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Review

Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis

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ABSTRACT

Objectives: The aim of this meta-analysis was to provide a systematic review of intervention studies that investigated the effects of physical activity on multiple domains of executive functions, attention and academic performance in preadolescent children (6–12 years of age). In addition, a systematic quantification of the effects of physical activity on these domains is provided.
Design: Systematic review and meta-analysis.
Methods: Searches of electronic databases and examining relevant reviews between 2000 and April 2017 resulted in 31 intervention studies meeting the inclusion criteria. Four subdomains of executive functions (inhibition, working memory, cognitive flexibility and planning), three subdomains of attention (selective, divided and sustained) and three subdomains of academic performance (mathematics, spelling and reading) were distinguished. Effects for different study designs (acute physical activity or longitudinal physical activity programs), type of physical activity (aerobic or cognitively engaging) and duration of intervention were examined separately.
Results: Acute physical activity has a positive effect on attention (g = 0.43; 95% CI = 0.09, 0.77; 6 studies), while longitudinal physical activity programs has a positive effect on executive functions (g = 0.24; 95% CI = 0.09, 0.39; 12 studies), attention (g = 0.90; 95% CI = 0.56, 1.24; 1 study) and academic performance (g = 0.26; 95% CI = 0.02, 0.49; 3 studies). The effects did depend on the subdomain.
Conclusions: Positive effects were found for physical activity on executive functions, attention and academic performance in preadolescent children. Largest effects are expected for interventions that aim for continuous regular physical activity over several weeks.

1. Introduction

European preadolescent children (aged 6–12 years) spend 209 min/day (64%) of their school time in sedentary activities, while spending only 16 min/day (5%) in moderate to vigorous physical activity (MVPA).[1] This is concerning because apart from the clear physical health benefits of MVPA in children,[2,3] an expanding body of literature shows that MVPA is positively associated with key cognitive functions that are important for success in school.[4] Recently, many researchers have been focusing on the executive functions hypothesis.[5] This hypothesis states that MVPA leads to increased activity in selective parts of the brain structural network and especially improves executive functions.[5] Executive functions are higher order cognitive functions that are responsible for initiating, adapting, regulating, monitoring, and controlling information processes and behavior.[6,7] These functions are often thought of as an important prerequisite for successful learning in preadolescent children.[7] Other researchers have focused on more lower-order cognitive tasks, with particular interest in attention.[8] Attention is defined as a cognitive state in which a child focuses on a selection of available perceptual information.[9] Although attention is closely related to executive functions,[10] it can be seen as a lower order cognitive function and it is mostly measured with performance on reaction time or other simple decisional tasks.[11] Improvements in these cognitive functions as a result of increased physical activity may, in turn, improve children's academic performance.

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Within the preadolescent age range, previous meta-analyses have shown that enhanced cognitive functioning as a result of physical activity is most clearly seen in executive functions[12] and attention.[8] These cognitive functions are indispensable for success throughout life and are often thought of as an important prerequisite for successful learning.[7] Several underlying mechanisms might explain the effects of physical activity on cognitive functions. First, a single bout of physical activity (acute physical activity) is thought to immediately elevate the child's level of physiological arousal, which in turn facilitates the cognitive performance by an increased allocation of attention.[13,14] From a psycho-physiological perspective, acute physical activity triggers an increase of neurotransmitters (e.g. epinephrine, dopamine, brain-derived neurotrophic factors), which are thought to enhance cognitive processes.[15,16] Secondly, according to the cardiovascular fitness hypothesis, an intervention program that contains continuous aerobic physical activity over several weeks (longitudinal physical activity program) is thought to improve aerobic fitness and consequently improve cognitive performance.[17] This hypothesis is supported by the argue that physical activity enhances the angiogenesis[18] and neurogenesis[16] in areas of the brain that support memory and learning, subsequently enhancing cognitive performance.[19] More recently, other researchers argue that instead of 'simple' aerobic physical activity (i.e. physical activity that is intended to improve cardiovascular performance), cognitively engaging physical activity (i.e. physical activity that is cognitively challenging) is more beneficial for cognition.[20–22] Cognitive engagement is the amount of both the allocation of attention and the cognitive effort that are needed for a certain activity.[20,23] Physical activities with a relatively high cognitive engagement (e.g. tennis, where children have to plan strategically, focus attention, and so forth) are suggested to have more effect on executive functions, compared to physical activities with a relatively low cognitive engagement (e.g. long distance running, which involves more automated movements).[20,22] These different underlying mechanisms suggest that the effects for physical activity to improve attention, executive functions and academic performance in children might depend on the duration or type (aerobic vs cognitively engaging) of physical activity is chosen.

