of time to be allocated to academic instruction?

Several previous reviews have examined the broader question of relationships between physical activity and academic achievement in the context of state schools.[8-15] A meta-analysis of 44 studies, both experimental and cross-sectional, found an average effect size of 0.32, significantly greater than zero,[13] for an enhancement of cognition.

The present review looks at published quasi-experimental and cross-sectional studies of the problem, considering also experimental investigations of potential mediating mechanisms. We have excluded most studies on the relationship between physical fitness and cognition since a recent meta-analytic review concluded that physical fitness was not significantly associated with cognitive performance.[16] In any event, most studies linking physical fitness and cognition have been cross-sectional, with inherent problems of selection (biological or socioeconomical). Limitations of space have also precluded discussion of such special cases as individuals with hyperactive disorders[17] or learning disabilities.[18,19]

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Method

Databases searched for the purpose of this review included MEDLINE (1966 to 2008), PSYCHINFO (1974 to 2008), SCHOLAR.GOOGLE.COM, ERIC, HealthStar OVID (1950-2008), and Sport Discus (1993-2008), as well as the extensive personal databases of both authors. The reference lists of the articles identified and "find similar articles" computer linkages were also consulted when available. A number of other experimental studies possibly relevant to this issue have been excluded from consideration since they are available only as microfiche summaries of doctoral theses rather than peer-reviewed reports.

The successful academic records of British public schools (where each weekday afternoon is devoted uniquely to sport) have long suggested that a substantial commitment to athletic endeavor is not necessarily a handicap to learning for most of the students concerned. Formal evidence of a possible connection between sports participation and intellectual achievement has been of research interest since a review by Davis and Cooper[20] claimed a positive association between the 2 variables. Nevertheless, it is difficult to isolate the effects of physical activity from the academic support enjoyed by athletes[7] and the attitudes of academic teachers toward the sports program.[7] Moreover, considerable caution is needed in equating physical activity with organized sports programs. The latter generally have a greater impact on the individual's social status and self-esteem[21]; time demands are often much greater (due to both extensive training and the travel

Table 1.

Search Results on Various Research Engines

	PubMed[a]	SportDiscus	PSYCHINFO	Scholar Google	HealthStar Ovid
Physical activity academic achievement	101	45	24	201 000	14
Sport academic achievement	131	407	159	71 500	10
Physical activity cognitive health	101	5	4	397 000	

[a]After using Related Articles links.

associated with competition), and the learning process may be helped by scholarships and special coaching[22] or curtailed by major injuries. Potential indices of academic outcome used in this review include not only grade point averages and student or teacher assessments but also such accepted classroom determinants of academic performance as assessments of concentration, class behavior, and school engagement.

The most prolific source of citations relevant to these various topics was the database "Sport Discus full text"; this yielded 407 entries for a combination of the terms *Sports* and *Academic Achievement*. However, when the articles were reviewed, many entries were for popular rather than peer-reviewed scientific publications (Table 1). In contrast, entry of the term *Academic Achievement* into HealthStar-Ovid yielded only 10 articles that were linked to *Sports Participation*, 7 linked to *Physical Education or Physical Education and Training*, and 14 linked to *Physical Activity*. Both of the present authors evaluated all potentially relevant articles for possible inclusion in this review. Effect size was measured using Cohen's d (standardized mean difference), calculated for quasi-experimental studies with a pooled standard deviation.

Experimental Studies

Experimental studies undertaken in both animals and humans provide additional evidence of the influence of physical activity on cognitive development. Investigations have focused on both physiological and learning/developmental mechanisms. Physiological concerns have included changes in the cerebral circulation, levels of arousal, concentrations of neurotransmitters and neurotrophins, structural changes in the central nervous system, and resulting long-term hippocampal potentiation (LTP). Studies of learning and developmental mechanisms have examined the carryover of physical skills and understanding of spatial relationships into academic learning.[13,23]

