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REVIEW ARTICLE

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Physical Activity, Academic Performance and Cognition in Children and Adolescents. A Systematic Review

Authors' Contribution:
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

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Abstract

A literature review was conducted to investigate the effect of physical exercise and physical training on cognition and academic performance in children and adolescents. Nine randomized or quasi-randomized controlled trials with 2,013 participants were identified by employing the following data sources: the Cochrane Register of Controlled Trials, Medline, Eric, CINAHL, PsychINFO, and ISI Web of Knowledge. Five studies indicated positive effects of physical exercise on attention, concentration, and working memory, and three studies reported positive effects of 14 to 64 week physical training on language and arithmetic skills. Thus, there is some evidence that physical exercise may facilitate cognitive functions related to learning and enhance academic performance.

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Introduction

An increasing number of children and adolescent in the Western world does not meet the health promoting physical activity (PA) recommendations [1]. The decrease in PA in our everyday life is related to many chronic diseases and risk factors such as type 2 diabetes mellitus and obesity even in children [2], but growing evidence indicates that an increase in physical activity may enhance cognitive functions at least in older adults [3]. However, more research is needed on looking at the associations of PA with cognition and academic performance in children.

In addition to remarkable benefits on cardiovascular health, PA is known to have positive effects on brain health and function [4]. PA is recently found to be a counter regulator against cognitive decline due to Alzheimer´s disease [5] and it may prevent vascular dementia due to atherosclerotic changes in cerebral vasculature in older adults [6]. PA is also associated with improved cognition [7] and certain measures of academic skills in children [8]. In addition to regular physical training, single bouts of physical exercise are associated with enhanced neuroelectrical processes in the cortex and with improved cognitive control [9, 10] in adults and in children. Single exercise bouts may also contribute to neural protection and synaptic plasticity due to increased levels of the brain-derived neurotrophic factor (BDNF) [11].

In the view of public health, it is reasonable to support children´s cognitive development and academic performance with increasing daily PA. As childhood obesity is today more prevalent in the Western countries than a few decades ago [12,13], effective interventions for preventing and treating overweight and obesity are needed. Evidence from the controlled training studies suggests that PA decreases adiposity in overweight and obese children and may prevent weight gain in normal weight children [14]. Additionally, a number of studies show that childhood obesity is associated with poor academic performance and cognitive function in children and adolescents [15, 16]. Also reversed associations between academic achievement and obesity have been found. A recent study suggests that poor academic performance through childhood to adolescence is associated with obesity among middle-aged Finnish women [17]. Thus, participating in physical activities during childhood may support cognitive development and enhance academic performance in childhood by improving cognitive functions or preventing overweight and obesity. However, it is not proved that PA interventions designed to enhance cardiometabolic health in children and adolescents are associated with improvements in cognitive functions and academic performance.

The purpose of this systematic review is on overview of the evidence of the effect of PA interventions on 1) cognitive ability such as concentration, attention, and memory, 2) academic achievement such as arithmetic and language skills, and standardized test scores in children and adolescents.

Material and Methods

Literature Search

Literature search (from 1966 to 2011) was conducted using Medline, PsycINFO, CINAHL, ISI Web of Knowledge, Eric, and Cochrane Register of Controlled Trials using the PICO (population, intervention, control/comparison, outcome) search method. Search words were: children, adolescent, young, exercise, physical activity, physical training, sport, physical education, academic performance, cognitive ability, cognition, memory, school performance, concentration, attention. A repeated search was conducted in March 2012 to identify articles possibly missed during the first search.

After computer-based search, a hand search for additional reports was made from reference lists of earlier reviews [7, 8, 18]. The focus in the literature search was on randomized controlled trials (RCTs). Only reports written in English were reviewed.

Inclusion Criteria

This review includes randomized intervention studies with parallel intervention and control groups. The study concerning a single exercise bout should report data on physical exercise, cognitive ability such as memory or attention, or academic performance in healthy school-aged

(7–18 years of age) children or adolescents. Physical training studies should report data about standardized test scores or academic skills. Only studies on children without pathological states were included. Included studies must also report both baseline and post intervention measures of the key outcomes.

