

The impact of physical activity and fitness on academic achievement and cognitive performance in children

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(Received 9 March 2009; final version received 3 August 2009)

The potential for physical activity and fitness to improve cognitive function, learning and academic achievement in children has received attention by researchers and policy makers. This paper reports a systematic approach to identification, analysis and review of published studies up to early 2009. A three-step search method was adopted to identify studies that used measures of physical activity or fitness to assess either degree of association with or effect on a) academic achievement and b) cognitive performance. A total of 18 studies including one randomised control trial, six quasi-experimental and 11 correlational studies were included for data extraction. No studies meeting criteria that examined the links between physical activity and cognitive function were found. Weak positive associations were found between both physical activity and fitness and academic achievement and fitness and elements of cognitive function, but this was not supported by intervention studies. There is insufficient evidence to conclude that additional physical education time increases academic achievement; however there is no evidence that it is detrimental. The quality and depth of the evidence base is limited. Further research with rigour beyond correlational studies is essential.

Keywords: physical activity; physical fitness; children; young people; academic achievement; cognitive performance

Introduction

The physical health benefits of participating in regular physical activity and maintaining physical fitness are widely established (Department of Health, 2004, United States Department of Health and Human Services, 2008). It has been clearly demonstrated that physical activity decreases risk of developing cardiovascular disease (CVD), stroke, some cancers, obesity, type 2 diabetes mellitus and is also effective in the treatment of several of these diseases.

There has also been growing interest in the benefits of physical activity for mental health and a strong evidence base shows that regular activity and improved fitness increases psychological well-being (Biddle, Fox & Boutcher, 2001, Biddle & Mutrie, 2008). Exercise can help people feel better about themselves and their lives, reduce anxiety and improve mood. Evidence is also building to show that physical activity is associated with substantially reduced risks of mental illnesses and conditions such as

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depression, cognitive impairment and dementia (Fox & Mutrie, in press; Hamer & Chida, 2008). The benefits of physical activity in the treatment of depression (National Institute of Clinical Excellence, 2004) and improvement in select aspects of cognitive function in older adults are becoming increasingly well established (Angevaeren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008). Furthermore, acute bouts of well managed physical exercise may facilitate certain aspects of information processing in adults (Tomporowski, 2003).

Some of these positive effects on mental health have also been shown in children and adolescents, although the evidence base is limited. Few studies have investigated the preventive or treatment effects of exercise on mental illness within this population, partly because incidence is low. However, reviews have indicated that exercise and/or sport involvement can have beneficial effects on psychological well-being. For example, exercise has been shown to improve physical self-perceptions and to a lesser extent self-esteem in children (Fox, 2001) although effects are inconsistent.

In addition to the effects on psychological health, there has been substantial interest in the potential impact of improved fitness and exercise on cognitive function and learning in children. The notion that higher levels of activity or fitness may enhance thinking, concentration and subsequently academic performance is attractive to educators. Not only could it benefit children, it could improve the school's added value for academic achievement. For physical educators and sports coordinators, it could justify greater provision of physical activity in the school curriculum. Indeed, since the early 1990s schools have been adopting commercial programmes such as *Brain Gym* (www.braingym.org.uk), a system that utilises motor coordination exercises to enhance learning, despite evidence of its effectiveness. Other schemes such as 'Wake Up Shake Up' (www.foundation-stage.info) and 'Energizers' (www.ncpe4me.com/energizers) are also emerging in schools within the UK and the US respectively.

Four literature reviews have been published on the links between physical activity and cognitive function or academic performance since 2003. In a review of 44 studies Sibley and Etnier (2003) examined the evidence for the influence of physical activity on cognition in children. 28 cross-sectional associational and 16 intervention studies, with children between the ages of four and 18 years were included. Eight different categories of cognitive assessment were identified and associations or effects of single bouts and regular participation in various forms of aerobic training, resistance training and physical education curriculum were summarised. A mean effect size of 0.32 in favour of activity was reported. This review was very inclusive with several studies being unpublished, outcome measures were diverse and some samples were children with learning difficulties where relationships might be quite different.