Cerebral circulation. Most forms of physical activity lead to a substantial increase of systemic blood pressure, and since there is little vasomotor control of the cerebral circulation, the overall perfusion of the brain typically increases by 14% to 25% during a bout of endurance exercise.[24] In a healthy subject, the total cerebral blood flow exceeds the metabolic demands of the brain.[25] Some of the activity-induced increase in blood flow is directed to motor areas, but there may also be increased perfusion of other parts of the cortex. In a longer term perspective, regular physical activity may further augment cerebral blood flow by reducing the viscosity of the blood.[26] In an elderly person, in whom cerebrovascular atherosclerosis is threatening the adequacy of cerebral perfusion, these changes may result in some improvement of brain function. Even when at rest, trained humans and animals show an increased cerebral blood volume, with an increase of angiogenesis in the primary motor cortex[27] and the dentate gyrus.[28] The latter is the most plastic region of the adult hippocampus, an area of the brain responsible for learning and memory consolidation. However, such mechanisms seem unlikely to modify cognition in children and adolescents, in whom the cerebral circulation is generally in good condition, and there is little evidence that brain oxygenation or substrate utilization is compromised, at least until effort approaches exhaustion.[29] Nevertheless, during fatiguing exercise, the cerebral uptake of oxygen relative to carbohydrate (glucose and lactate) drops from 6 to less than 3.[30]

The high daily energy expenditures demanded in many sports and physical activities requires a high overall intake of nutrients, Micronutrient deficiencies sufficient to limit the cognitive development of the average child nevertheless remain unlikely except in impoverished segments of the population and in categories of athletes who engage in rigorous dieting in attempts to "make weight" or enhance slimness.[31]

Arousal. Participation in physical activity generally increases an individual's immediate arousal through an increase of neural activity in the reticular formation of the brain, although the long-term impact is less well established. A moderate increase of arousal is likely to increase attention and thus facilitate learning, but excessive arousal may be detrimental to the learning process.[32] In the extramural context, sport is likely to offer greater mental stimulation than the common alternative of passive television watching.[33] Other types of physical activity and some mental pursuits can increase arousal, but on the other hand, repetitive movements such as walking or moderate jogging have a calming effect,[34] a view substantiated by electroencephalography (EEG) studies.[35] Relaxing forms of physical activity may be helpful in countering the stress of examination time, thus bettering a student's academic grade.[36] In young children, any form of physical activity may be helpful; thus, one recent experimental study of students in grades 2 to 4 found an immediate increase of concentration in response to 15 minutes of stretching and walking.[37]

EEG. A simple Fitnessgram of preadolescent children demonstrated an association between a high fitness score and shorter latencies of P3, an evoked response potential associated with attention processes and the capacity of the working memory during stimulus discrimination.[38] This interesting observation needs verifying by a longitudinal study to isolate potential selection effects; furthermore, such EEG features could reflect a high intrinsic level of physical fitness rather than an underlying difference in habitual physical activity.

Concentrations of neurotransmitters. Physical activity increases transfer of the serotonin precursor tryptophan across the blood-brain barrier. The resulting increase in cerebral serotonin has an immediate calming effect. Whether this facilitates or hampers learning depends on the child's initial level of arousal. Two studies have reported negative correlations between plasma serotonin levels and vocabulary scores, particularly in autistic children,[39,40] although there have been no studies looking at serotonin levels within the cerebrospinal fluid.

Neurotrophins and LTP. Much of the recent experimental research on physical activity and cognition has centered on the hippocampus. LTP is an essential process in the consolidation of memory and is characterized by an increase of synaptic efficacy.[41] Physical activity seems to facilitate LTP[42] through several short-term and longer term mechanisms: improved synaptic transmission, increased concentrations of neurotrophins, protection against the adverse effects of free radicals, and increased neurogenesis.

In rats, improved synaptic transmission after voluntary running has been demonstrated as associated with a faster learning of maze pathways.[43-45] These gains have been associated with increased expression of brain-derived neurotrophic factor (BDNF).[46] The hippocampal glutamate receptors of aged rats were unaffected by exercise,[47] suggesting that postreceptor mechanisms are responsible for the stronger LTP seen in active animals. However, this remains to be confirmed by studies of the hippocampus in younger animals.