Quality Assessment

The methodological quality of included reports was assessed using the PEDro Scale. The scale is based on the Delphi List [19]. A lower score (scale 0 to 11) indicates poorer methodological quality of the trials; a higher score is indicative of higher methodological quality. PEDro´s scale was chosen because it has fair to good reliability and it is easy to use, although it has mainly been used in physiotherapy research [20].

Results

The electronic search yielded 101 potential articles. The search also yielded 15 review articles and the reference lists of the latest of them were reviewed. Two additional articles were identified. 36 studies were excluded because they were not relevant to the topic, 42 studies were excluded due to lack of a control group or being cross-sectional. Nine studies satisfied the inclusion criteria and were included in this review. A summary of the included studies is presented in Tables 1 and 2.

Two thousand and thirteen children and adolescents aged 7 to 16 years participated in these nine studies. In physical training studies the intervention duration varied from 14 to 64 weeks. The mean PEDro´s score was 6.3 which represent moderately good methodological quality. There were four trials which could be rated methodologically as high-quality with PEDro´s minimum score of seven [21-24]. Although the scores from the PEDro´s scale revealed such high scores, there were no studies reported faithfully according the CONSORT statement [25]. There were flaws in reporting random allocation and blinding of outcome assessors. There was no systematic reporting of adherence to exercise interventions. Only one training study reported a retention rate of 62% [26].

Physical Exercise and Cognitive Function

Five studies examining the effect of exercise on cognitive variables were included (Table 1) [22, 23, 27, 28, 29]. In one study, there was no no-exercise control group, but regular physical education based intervention served as a control group [22].

Budde et al. [22] reported concentration as an outcome related to physical exercise. The experimental group performed coordinative exercises for 10 minutes and the control condition participated in regular physical education class for 10 minutes. Coordinative training contained exercises for balance, reaction, adjustment, and differentiation skills. They found a significant improvement in both groups, but the improvement in concentration was greater in the coordinative exercise group. Further analysis revealed a greater improvement in the coordination group in the standardized scores and mistakes related to the total count of answers.

Ellenberg and St-Louis-Deschénes [29] used choice response and reaction time as an outcome in evaluating effects of physical exercise on concentration in 7- and 10-year-old boys. Exercise intervention consisted of stationary cycling for 30 minute at the heart rate 130 beats per minute while watching TV. Children in the control condition sat and watched TV for 30 minutes. ANOVA revealed a significant difference between the exercise and the control group in both age groups. Both 7- and 10-year-old boys participating in the exercise intervention improved significantly in both measures. Neither age group in the control condition showed any improvement in their results in any of the two measures.

McNaughten and Gabbard [28] conducted an experiment to evaluate the effect of exercise on timed mathematical computation test in 11-year-old boys and girls. They stated that the test measured mainly concentration. They assessed the effect of 20, 30 and 40-minute moderate intensity walk compared with a no-exercise control condition. Assessments were made on three separate week days at one of the following times, 8:30, 11:50 a.m. or 2:20 p.m. They found no significant interaction between the control and intervention groups. Further analysis revealed a significant improvement in mathematical performance after 30 and 40-minute walking compared to 20-minute exertion, but only at 11:50 a.m. and 2:20 p.m.

Budde et al. [23] showed a significant improvement in working memory in the Letter Digit Span (LDS) task after 12-minute moderate intensity running in adolescents. They conducted trial with three conditions: no-exercise control condition, moderate intensity exercise, and high intensity exercise conditions. In the exercise conditions the participants ran at 50–60% or 70–85% of their maximum heart rate (HRmax), respectively. The individual HRmax was defined using the shuttle run test. All adolescents in the moderate intensity exercise group increased a total number of correct answers. Neither high intensity exercise group nor control group showed improvements in working memory. Additionally, adolescents with low working memory scores at baseline improved their results after both moderate and high intensity exercise.

Zervas et al. [27] conducted a trial with three conditions: endurance trained, untrained, and control condition. Endurance trained and untrained groups participated in a strenuous treadmill exercise whereas control group participated in sedentary behaviors. Attention, alertness, and concentration were assessed using the Cognitrone Test before and after the treadmill exercise. The control group rested 60 minutes between the tests. Before the exercise test, endurance trained group participated in a training program designed to improve cardiorespiratory fitness. At the time of the test endurance trained group showed significantly higher VO_{2max} compared to the untrained group (difference 2.1 ml/kg*min). Their results did not show differences between the groups which participated in the treadmill exercise, but both groups had more correct answers and faster decision times in the post exercise test compared to the pre-exercise test. In contrast, the no-exercise control group did not show improvement in answer accuracy, but also the control group showed improvement in decision time.