The association between physical activity and school performance was reviewed by Taras (2005) in a paper reporting 14 studies, including an unstated number with abstract only, published between 1984 and 2004, involving participants between five and 18 years of age. In a narrative summation of the findings, showing weak or no correlation between activity level and academic performance, Taras concludes that the field requires further research to better understand the impact of activity levels upon student performance. Trudeau and Shephard (2008) presented a recent review of studies linking school time physical activity and academic performance. Nine cross-sectional studies and seven quasi-experimental studies assessing

academic performance by grade point averages (GPAs) and determinants of GPA (concentration, classroom behaviour etc), published between 1966 and 2007, were included. The review reported non-significant trends in studies and concluded that academic achievement is not affected by limiting the time allocated to PE instruction, school physical activity and sports programmes.

A narrative summary of the research into the effects of physical activity on cognition in childhood was presented by Hillman, Erickson and Kramer (2008) as a short sub-section of a paper assessing the wider effects of physical activity on cognition across all age groups. The authors concluded that, from the limited amount of published research there was no indication that an increase in curriculum time physical activity is associated with a decrease in academic performance. A further narrative review is offered by Tomporowski, Davis, Miller, and Naglieri (2008), of studies of the effects of physical exercise on cognition and academic achievement. The conclusion reached by these authors is that exercise may be an important method of enhancing aspects of mental functioning that are central to cognitive development. Highlighted in this paper is the variability of the outcome of studies and poorly selected outcome measures. The authors suggest that this may be due to factors including researchers selecting populations that do not represent the general population, for example, children with mental or physical disabilities.

Given the interest in the potential for physical activity in its various forms to enhance cognitive and school performance, we feel that a more systematic and rigorous approach to reviewing the literature is warranted that provides a robust and objective summary of the state of knowledge on this important topic. This is required in order to judge what is required to take the field forwards. Currently, the conclusions of existing reviews are equivocal and it is not possible to determine whether this arises from study or population selection, combining studies of different design or that address different research questions, or interpretation of findings. There are several study characteristics that require clearer segmentation including distinguishing between physical activity versus fitness effects, extra versus within curriculum activity, cognitive function versus academic achievement, and perhaps short term or acute versus long term effects.

This review has attempted to address some of these issues by taking a carefully delineated approach to reporting the current published literature (until February 2009). Studies investigating academic performance and cognitive function as outcome variables are assessed separately, as are those taking physical activity and physical fitness as exposure variables. Furthermore cross sectional studies are separately assessed from intervention studies and greater precision in the definition of variables is attempted. Summaries are confined to outcomes that have achieved the researchers' set levels of statistical significance. Results are discussed in the context of the potential for this area of research and the kinds of research questions and designs that would be needed to take the field forwards.

Terms of reference

The following definitions are provided to maintain clarity and consistency through the remainder of the review.

Exposure-independent variables

Childhood **physical activity** is a complex mix of behaviours that take place in diverse social settings. Consideration could be given to categories such as break-time play, active travel, sport and physical education (both within and additional to the school curriculum), informal play and sports and dance clubs outside school. This review considers contexts as well as modes of activity which might include walking, running, cycling, swimming, vigorous sports, and dance. Furthermore, consideration is given to how each of these was quantified in terms of duration, frequency and level of intensity.

In contrast to physical activity, **physical fitness** is a complex set of functional capacities and capabilities. In children, these are partly determined by genetic factors and stage of biological maturation as well as the amount of physical activity undertaken. Often a battery of tests are used to assess components such as cardiovascular fitness, muscular strength and endurance, sometimes body composition or degree of fatness, flexibility, agility, coordination, balance and reaction time. This review includes any aspect of physical fitness when it has been assessed using a standardised test or measure to score subjects.

Outcome variables

Academic achievement is the child's performance when assessed by standardised tests within a school, or educational setting. Often this is quantified as achievement in specific subjects such as mathematics or reading skill, grade point average (in the US) or through standard national assessment tests (SATs). This variable is dependent on the ability of the child, their home background and environment, as well as the quality and quantity of academic instruction that child receives.