BDNF not only promotes neural growth but also protects neurons from oxidative damage. Several animal studies have shown increases of BDNF and other growth factors, including insulin-like growth factor (IGF-1), nerve growth factor, and fibroblast growth factor 2 (FGF-2), in response to exercise.[48] Concentrations of BDNF mRNA have increased in pyramidal cells of the CA1, CA4, CA3, and dentate gyrus,[49-51] and conversely, BDNF mRNA levels have been reduced by exercise deprivation.[52] In young human adults, plasma levels of BDNF have risen with acute bouts of exercise,[53] particularly if the intensity was at or above the ventilatory threshold.[54] Stroop test scores have also improved in response to physical activity, although such gains were not correlated with increases in plasma BDNF.[54]

IGF-1 is also neuroprotective. Subcutaneous administration of an IGF-1 antibody to animals reverses the neuroprotection against domoic acid–induced injuries that is usually seen after exercise. Conversely, IGF-1 injection has a neuroprotective effect in sedentary rats. These observations suggest that exercise-induced increases of IGF-1 may contribute to the enhanced neurogenesis seen in trained animals.[55] Fibroblast growth factor (FGF), sometimes known as epidermal growth factor, is another important variable. Voluntary wheel exercise augments FGF-2 mRNA expression in the hippocampus.[56] FGF-2 mimics the exercise-induced stimulation of angiogenesis seen in the cerebellar cortex and the hippocampus,[57] whereas motor learning augments synaptogenesis in the same areas.[58] FGF-2 administration also enhances LTP in hippocampal CA1 pyramidal cells[59] and in the granular cells of the dentate gyrus.[60,61]

The concentration of other antioxidants is increased in the brain of trained animals, further protecting the hippocampal cells from damage.[62] Radak et al[63] studied the acute effects of 2 hours of exercise on previously immobile animals. Oxidative damage to macromolecules was prevented through an increase of glutathione synthetase activity and a reduction in the deleterious efflux of glutamate induced by immobilization. Acute exercise also normalized memory functions, as measured by orientation time to novelty and passive avoidance.

In humans, regular physical activity increases protection against reactive species, more than counterbalancing the increased production of oxidative species during effort, and this could protect the brain against functional loss.[63] However, such a process would benefit mainly elderly individuals, in whom cognitive function was already showing signs of deterioration. Histological studies have confirmed an increase of neurogenesis in mice following chronic exercise.[45,64]

Although these mechanisms have the potential to enhance learning and memory, to our knowledge, they have yet to be demonstrated in younger animals at a stage of development corresponding to school-age children. However, it is conceivable that the changes observed in adult animals could assume even greater importance in the more plastic brains of young children.

Quasi-experimental and Longitudinal Studies

Our literature search did not identify any randomized controlled trials examining the impact of sport or physical activity interventions on academic performance. We were not surprised since such studies are impractical in most school and university settings. However, a number of quasi-experimental trials have been completed. All involved relatively young (primary school) children; some of the interventions included sports, but none isolated the specific effects of sports from participation in other forms of physical activity.

The first such investigation was undertaken in Vanves, a suburb of Paris (France). The subjects were a small group of children in their final year of primary school. The authors claimed that despite a 26% reduction in the time allocated to academic work, students who spent mornings in the classroom and afternoons undertaking a variety of physical activities (gymnastics, swimming, training, sports and outdoor pursuits, to a total of 15 hours per week) had a better academic performance than control students who were given only 2 hours of athletic activity per week.[65,66] Unfortunately, available information is limited, and details of the study were never published in peer-reviewed journals.

A second and more sophisticated quasi-experimental study was conducted between 1970 and 1977 in Trois-Rivières (Québec, Canada). It involved a very substantial sample of primary schoolchildren (n = 546), and the findings were documented extensively in peer-reviewed journals. One issue examined over the 6-year study was the impact of an hour per day of vigorous, professionally taught physical education on overall academic performance[67]; the control group, formed from immediately preceding and succeeding classes at the same schools, were instructed by the same teachers but received only the standard program of 40 minutes per week physical education from their homeroom teachers. Despite a 14% loss of time for academic instruction, the overall school performance of the experimental group, as assessed by the classroom teachers, improved significantly relative to the controls. In the early stages of the program, the experimental students also demonstrated an accelerated development of various psychomotor skills, such as the appreciation of body size, perception of the vertical, and finger recognition, but in the later years of primary school, the control students made good their disadvantage.[68] Weschler Intelligence Scale for Children scores showed small (3%-4%) but statistically significant advantages for the experimental students on both verbal and nonverbal items. In standardized provincial examinations, experimental students attained higher scores in mathematics (23.8 ± 7.9 vs 18.5 ± 6.1) but lower scores in English (22.1 ± 6.1 vs 27.4 ± 6.8), despite the fact that mathematics instruction was reduced by 33 minutes per week, but the time for English instruction was unchanged.[69] Scores for French language were comparable for experimental and control classes, but overall intelligence was rated substantially lower in the experimental students (40.8 ± 10.3 vs 62.6 ± 14.0).