Previously, studies have mainly focused on the association between physical activity and overall cognitive functioning in children. The results from a previous meta-analysis showed a positive association between physical activity and overall cognitive functioning in children (effect size [ES] = 0.21; 8–10 years).[24] Meta-analyses on studies allowing the investigation of causal relationships showed significant positive effects of physical activity on children's executive functions (ES = 0.57; 6–12 years)[12] and academic performance (ES = 0.27; 3–18 years).[4] In these previous meta-analyses only a few intervention studies investigated the causal effects in preadolescent children, especially those intervention studies that implemented a longitudinal physical activity program.[12] More recently, several randomized controlled trials have become available, aimed at investigating the effects of acute physical activity and longitudinal physical activity programs on cognitive functioning in preadolescent children.[20,25,26]

The current meta-analysis updates and expands previous meta-analyses by including only studies that investigate the effects of acute physical activity or longitudinal physical activity programs with an appropriate control group. All correlational studies were excluded from the present meta-analysis, as these designs do not allow investigation of causal effects. In addition, uncontrolled studies were excluded, because these designs do not allow conclusions on whether the possible improvements would also have been found if the participants had been exposed to another intervention not involving physical activity.[27] The aim of the present meta-analysis is to provide a systematic review of all available studies that investigated the effects of physical activity on multiple domains of executive functions, attention and academic performance in preadolescent children. In addition, a systematic quantification of the effects of physical activity on these domains is provided.

2. Methods

The electronic databases PubMed, Web of Science, MEDLINE and ERIC were searched for studies that investigated the effects of physical activity on attention, executive functions and/or academic performance. Key search terms included the words physical activity, physical fitness, executive functions, cognition, academic performance and children. Medical Subject Headings (MeSH) terms, free text words and all possible equivalents were used (Table 1S, see Supplementary material). The current meta-analysis included all studies that: (a) investigated the effects of physical activity on executive functions, attention and/or academic performance, (b) were written in the English language and published between 2000 and April 2017, (c) focused on primary school children between the age of 6–12 years, (d) included a random assignment or matching with appropriate adjustments for any pre-test differences[28] and (e) included outcome variables measuring executive functions, attention or academic performance on interval- or ratio-level scale. Exclusion criteria for the current meta-analysis were: (a) studies targeting special populations (e.g. children with mental or cognition disorders, nervous system diseases or brain injuries), (b) studies without appropriate control conditions or groups[29] and (c) studies of which the intervention consisted of more than just specific physical activity (e.g. interventions that included physical active and cognitive tasks). The PRISMA-statement for reporting systematic reviews and meta-analysis was used as a guideline to conduct the review.[30] A trained research assistant screened the titles of all studies retrieved from the electronic databases for potentially suitable studies, after which the trained research assistant and the first author screened the abstracts of the selected studies. If there was a doubt about the suitability of the study based on the abstract, the authors assessed the eligibility based on the full text of the article. The reference list of relevant reviews were searched for additional studies. Lead authors from studies without details that allowed for the calculation of ESs were contacted by email to retrieve missing details.

After removing duplicates and adding 7 studies from previous reviews, our initial electronic search yielded 3032 studies that were reviewed based on their title (Fig. 1). Seventy five (n = 75) full-text articles were reviewed, after which 41 were excluded (Table 2S, see Supplementary material). Common exclusion reasons were: studies without appropriate control conditions or groups (n = 9), cognitive tests that did not explicitly assess executive functions (n = 7), ages of participants were (partly) outside of target age range (n = 7) or interventions that combined physical activity with academic assignments (n = 6). Finally, one study was excluded because additional details were needed to calculate an ES and we received no response on our email nor on our reminder.[31] Thus, a total of 31 studies (4593 children) were included in the meta-analysis. The characteristics of the included studies can be found in Table 3S (see Supplementary material).

The study quality of the selected studies was assessed independently by a research assistant and the first author according to the Physiotherapy Evidence Database (PEDro) scale. The PEDro scale is an 11-item scale which has been used extensively in meta-analyses and reliably assesses randomization, blinding, intention-to-treat, between-group comparison and measures of variability.[32] Scores on the PEDro scale range between 0 and 10 (one item pertains external validity and is not used to calculate the score). An adequate quality is defined as a study having an adequate generation

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