Cognitive performance refers to the child's performance when assessed using a recognised and validated test of cognitive function. Tests assess components of cognition such as reaction time, attention, working memory and stimulus response (collectively referred to as executive control). Cognitive and academic performance are thought to interrelate as aspects of cognition such as attention and working memory are vital for academic success.

Method

Search strategies

A three-step search method was used to identify studies meeting inclusion criteria that investigated the relationship between physical activity or physical fitness and cognitive performance or academic achievement. The terms, and their combinations were searched in the databases of MEDLINE, PSYCHINFO, Cochrane data base, Google Scholar and ERIC: physical activity; habitual activity; physical education; physical fitness; physical education; cognition; cognitive function; cognitive performance; cognitive health; academia; academic performance; academic achievement and academic grades. The references lists of all identified studies were also searched for titles containing any of the above terms, and all relevant studies followed up. Three selected prominent authors in the field were then contacted by email and

provided with the list of studies meeting inclusion criteria and asked to identify further relevant papers.

Inclusion and exclusion criteria

For inclusion within this review studies had to meet all the following criteria:

- Involved a study population of children and/or adolescents, without learning disorders or special needs, aged between four and 18 years;
- used one of the following research designs: randomised control trial (RCT), quasi-experimental, cross-section or longitudinal correlational;
- used a measure of physical activity (objective, self-report, or teacher rated) or physical fitness as an independent or exposure variable;
- used a measure of academic achievement or cognitive performance as a dependent or outcome variable; and
- was published or accepted for publication in a peer reviewed journal.

Data extraction

A standard data extraction template was used to extract the following data from all studies meeting criteria; primary and secondary research questions, location, sample size and characteristics, study design, exposure and outcome measures, adjustment variables, results with significance levels, and conclusions. These were then used as a basis of the summary tables.

Results

Search results

17 studies satisfied inclusion criteria. Of these, 11 were cross-sectional correlational studies. Five studies were of quasi-experimental design. One randomised controlled trials was identified. Five studies of correlational design (Table 1a) and five studies of quasi-experimental design (Table 1b) assessed physical activity and academic achievement. Four studies of correlational design assessed physical fitness and academic achievement (Table 2). Two studies of correlational design (Table 3a) and one study of experimental design (Table 3b) assessed physical fitness and cognitive function. No study examining the links between physical activity and cognitive function were found.

Physical activity and academic achievement

The five studies in Table 1a were all cross-sectional and were conducted in North America, Canada, Australia, Iceland or Hong Kong. Sample sizes varied from 333 to 7691, with ages ranging between kindergarten age and 15 years old. In four studies, total daily physical activity was assessed using a children's self-reported physical activity recall questionnaire and the other featured teacher-rated physical education curriculum time. Academic performance was assessed by test and examination results and in one case by an educational professional. In three of the studies