In California, a 2-year quasi-experimental study followed 759 children through the fifth and sixth grades.[70] Subgroups of children were taught the Sports, Play and Active Recreation for Kids curriculum by a professional physical educator (n = 178) or a trained homeroom teacher (n = 312), whereas a third group continued in the normal program (n = 165). The impact of the 2 interventions on the amount of school-based physical activity was relatively small; the 3 categories of students received, respectively, 80, 65, and 38 minutes per week of physical education. Metropolitan achievement scores were compared at the conclusion of the study. Students in the specialist teacher group were superior to controls with respect to reading but inferior on English language. Students in the trained teacher group fared rather better, being superior to the controls on language, reading, and the basic test battery. The authors concluded simply that there was no negative effect on academic achievement when more time was devoted to physical education.

In South Australia, a 500-student randomized control trial added 1.25 hours per day of endurance training to the curriculum of 10-year-old primary school students for a 14-week period.[71] Control groups received either a skills program or normal physical education. Arithmetic and reading scores were not adversely affected in the experimental classes, although academic instruction was reduced by 45 to 60 minutes per day; indeed, a 2-year follow-up of 216 continuing participants showed statistically nonsignificant trends for better arithmetic and reading grades relative to their peers, as well as beneficial effects on teachers' ratings of classroom behavior.[72]

In British Columbia, a study of 287 nine- to 11-year-old primary school students[73] added an average of 47 minutes per week of various physical activities to the normal curriculum, where physical education was judged as inadequate (139 ± 62 in experimental students vs 92 ± 45 minutes in control students, $P < .001$). The experimental program was delivered by suitably briefed homeroom teachers. Despite a 47-min/wk reduction in time for academic learning, performance as measured by the computer-scored Canadian Achievement Test remained essentially unchanged; there was a slight trend toward enhanced performance in the intervention schools (from 1595 to 1672 units) but unchanged scores in control schools (1678 to 1689 units).

A crossover trial was carried out on 214 sixth-grade US students.[74] Academic grades were compared between a curriculum in which students spent 55 nominal minutes per day on physical education (an actual 19 minutes of moderate or vigorous activity) and an alternative program in which a similar amount of time was allocated to arts or computer sciences. Students in the 2 programs performed equally well in mathematics, sciences, and English, as well as on a national standardized test.[74] A post hoc cross-sectional analysis showed that students who reported engaging in additional periods of vigorous physical activity on their own initiative had substantially superior academic scores. Although the authors lacked information to control this additional data for socioeconomic status, they suggested that greater benefit might have been observed if the intervention for the remaining experimental students had been more intensive.

A recent prospective study on 1411 French middle-school schoolchildren suggested a graded effect between the amount of extracurricular sport involvement and self-declared academic performance.[75] Students reported academic grade point average (GPA) outcomes of 12.9/20, 12.4, and 12.0 if they reported regular, occasional, or no extracurricular sport practice. This difference was maintained throughout the 4-year follow-up.[75]

A controlled study from Israel looked at the responses of 92 preschool and 266 first-grade children to a program of movement education; relative to controls, the experimental children showed better balance and throwing abilities, together with greater reading skills and arithmetic readiness scores.[76]

Finally, a small-scale study of 9 pairs of monozygotic twins found that after 6 months of treadmill running (20 minutes per day at an intensity above the anaerobic threshold), the correctness of scores and decision time were improved relative to 8 control students of the same age.[77]