Physical Training, Cognition, and Academic Performance

The literature search revealed four intervention studies concerning physical training and academic performance [21, 24, 26, 30]. Summary of the included studies is presented in Table 2.

The positive effect of physical training on mathematical, reading, and language skills were reported in three studies [24, 26, 30]. Ahamed et al. [30] did not find any differences between the training and control group in a 16-month trial. Also Dwyer et al. [21] reported no differences in arithmetic and reading scores between the physical training and control condition after a 14-week trial. However, they reported better classroom behavior in children who participated in intensity centered training. In addition, it should be taken in consideration that in Ahamed et al. study [30] baseline scores in the intervention group were significantly lower than in the control group. Thus, the intervention group had a greater increase in the Canadian Achievement Test (CAT) scores, and the difference at the end of the study between two groups was insignificant.

Sallis et al. [26] conducted a 36-week randomized trial with three different groups. Two exercise training groups were supervised by an exercise specialist or a trained classroom teacher, and the control group. They assessed academic performance using Metropolitan Achievement Test (MAT). The baseline MAT scores in their sample were higher than the national average. The study consisted of two different cohorts which were recruited in two consecutive school years. They reported higher achievement scores in language and reading in the training group taught by an exercise specialist or a trained classroom teacher compared to the control group. In cohort 1 language and reading scores decreased in all three groups during the intervention period, but the decrease was smaller in both training groups. There was a significant association between taking part in the physical training program executed by an exercise specialist and reading scores. In cohort 2 there was an association between total, language, and reading scores and participation in the trained classroom teacher condition. In that group the decrease in academic scores was smaller than in the two other conditions. In cohort 2 there was a negative association between participating in the specialist condition and language scores compared to the two other conditions.

Tab. 1. Summary of the effects of a single exercise bout on cognition

Reference	PEDro´s score	Randomization	Sample	Exercise intervention group(s)	Control group	Academic outcome and assessment	Results
Budde et al., [22] (Germany)	7	Randomization stated in methods	99 healthy adolescents aged 13–16 yrs old (80 males; 19 females)	10 minute coordinative exercises	10 min of normal PE lesson	Attention and concentration; d2-test	Both groups significantly improved their results. Improvement in the total number of answers IG was from 413.64 to 773.06 and in the control group from 430.42 to 452.1. Improvement in the standardized test scores IG from 97.38 to 107.27 in CG group from 99.48 to 103.27.
Ellemberg & St-Louis-Deschênes, [29] (Canada)	7	Randomization in methods stated, no other details	36 boys (7 yrs old) and 36 boys (10 yrs old)	30 min stationary cycling (5 min warm-up 5 min cool-down) while watching TV at HR 130 bpm	Sitting still on the ergometer while watching a TV-show for 40 min	Reaction time, concentration, accuracy and choice response, Matlab™ computerized device	The IG improved reaction time significantly (7-yr-olds from 500 to 450 ms, 10-yr-olds from 400 to 350) and choice response task (7-yr-olds 680 to 550, 10-yr-olds 500 to 450). No improvement in the control group
McNaughten & Gabbard, [28] (USA)	3	Solomon four-group design	120 sixth-grade students (60 boys, 60 girls) mean age 11.3 yr.	At IG: 20, 30 and 40 min walking exercise at HR 120–145 bpm. Testing on 3 week days at 8:30, 11:50 a.m. or 2:20 p.m	Not stated	Mathematical skills; timed mathematical computation test	No between-group testing reported, improvement in the mathematic performance at 11:50 am and 2:20 pm after 30 and 40 min exercise
Budde et al., [23] (Germany)	8	Concealed allocation by an outsider, no other details given	59 healthy high school students aged 15–16 yrs (33 males; 26 females)	Group 1: 12 min run at 50–60 % HR_{max} Group 2: 12 min run at 70–85 % HR_{max}	Sedentary behavior for 12 min	Working memory; Letter Digit Span (LDS) task	Low intensity IG improved their results. Also children with low pre-exercise LDS scores improved their results significantly after low- and high intensity exercise.
Zervas et al., [27] (Greece)	5	Randomly assigned to two experimental groups; control group not randomly chosen	18 boys aged 11-14 yr (9 monozygotic pairs) as experimental group; 8 more boys (12–13 yrs old) served as a control group	Both experimental groups were tested before and after strenuous 20-min exertion on a treadmill. The 1st experimental group participated in high-intensity 25-wk training, three times a week: warm-up 15 min and 60 min continuous or interval running + regular PE classes 2–3 times a week. The 2nd experimental group: curricular PE 2–3 times weekly	60 min rest between the pre- and post test. Participation in curricular PE 2–3 times weekly	Mental performance; Cognitrone Test	No significant differences between groups. Both exercise intervention groups improved significantly their post-test results compared to the pre-test in correct answers; decision time decreased significantly in all groups. Trained groups correct answers from 20.7 to 23.4 and decision time 139 to 125 ms. Control group 22 to 23.3 and 145 to 128.