Table 1a. Physical activity and academic achievement: correlational studies

Author, (date)	Location	Subjects	Physical activity assessment	Academic assessment	Primary finding
Carlson <i>et al.</i> (2008)	USA	5316 students followed from Kindergarten to 5th grade.	Teacher reported frequency and duration of PE lessons. Tertiles formed.	Mathematics and reading tests.	Third tertile girls (70–300 mins of PE per week) achieved slightly higher academic scores in kindergarten, first grade and fifth grade reading and first grade mathematics compared to first tertile girls (0–35 mins of PE per week).
Sigfusdottir <i>et al.</i> (2006)	Iceland (nationwide)	5810 ninth and tenth grade students	Self-reported physical activity.	Self-reported average grades for Icelandic, Maths, English and Danish	A very weak positive ($r = 0.09$) and significant ($p < 0.01$) correlation between self-reported PA and self-reported grades.
Yu <i>et al.</i> (2006)	Hong Kong, China	333 students aged 8–12 years.	Physical activity questionnaire for older children (PAQ-C).	Examination/test results and teacher reported conduct grades.	PA not associated with academic achievement in either boys ($r = -0.067$, non-sig) or girls ($r = 0.068$, non-sig). PA negatively associated with school conduct in girls ($r = -0.124$, $p < 0.01$)
Dwyer <i>et al.</i> (2001)	Australia	7691 students aged 7–15 years	Experimenter administered questionnaire assessing frequency, duration and intensity of previous weeks PA and usual activity	School representative rated each students academic ability	Weekly PA associated with scholastic rating in 9, 10 and 11 year old girls (r range = 0.11 to 0.14, p range < 0.05 to < 0.01) and 9, 10 and 12 year old boys (r range = 0.11 to 0.17, p range < 0.05 to < 0.001). Usual lunchtime activity positively (r range = 0.08 to 0.18 and significantly (p range < 0.05 to < 0.001) associated with scholastic rating in boys and girls.
Tremblay <i>et al.</i> (2000)	New Brunswick, Canada	6923 sixth grade students	Four questions assessing participation in physical activity	Maths and reading test scores	A weak negative relationship between PA and academic achievement.

Table 1b. Physical activity and academic achievement: intervention studies

Author, (date)	Location	Subjects	Intervention	Academic assessment	Primary finding
Ahamed <i>et al.</i> (2007)	British Columbia, Canada	288 primary school students, aged 9–11	<i>AS/ BC</i> : 16 months of an additional 47 min/wk of school time PA	Canadian Achievement Test (CAT-3)	Usual practice schools had significantly ($p=0.001$) higher scores at baseline than intervention schools, but not at follow-up.
Coe <i>et al.</i> (2006)	Michigan, USA	214 sixth grade students	One semester of one 55 min lesson of PE per day	Academic achievement grades and standardised test score	Academic achievement not affected by the one semester of increased PE.
Sallis <i>et al.</i> (1999)	Southern California, USA	654 fifth and sixth grade students	<i>Project SPARK</i> : 2 years of an additional 27–42 min/wk of PE and an additional 27–29 min/wk of ‘self-management’ classes	Metropolitan Achievement Test (MAT6/7)	Intervention group showed significantly (p range =0.02 to 0.001) smaller declines in academic performance compared to control group.
Shephard <i>et al.</i> (1984)	Trois Rivieres, Quebec	546 first to sixth grade students	5 hours of PE per week for five years; control 40mins per week for same time period.	Standardised exam and teacher rating.	Improvement in performance in English, but not maths in standardised exam. Improved teacher ratings.
Dwyer <i>et al.</i> (1983)	South Australia	500 fifth grade students	2 years of 75 min/day of PE focusing either on skill or fitness. Controls maintained three classes of 30 min/week	ACER arithmetic test and GAP reading test	No significant difference in either measure of academic performance.

Table 2. Physical fitness and academic achievement: correlational studies

Author, (date)	Location	Subjects	Physical fitness assessment	Academic assessment	Primary finding
Eveland-Sayers <i>et al.</i> (2009)	Tennessee, USA	134 third, fourth and fifth grade students	1 mile run, sit-up, sit-and-reach and BMI.	Mathematics and reading/language sections of Terra Nova test	A significant negative correlation between 1-mile run times and mathematics ($r = -0.28$, $p < 0.01$) and muscular fitness and mathematics ($r = 0.20$, $p < 0.05$). When analysed by sex difference correlations were significant in girls but not in boys.
Castelli <i>et al.</i> (2007)	Illinois, USA	259 3rd and 5th grade students	The Fitnessgram	Annual ISAT test	Total ($r = 0.42$, $p < 0.01$), Maths ($r = 0.45$, $p < 0.45$) and Reading ($r = 0.41$, $p < 0.01$) achievement positively and significantly associated with "total fitness". Total ($r = 0.48$, $p < 0.48$), Maths ($r = 0.49$, $p < 0.01$) and Reading ($r = 0.45$, $p < 0.01$) achievement positively and significantly associated with cardiovascular fitness.
Grissom (2005)	California, USA	884,715 5th, 7th and 9th grades students	The Fitnessgram	STAR, SAT/9 and CAT/6 tests	Consistent, positive and significant association between fitness scores and academic achievement scores
Dwyer <i>et al.</i> (2001)	Australia	7691 students aged 7–15 years	Numerous subjective measurements and PWC170	School representative rated each students academic ability	Consistent, positive (r range = -0.11 to -0.18 – scaled by increasing time on 1.6 km run) and significant (p range < 0.05 to < 0.001) association between cardiovascular fitness and academic achievement. Disparities of results between subjective and objective measurements.