Several other projects with an experimental design have been excluded because the subjects had some form of learning disorder. Finally, we may note a few reports that looked only at immediate, short-term responses to additional physical activity.[78] For example, students showed an immediate increase of concentration following 15 minutes of stretching and walking,[37] and improved computational skills were seen immediately after 20 to 40 minutes of walking in the afternoon (but not in the morning).[79] Although not quasi-experimental, a recent American investigation of data from the Early Childhood Longitudinal Study indicated that, in girls, the group undertaking more physical education in kindergarten (ie, from 70 to 300 minutes weekly) had better scores for mathematics and reading during their subsequent primary school years (although no such effects were found in boys).[80]

Cross-sectional Studies

Many cross-sectional studies have looked for possible relationships between academic achievement and sport or other forms of physical activity. Unfortunately, such studies cannot indicate the direction of any associations that may be observed, and they are of interest only insofar as potential sources of bias can be controlled. One of the most important covariates is the student's socioeconomic status; this is a strong predictor of both academic achievement[81] and participation in various forms of physical activity.[82-84]

Early reports commonly noted a positive univariate association between academic achievement and sport participation, physical activity, or resulting fitness.[10,17,22] For instance, the "sit and reach" scores of primary school students showed a positive correlation with standard academic achievement scores,[85] and in women entering university, scores on a physical fitness index were associated with their academic data.[86] Against these positive associations must be set several reports of null or negative associations.[10,87,88] Negative correlations were noted between the time allocated to sport and marks in English language (r = –0.29 to –0.30) in a sample of 232 English adolescents aged 13 to 16 years.[89] Likewise, a study of grade 6 children from New Brunswick (Canada) found a weak inverse association between physical activity and academic achievement, despite a positive relationship to self-esteem.[90] Similarly, preadolescent boys in Hong Kong had an association between a high level of physical activity and self-esteem, but academic achievement was unaffected.[91]

Some cross-sectional studies have attempted to allow for major confounders by covariate analysis, examining data from a single social stratum or using representative sampling. The may limit the generality of findings since it is likely that the influence of sport on academic achievement will differ with social class. Among studies in which allowance was made for covariates, the US National Longitudinal Study of Adolescent Health observed that students who were physically active in school were likely to achieve high grades. After adjusting for socioeconomic status and demographics, the grades of active individuals remained 20% higher for mathematics and 21% higher for English.[92] In a similar vein, a British study found a positive association between sports participation and academic achievement after controlling for socioeconomic status.[93] A study involving 52 female and 37 male high school seniors adopted the alternative tactic of evaluating only those of middle and upper-middle socioeconomic status; again, the more active group had a higher GPA.[94] An association between perception of little or no involvement in physical activity and perception of low academic performance was reported in a representative sample of US adolescents.[95] Another representative cross-sectional survey studied 109 schools in South Australia[8] (9000 schoolchildren aged 7 to 15 years). In most age and sex categories, linear regression analysis demonstrated significant associations between the school principals' ratings of academic achievement and physical activity both at lunch time and over the entire previous week. Correlations between simple field tests of performance and academic ratings were very weak (r = 0.08 to 0.19), and they became nonsignificant when the influences of motivation and obesity were excluded by making an objective cycle ergometer assessment of physical work capacity per unit of lean mass. In support of this negative conclusion, a survey of 117 Australian primary schools showed that literacy and numeracy results were unaffected by spending more time on physical education.[96]

Two studies from Hong Kong underlined the problems that can arise from interactions between social class and the response to sport. In a first analysis of 4690 children aged 10 to 18 years, responses to a prevalidated questionnaire on sports and exercise participation showed weak correlations with perceived academic performance (r = 0.10 for the whole sample, $P < .01$; r = 0.17, $P < .01$ for girls; r = 0.06, nonsignificant for boys).[97] A second report[98] examined the same issue in 1447 schoolchildren aged 13, 15 and 17 years, taking into account the participants' class banding, or scholastic ability (40% low, 17% middle, 43% high). For students in the high band, GPA was positively linked to physical activity, but for those in the low band, the relationship was negative. A study from Iceland[99] likewise found that weak associations of physical activity with self-reported absenteeism (r = –0.11) and school grades (r = 0.09) were further diminished by integrating confounders such as body mass index, gender, parental education, and family structure into the analysis. Furthermore, academically gifted children involved in sports did not display an increase of grades in mathematics or in verbal skills, possibly indicating an effect of the initial value (ie, those with lower academic grades may benefit more than higher academic achievers).[100]