PE – physical education; IG – intervention group; HR – heart rate; HR_{max} – maximum heart rate; IG – intervention group

Tab. 2. Summary of the effects of physical training interventions on academic performance

Reference	PEDro´s score	Randomization	Duration of the intervention	Sample	Exercise intervention group(s)	Control group	Cognitive or academic outcome and assessment	Results
Ahamed et al. [30] (Canada)	5	Cluster randomized by school classes, no given details	16 months	288 students (143 boys; 145 girls, aged 9–11)	Classroom-based activities continuous 15 min/5 d/wk + curricular PE (2*40 min/wk)	Curricular PE (2*40 min/wk)	Academic achievement; Canadian Achievement Test (CAT3)	The exercise training group improved their test results in CAT3 from 1595.4 to 1672.2. The control group improved their scores from 1676.7 to 1686.6. Statistically significant difference at the baseline between the groups vanished during the intervention.
Sallis et al. [26], (USA)	5	Cluster randomized by schools, no other details; two different cohorts	36 weeks	955 students (aged 9 yrs) in 2 cohorts	Minimum 3 days/wk of 30 min standard SPARK PElesson: 15 min HRF and 15 min motor skill-fitness activity, taught by a trained teacher or a PE specialist	Continuing usual PE program and request not to begin a new mode of PA	MAT6- and MAT7-tests for reading, mathematics and language skills	Cohort 1: Post-test language scores differed (p=0.04) between the trained teacher and control conditions (pre-post difference -1.5 vs. 7.4). Reading scores differed (p=0.02) between specialist and control conditions (4.9 vs. -3.7). Cohort 2: Basic battery scores differed (p=0.001) between the trained teacher and both specialist and control condition (-9.0 vs. -17.3 and -15.9). The trained teacher and control condition performed better in language compared to the specialist condition (p=0.004) (-8.7 and -11.1 vs. -18.0). The trained teacher condition performed better in reading compared to the specialist and control conditions (p=0.001) (-16.3 vs. -21.8 and -22.3). The retention rate in both cohorts combined was 62.1%
Davis et al., [24] (USA)	9	Concealed randomization	18 weeks	171 overweight (BMI > 85%ile) children (44% boys; 56% girls, aged 7–11 yrs)	Extra-curricular exercise training: Low-dose exercise group: 20 min/5 d/wk at HR_{avg} > 150 bpm. High-dose exercise group: 40 min/5 d/wk at HR_{avg} > 150 bpm	No exercise	Academic performance: Woodcock-Johnson Test III; Cognitive performance: the Cognitive Assesment System (CAS)	Planning scores were associated with participation in low- and high dose IG. Mathematic skills were positively associated with physical training
Dwyer et al. [21] (Australia)	8	Cluster randomization by schools, no other details	14 weeks	231 students (115 boys; 116 girls, aged 10 yrs)	Curricular exercise training. Fitness group: 75 min daily; focus on intensity and increase in HR. Skill group: 75 min daily; focus on skills, not intensity or prolonged exercise	Curricular PE three 30 min periods weekly	ACER arithmetic test, GAP reading test, classroom behavior assessed by teachers with KAB Child Behavior Scale	No differences in the tests of arithmetics or reading; the fitness group showed better classroom behavior