Table 3a. Physical fitness and cognitive performance: correlational studies

Author, (date)	Location	Subjects	Physical fitness assessment	Cognitive assessment	Primary finding
Buck <i>et al.</i> (2007)	Illinois, USA	74 children aged 7–12 years	The Fitnessgram	The Stroop colour-word task	Aerobic fitness was positively and significantly ($p = 0.001$) associated with the word, colour and incongruent colour-word conditions of the Stroop task. Results suggest aerobic fitness was associated with better cognitive functioning and executive control.
Hillman <i>et al.</i> (2005)	Illinois, USA	24 children mean age 9.6 years	The Fitnessgram	A visual oddball paradigm	High fit children had a significantly faster reaction time ($p < 0.01$), greater P3 amplitude ($p < 0.001$) and shorter P3 latency ($p < 0.001$). Results suggest greater allocation of of attention and working memory in high fit children.

Table 3b. Physical fitness and cognitive performance: intervention studies

Author, (date)	Location	Subjects	Intervention	Cognitive assessment	Primary finding
Davis <i>et al.</i> (2007)	Augusta, Georgia, USA	94 children, aged 7–11 years, mean age 9.2 years.	Low-dose (20 mins) vs High-dose (40 mins) of gymnasium based exercise eliciting a Heart Rates of >150BPM. 5 days per week for 15 weeks.	CAS (based) on the Planning, Attention, Simultaneous and Successive (PASS) theory.	Controls showed significantly lower post-test CAS Planning score than high-dose exercise group $p = .01$. No significant difference between control and low-dose exercise groups or low and high-dose exercise groups.

associations were reported when controlled for socio-economic status, parental education and ethnicity of the child.

Results from the studies in Table 1a were mixed. The Hong Kong study, which had the smallest sample, found no association between physical activity (as measured by the Physical Activity Questionnaire for Children (PAQ-C)) and examination/test scores. The study by Carlson *et al.* (2008) where physical education time tertiles were compared did show significantly higher mathematics and reading scores in the high versus the low PE tertile. This effect was weak but provides some indication that more time dedicated to PE is not detrimental to academic performance. In the remaining three correlational studies weak positive relationships, with r values ranging from 0.08 to 0.18, were found. There were no consistent patterns for age and gender.

In summary, these cross-sectional associational studies provide limited evidence of a weak relationship between physical activity and academic achievement.

No inference can be made on the causal nature of the relationships described in these correlational studies. Table 1b details five non-randomised controlled interventions that varied in duration from six months to five years. These studies were conducted in Canada, Australia and North America. All groups were of primary school age and cohort size varied between 214 and 654. The interventions were based on sustaining higher levels of physical activity through increased PE curriculum time and in one case (Sallis *et al.*, 1999) additional self-management classes. Therefore, in all cases the increase in PA was at the expense of academic instruction, with control schools continuing their normal curriculum provision. Increases in PE time varied from 27 minutes per week to 75 minutes per day. The measurement of children's physical activity varied from direct observation to use of the PAQ-C and the calculation of MET values. Academic achievement was assessed using standardised national tests, grades and in one case teacher ratings were added.

Two studies showed that an increase in school time physical activity was not associated with a change in academic performance. One study showed significantly smaller declines in four out of the eight measures of academic performance when compared to control schools. One showed an increase in performance in Mathematics but not in English and one showed a closing of a baseline difference in academic performance which was suggestive of a positive effect for higher levels of curriculum-based physical activity. None of the studies reported a significant detrimental effect of school time physical activity on academic performance. There was no obvious dose response relationship between the degree of the increase in physical activity or the length of intervention and academic performance in the school.