Specific studies of sports generally refer to high school or university rather than primary school. The competitive nature of most sports introduces new problems, and partly for this reason, the findings are even more equivocal than for physical activity as a whole. Moreover, many authors have failed to take account of biases common to athletic and academic endeavor.[101,102] Any interaction with academic status is likely influenced by the type and status of the sport,[103] the gender of the participant,[104,105] secular trends in gender roles,[104] socioeconomic status,[104] ethnicity,[106] the level of competition, and the location of the activity (intramural or extracurricular).[107] The impact on academic scores may also vary with the discipline; thus, subjects such as English may be more susceptible to the cultural influence of sport participation than are achievements in mathematics or scientific subjects.[103]

Students engaged in extracurricular sports generally have more interactions with significant adults than their peers, greater educational motivation, and a greater level of satisfaction with their educational experience, although this does not always translate into a higher GPA.[108-112] For example, involvement of British Columbia students in school or minor-league hockey was associated with a low rate of absenteeism but no grade point advantage.[113] In contrast, a study of Maryland adolescents[114] found that participation in extracurricular physical activities was associated with both higher academic expectations and better actual academic achievements. Sports participation by eighth-grade African American students, likewise, was linked to a lesser likelihood of inappropriate school behavior and absenteeism and a greater desire for university education.[115]

Cooper et al[116] calculated that even after allowing for confounding variables, extracurricular sports and physical activity were predictors of academic achievement in a sample of 2200 US high school students. Likewise, after standardization for socioeconomic status, sports participation with parental presence was associated with an adjusted relative risk of 1.232 of better grades in English and mathematics in a sample of 11 957 US adolescents.[117] Other investigators have reported either a small positive association between sport participation and General Certificate of Education grades in mathematics and English[118] or no effect.[112-120]

It is commonly claimed that relative to nonathletes, elite and varsity-level athletes later experience greater success in the labor market.[108,109,121-124] Some of these studies have been plagued by technical problems; for instance, in the investigation by Marsh and Kleitman,[122] two-thirds of the subjects had missing data. Furthermore, as with immediate academic achievement, any apparent effect may be mediated in part by external factors such as maternal education and prior academic achievement,[125] racial group,[126] the availability of scholarships, and the large amounts of capital accumulated by top athletes. Nevertheless, a multiple regression analysis by Carlson and associates[121] showed that after controlling for sex, ethnicity, socioeconomic status, and academic grades, 8 years after high school, elite athletes were more likely to have completed postgraduate education, to be employed, and to have a high income.

Correlations With Determinants of Academic Performance

Another line of inquiry has been to evaluate associations of physical activity with possible determinants of academic success such as motor coordination, body image, psychosocial characteristics, and overall classroom behavior.

Motor coordination. The concept of a linkage between the development of motor skills and learning dates back to Piaget.[127] A study in Köln, Germany, reported data from 12 intervention (n = 668) and 5 control schools (n = 218). The children were aged 6 to 7 years (3 months older in control schools because the students were tested sequentially). Overall, scores on a motor coordination test did not differ between intervention and control students, but motor coordination in the pooled sample was positively associated with the rate and accuracy of symbol processing.[128] This was interpreted as supporting communality between cerebral learning and motor control processes.

Body image. Sports programs have commonly contributed to an enhanced body image.[129,130] The body image of the successful athlete has traditional meant more to the status of boys than girls, although this is changing. Conversely, the body image of girls is particularly vulnerable to obesity. A cross-sectional study of third- and fifth-grade children found a positive association between aerobic power and academic achievement.[131] Likewise, field measures of fitness were associated with several measures of cognitive function (Stroop test, digit span, digit symbol test, and trail-making test) in a sample of 203 German students aged 8 to 16 years.[132] However, perhaps because the baseline level of physical activity is greater in a developing society, these findings were not duplicated in 212 rural South African children aged 7 to 14 years.[133]

Several authors have reported a negative association between obesity and academic achievement.[131,134,135] For example, a multivariate analysis of data for 11 192 kindergarten and first-grade children in the United States showed a negative association between obesity and academic achievement.[135] However, it is less clear that the obesity would be reversed by a required school program of sports or physical education; such initiatives have generally had little effect on body fat content, unless students have been sent to a residential camp, where diets can be rigidly controlled.