PE – physical education; IG – intervention group; HR_{avg} – average heart rate; HRF – health related fitness; PA – physical activity; SPARK – Sport, Play, and Active Recreation for Kids; MVPA – moderate to vigorous physical activity

Davis et al. [24] conducted an 18-week trial with obese children with the body mass index (BMI) ≥ 85th percentile. They randomized the children into three conditions: no-exercise, low-dose (20 min/day exercise), and high-dose (40 min/day exercise). They assessed cognitive ability and academic performance using the Cognitive Assessment System (CAS) and Woodcock-Johnson Test 3. Children in both exercise groups performed significantly better in the planning task which requires effective executive functions than children in the control group. Children in the high-dose training group showed enhanced performance in the mathematical test. They did not find significant improvement in the reading scores or other fields of the CAS.

Discussion

This review highlights the benefits of single bouts of exercise on cognition. This review does not support the idea that training interventions are highly effective for enhancing academic performance. The earlier reviews [7-9,18] concerning both cross-sectional and prospective exercise studies showed possible benefits of both short term exercise and long term training on academic performance. However, results of the present review indicate that specific training interventions seems to have only mild if any effect on such measures in children.

Single exercise bout improves cognitive function immediately after the exercise. The evidence rising from the present review suggests improved concentration resources after 10 minutes of moderate intensity exercise [22, 27, 28]. The dose response issue concerning exercise and concentration is not clear, but the results indicate that moderate intensity exercise lasting 10 to 30 minutes is effective.

A single bout of moderate intensity exercise for 10 to 30 minutes was found to be associated with improved executive function and working memory. No improvements were seen after sedentary behavior or high intensity exercise [22, 23, 29]. Interestingly, aerobic physical training is shown to enhance executive function like a single bout of exercise, but physical training seems to be ineffective in improving working memory in young adults [31]. These acute improvements in cognitive processes may be due to increased plasma catecholamine concentration [32] or improved prefrontal activation [33]. Yanagisawa et al. [33] reported facilitated prefrontal cortex activity in the Stroop test after moderate intensity exercise. Furthermore, moderate intensity exercise increases cortical blood flow and oxygenation but maximal exercise causes deoxygenation in the prefrontal, frontal, and motor cortices [34], and due to this mechanism or others, strenuous exercise can cause fatigue and impair cognitive performance [35].

Physical training may improve academic performance in children and adolescents, but evidence is lacking. The most convincing evidence supports that short intervention times, fewer than 36 and 64 weeks, have little or no effect at all on academic performance. Thus, the included studies may have been too short for bringing remarkable benefits on learning. However, Davis et al. [24] showed promising results of the effect of physical activity on executive function and increased prefrontal activity during a mental task after 18 weeks of training in obese children. This finding is important because the prevalence of childhood obesity is increasing and obesity is associated with lower executive processes in children and adolescents [16].

As is known, learning is a complex process which is affected by motivation and learning readiness of the student but also external factors such as teachers and home environment. Thus, longterm, perhaps lifelong physical training enhances brain function and development. Included interventions were perhaps too short in duration to produce significant effects. It is also known that cardiorespiratory fitness is associated with better academic performance [36]. There is not data available on whether cardiorespiratory fitness differed significantly after the intervention period between the control and training groups in the included studies.

However, a positive effect of cardiorespiratory fitness on brain function and academic performance is supported in a large cohort study [37], and also Stroth et al. [38] showed interesting results regarding cardiorespiratory fitness and cognitive functioning in adolescents. In their study cardiorespiratory fitness, but not acute exercise, was related to more efficient executive control.

Conclusion

Single bouts of exercise may enhance cognitive processes and academic performance in children and adolescents. Exercise can improve concentration and working memory which may increase academic performance in the long term. Learning is a complex neurobiological and social process which can be affected by external factors such as parental education, school environment, and socioeconomic status. Physical training can improve brain function, but major improvements in cognition and academic performance may need longer interventions and lifelong physical training of the amount and mode proper for age. Also cardiorespiratory fitness may play a role in learning processes. There is a need for further research in longer intervention studies with more accurate assessment tools for leisure time PA, sedentary behavior, and academic skills.

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