In summary, these studies indicate that the introduction of more curriculum time physical activity, at the expense of time allocated to academic subjects, does not have a detrimental effect on childrens' academic performance. Only one study reported a significant improvement in elements of academic achievement with increased school time physical activity.

Physical fitness and academic achievement

The four studies, three from North America and one from Australia, included in Table 2, examined the relationship between physical fitness and academic

performance. Ages ranged from 7 to 15 years with sample sizes ranging from of 134 to 884,715. Two studies used the US Fitnessgram which includes the following tests: PACER (cardiovascular endurance), push-ups and sit-ups (muscular endurance), sit and reach (flexibility) and body mass index. In the Eveland-Sayers *et al.* (2009) study all but the PACER test of the US Fitnessgram battery was used, replacing this with a one-mile run. The fourth study (Dwyer, Coonan, Leitch, Hetzel, & Baghurst, 2001) used a battery of tests including standing long jump (muscular power), sit ups and push ups (muscular endurance), sit and reach (hip flexion), skinfold thicknesses (fatness), lung function, 50 meter sprint (muscular power) and 1.6 kilometer run (cardiorespiratory endurance). Three studies used standardised tests to assess academic achievement while one study used a rating of academic ability on a five-point scale by an adult school representative (usually the school principal). Two studies (Castelli, Hillman, Buck, & Erwin, 2007; Dwyer *et al.*, 2001) reported controlling for socioeconomic status and parental education.

Consistent moderate positive correlations between physical fitness and academic performance were seen across the studies. The strongest correlations were seen with cardiovascular fitness, with r values ranging from 0.41 when using the PACER to -0.20 using the increasing time on 1-mile run. Associations were also seen between measures of muscular force/power and flexibility and academic scores. Dwyer *et al.* (2001), with 7691 children, also used a laboratory bicycle-based PWC₁₇₀ that measures physical capacity at the heart rate of 170 beats per minute per kilogram of lean body mass. In contrast to the field test of cardiovascular fitness, there was no relationship found with academic performance. This raises questions about the possible confounding of motivation, confidence, or cognitive skill factors when operating field tests of cardiovascular fitness.

In summary, these four studies provide evidence of a relationship between mainly cardiovascular fitness and academic performance when field tests are used as estimates of fitness. However, this was not confirmed by the only study that used a more precise laboratory-based measure of cardiovascular fitness.

Physical fitness and cognitive performance

Our search strategy revealed two small correlational studies (Table 3a) and one intervention study (Table 3b) conducted in the US that assessed the association between physical fitness and cognitive performance. The Fitnessgram described in the previous section was used in both the correlational studies. In the study by Buck, Hillmann, & Castelli (2007), using a sample of 74 children between the ages of 7 and 12 years, the Stroop colour word task was used to assess selective attention, response inhibition, interference control and speed response (executive control). In the Hillman, Castelli, & Buck (2005) study of 24 children, with an average age of 9.6 years, a visual oddball paradigm was adopted to assess the ability to discriminate, time for task completion, as well as P3 latency and amplitude. The P3 is part of the event-related brain potentials occurring 300–800ms after stimulus and occurs when the participant is attending to and discriminating between stimuli. In both studies higher levels of aerobic fitness were associated with significantly better performance on the cognitive task. These two studies provide initial evidence of a potential relationship between aspects of fitness (mainly aerobic) and cognitive performance.

The only intervention study was conducted recently by Davis *et al.* (2007). They used a pre and post intervention aerobic fitness treadmill test and the CAS test, based on the Planning, Attention, Simultaneous and Successive (PASS) theory of cognitive functioning. The intervention consisted of low and high-dose gymnasium based exercise programmes, focused around group games. Children in the low-dose group exercised for 20 minutes, five days per week for 15 weeks and the children in the high-dose group exercised for 40 minutes. Both groups aimed to achieve an average heart rate of 150 bpm for each session. The high-dose exercise group differed significantly from the no additional exercise control group on the Planning aspect of the CAS test. This well-designed study provides initial evidence for an effect of exercise upon at least one aspect of executive function. It is of note that low and high-dose intervention groups did not differ significantly on the treadmill post-test, suggesting that difference in fitness gains made by the two groups were small. Factors other than fitness change may have been responsible for the difference in cognitive function.