Psychosocial characteristics. It has been hypothesized that the enhanced self-concept,[136] social status,[137] and self-esteem associated with improved motor skills may increase a child's desire to learn.[138] The classic view has been that self-esteem is a determinant of student motivation, persistence, and academic success.[139,140] Success in high-profile sports is commonly associated with a greater self-esteem.[22,117,141,142] The US National Longitudinal Study of Adolescent Health reported a positive association between physical activity and several components

Table 2.

Quasi-experimental Studies of the Influence of Sport, Physical Education, or Physical Activity on Academic Achievement

Author	Sample	Milieu	Intervention	Outcome Measure	Response	Effect Size (Cohen's *d*)
Fourestier[65]	Vanves (Paris)	Children in final year of primary school, n = ?	Various sports and other activities, 13 h/wk increase for 1 y	Overall academic performance	Enhanced in experimental group	No data available
Shephard et al[67]	Trois Rivières, Québec	546 children in grades 1 through 6	5 h of specialist physical education per week for 6 y	Teacher ratings Standard Provincial examination, WISC tests	Enhanced teacher ratings, math but not English improved in provincial exams, 3%-4% gain on WISC	French language: 0.22* Mathematics: 0.75 English language: 0.80[a]
Sallis et al[70]	California	655 children in grades 5 and 6	27-42 min additional physical education per week for 2 y	Metropolitan achievement tests	Nonsignificant trend to gains in English, arithmetic and behavior	Reading: 0.44
Dwyer et al[71]	South Australia	500 10-y-old students	75 min/d of endurance training	Scores for reading and arithmetic	Nonsignificant trend to gains in English and arithmetic at 2-y follow-up	Arithmetic: 1.21 Behavior: 5.66
Ahamed et al[73]	British Columbia	287 9- to 11-y-old primary students	Added 47 min/wk of varied activities for 16 mon	Canadian Achievement Test (CAT-3)	Slight trend to improved scores	CAT-3: 0.79 boys and girls Girls: 1.17 Boys: 0.84
Coe et al[74]	Western Michigan, United States	214 grade 6 students	Nominal 55 min/d (actual 19 min/d) physical education for 1 semester	Classroom assessments and nationally standardized achievement scores	Change in academic performance only in subgroup who exercised vigorously	For vigorous physical activity exceeding Healthy People 2010 guidelines: 0.47

Abbreviation: WISC, Weschler Intelligence Scale for Children.
[a]In favor of the control group.

of mental health, including self-esteem, emotive well-being, spirituality, and future expectations.[91] Associations were particularly marked if the sport or physical activity included parental involvement. Regular participation in sports or physical activity has also been linked to greater school satisfaction and connectedness,[143] with a reduced dropout rate from school.[144]

However, an increase in self-esteem has not always translated into better academic performance, and better academic performance can itself result in an increase of self-esteem.[145] For instance, a study of almost all grade 6 students in New Brunswick (n = 5856) found that after controlling for socioeconomic circumstances, sex, and the number of parents and siblings, there was a weak positive association between self-esteem (responses to a 16-item self-description questionnaire) and self-reported participation in sports and physical activity in and out of school but a weak negative relationship between physical activity and classroom scores for mathematics and reading.[90] Likewise, a cross-sectional questionnaire study of 245

Finnish seventh- and ninth-grade adolescents[146] found no significant correlations between physical activity level and school or educational problems, although there was a weak association between participation in physical activity and the absence of depressive mood (–0.20 and –0.26 for girls and boys, respectively). One problem may be that sports and school work are commonly related to differing psychological domains (perceived ability vs task orientation).[147] Positive associations are more likely to be observed if an effort is made to create a context in which both endeavors find common ground (ie, if a school offers a setting where sports can be modified to increase task orientation and skills acquisition without decreasing the element of pleasure). Even if sport participation has some positive influence on the social adjustment of a child, this must be tempered by observations suggesting that other extracurricular activities are more effective in this regard.[148]

Classroom behavior. It seems self-evident that a child who behaves well in the classroom is more likely to learn. Thus, considerable attention has been directed to the influence of sports programs on classroom behavior. If student behavior is indeed improved by sport participation, better teacher attitudes toward the students concerned could contribute to enhanced opportunities for learning, as suggested in the quasi-experimental studies from Vanves,[65] Trois-Rivières,[69] and Australia.[149] Improved teacher attitudes could also provide a halo effect, with an increase in the classroom marks assigned to students in intervention groups.

A meta-analysis suggested that most forms of physical activity prior to class significantly reduced disruptive behavior in disturbed students.[150] When emotionally or behaviorally disturbed adolescents participated in a program of jogging and football, they also showed more appropriate classroom behavior.[151] Gains are likely less marked if students are initially well adjusted. In the Trois-Rivières study, grades assigned for classroom behavior were similar in experimental and control groups, except in the sixth grade, where the average class mark assigned for behavior was better in experimental than in control students.[152] Nevertheless, others have commented on positive associations between sport participation, classroom behavior,[149,153] and attitudes to learning.[154] In high school students, self-identification as an athlete rather than a jock is associated with fewer reported of acts of misconduct in class.[105] One negative consideration is that participants in high school and university team sports seem more liable to become involved in binge drinking.[121]

Learning and developmental mechanisms. An early hypothesis of the French pediatrician Piaget was that the skills of spatial organization required for sport and other forms of active play would carry over into an understanding of the spatial relationships that comprise words and mathematical relationships.[127,155,156]

Several recent reports have given an experimental basis to this line of inquiry, particularly in elderly individuals. A positive effect of regular physical activity on learning, memory, and retention of cognitive function has been noted in elderly subjects.[1,3,157-162] It remains difficult to rule out a placebo effect from the added personal attention and social contacts experienced by experimental subjects, and the influence of physical activity on the cognitive health of younger subjects is less well established. Nevertheless, several early factor analyses have suggested a clustering of psychomotor training and cognitive development in young children.[163-165]

Conclusions

The overall conclusion from the studies reviewed is that the introduction of sport or physical education into the school curriculum has no striking effect on GPA. In some of the studies cited, the transfer of teaching time from academic subjects to physical activity was too small to anticipate any great effect on learning. Nevertheless, when taken together, the available data suggest that at least in primary school students, the physical activity needed to optimize the healthy development of a child (an additional 60-90 minutes per day[166,167]) can be provided without jeopardizing academic performance. In essence, active students compensated for a reduction of academic instruction time by greater efficiency of the learning process.[69] This is by no means a negative outcome. A study from Virginia's primary schools demonstrated that if the time allocated to physical education or the arts were to be reduced, as suggested by some school boards, such a change would not enhance performance in subjects such as mathematics or reading; increasing the time allocated to physical education is not detrimental to test scores for academic subjects.[168]

It is likely that findings would be similar if a modest amount of curricular time was allocated to organized sport rather than physical education, although this remains to be tested in both intramural and extramural settings. The issue of academic performance also needs to be evaluated more fully in older children and university students, who commonly allocate much larger amounts of time to sport and other physical pursuits. In many developed countries, older students commonly still have a large reserve of discretionary time, as shown by extensive television viewing.[169] However, in other parts of the world, the discretionary time of the older student may be severely limited by several hours of nightly homework assignments or a need to contribute to family income. Finally, much further information is needed about the impact of sports, physical education, and physical activity on the student's ultimate success in various types of careers and his or her brain health later in life. One cannot exclude the possibility that greater neurogenesis (induced by exercise begun early in life and continued over the life span) may enhance cognitive function later in life and offer protection against the neuropathologies of old age. But even if from the viewpoint of intellectual function physical activity is no more than an enrichment of the individual's life experience,[170] its numerous more general health benefits warrant advocating an active lifestyle at all ages. AJLM

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