Discussion

During the past 10 years, interest has grown considerably in the social, mental and educational benefits of physical activity for young people. There appears to be great potential in this area, and indeed a belief in the value of sport and activity for social and mental benefits has already underpinned considerable investment in their promotion by local and national government. Particular attention has been paid to the potential for physical activity to improve learning and academic achievement. However, the small number of published reviews that have focused on the effects of physical activity on academic and cognitive performance in young people have not produced consistent results. This review attempted to take a systematic and rigorous approach to the identification, selection, and interpretation of this body of literature.

The following general conclusions can be drawn about the state of the evidence base (until the end of February 2009):

1. There are few published studies. Only 17 were identified. The reasons for this paucity of research, especially given policy interest and indications of plausible mechanisms from related areas of research (discussed later) are not clear.
2. The majority of studies are cross-sectional and correlational in design. These at best have produced weak positive associations. There are several factors including level of motivation and aspirations, cognitive skills, clustering of abilities within individuals, parental encouragement and logistic support, that could provide alternative explanations for associations between engagement in activity and sport and mental performance. Controlled intervention studies are therefore necessary to isolate cause and effect.
3. Only six intervention studies were identified. Experimental studies have focused on the effect of additional school-time physical activity on academic performance. An exception is the recent work of Davis *et al.* (2007) that addressed aspects of executive function. No studies primarily addressing effects of physical activity in other contexts such as the active travel, break-time play, informal play from the home, or participation in non-school based clubs and teams were located.

4. Exposure variables have mainly been in school activity time or performance on a battery of physical fitness tests.
5. Outcome variables have been restricted to performance on standardised academic tests, grade point average and three studies provided scores on cognitive performance tasks.

Based on the existing evidence, we feel we are able to make the following statements.

1. Based on five cross sectional studies, a weak relationship may exist between total daily physical activity and academic achievement. There are several plausible alternative explanations for this relationship and no intervention studies to support it.
2. There is no consistently convincing evidence to show that increasing curricular-based physical activity improves academic achievement. However, where physical activity has replaced academic time in the curriculum in primary schools, there is no evidence of a detrimental effect on academic achievement. Given the benefits of physical activity for children's healthy growth, weight management, and general health, this could be taken as supportive evidence for a greater amount of school time spent on physical activity. However, experimental studies that compare the effects of replacing decreased academic time with physical activity or sedentary non-academic time are required before firm conclusions can be drawn.
3. Based on four cross-sectional studies, a weak relationship exists between aspects of physical fitness, primarily aerobic fitness as measured by field running tests, on elements of academic achievement. It should be noted that the only study to use a laboratory-based test of aerobic fitness did not find a relationship, and field tests are susceptible to confounding by motivational factors (Fox & Biddle, 1988). There is no experimental evidence to indicate that improving fitness will increase academic achievement.
4. Based on two cross-sectional studies, a weak relationship exists between aspects of physical fitness, primarily aerobic fitness and executive control elements of cognitive performance. This is supported by one recent well-designed randomised controlled trial showing positive effects for a programme of additional daily exercise.

As the literature stands, it is not possible to determine whether cognitive performance or academic achievement are improved by physical activity or physical fitness. Although there is weak cross-sectional evidence, there are too many other possible and plausible explanations for this relationship. Parents who support and encourage their children's academic activities are also likely to encourage them to be active. Similarly, children are likely to emulate their parents' values which might include both sport and academic achievement. Further, there may be some degree of clustering of academic and athletic abilities in children. As explained earlier, academically more capable or driven children may be more motivated in particular to do well on tests of physical fitness, particularly where running for speed and distance is the measure. Children with behavioural problems are less likely to be involved or survive in school sport. Children who are unfit and inactive may reflect greater illness and school absence, and miss out on school work.

In conclusion, there is only a small amount of research published, that features sufficiently rigorous measurement, and adequate study design. Only one randomised controlled trial was located. Clearly, there has been very limited investment in research in this area. This is surprising because of policy interest in the area, and the intuitive and grass roots belief that physical activity is good for the brain. Furthermore, there are indications from other research approaches, particularly in psychobiology and neuroscience, most of it based at this stage on animal models, that there may be some important underpinning mechanisms to explain effects of exercise on cognitive function. Neurogenesis is the growth of new nerve cells in the nervous system, and provides a potential mediating mechanism by which physical activity and fitness could improve cognitive efficiency. In mice, voluntary exercise and running have been shown to stimulate hippocampal neurogenesis (van Praag *et al.*, 2005, Brown *et al.*, 2003). Similarly, exercise induces angiogenesis (the growth of new vascularity and hypertrophy of existing blood vessels) within the cerebral cortex of rats (Kleim, Cooper, & VandenBerg, 2002). It has been postulated that this may benefit cognitive function by allowing greater perfusion of blood through this region.

It has been suggested that mechanisms such as these underpin the growing evidence base that indicates reduction in the region of 30% in subsequent risk of premature cognitive decline and dementia in older adults who have been and remain active (Fox & Mutrie, in press, Hamer & Chida, 2009). The notion that exercise helps maintain the hard wiring and blood supply in the brain seems plausible as metabolic turnover with exercise increases dramatically from rest. It seems equally plausible that exercise might stimulate neural growth and efficiency during the period of biological maturation in children. However, there is little current evidence to support this. Perhaps the most convincing evidence is provided by Winter *et al.* (2007) who showed through a randomised cross-over design that vigorous activity can improve brain-derived neurotropic factor, dopamine and epinephrine and these improve post-exercise capacity for aspects of short term and medium term cognitive performance. However, this study was conducted with young male adults.

Future research

Certainly, these diverse sources of evidence suggest that high quality research should be undertaken to investigate the impact of both acute and regular physical activity on the cognitive function of children and young people, particularly during important phases of growth. There is also a case for investigating the impact of exercise on the cognitive function of those who have cerebral impairment.

Our view of the work to date is that intervention designs are needed. Because of the early stage of this research, many small scale studies focusing on potential mechanisms and feasibility studies are required before more expensive trials are attempted. There is insufficient knowledge at the descriptive level to identify definitive mechanisms and interventions at this point. It would seem helpful to pay more attention to the path of potential effect. For example, before impact on academic achievement is addressed, it would seem appropriate to have some notion of the potential mechanisms by which physical activity or fitness would take effect. This may be through higher levels of specific cognitive performance such as concentration, memory, decision making, alertness and thinking speed. It may be

a result of psycho-physiological shifts caused by exercise or improved fitness on cerebral function so future research should be ambitious and consider endocrinological changes and functional fMRI techniques. This will require exercise researchers to team with neuroscientists. Social psychologists on the other hand may wish to investigate the effect of individual differences in motivation and factors in the activity setting as contributors to effect.

Other considerations are important. Objective measures of physical activity such as accelerometry and stronger measures of physical fitness are likely to provide greater insight into individual differences and help increase precision of estimates. It is notoriously inaccurate to assess activity through self-report in children.

Greater attention should be paid to the context in which activity takes place, and the mode, frequency and intensity of the activity. Different effects are likely to be seen as these factors vary. Similarly, different factors might dominate with developmental stage of the child, so careful thought needs to be given to choice of age group of the sample.

Future research needs to take into account current weaknesses but the quality of future research will be dependent on adequate funding. Currently, given the paucity of research, no strong tradition is established for work in this area. Although it will take time, if the research question or objectives are clearly stated, if a convincing case is provided for the need to address the research question, and there is high quality in the research method, measures and analytical tools proposed, then there will be increasing chance of the work being funded.

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