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Association of Physical Fitness with Cognitive Ability and Academic Performance in Elementary School Children

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Abstract

Background: The increasing pressure to improve academic performance in children and adolescents has contributed to a decline in opportunities for physical activity (PA) during and after school, which also affects physical fitness. Physical fitness, however, has been associated with cognitive ability and academic performance but available research focused predominantly on cardiorespiratory fitness with limited information on other components of physical fitness. **Materials and methods:** A total of 22 elementary school students (50% male; 9.1± 0.6 years) provided data on physical fitness, cognitive ability and academic performance. Specifically, participants performed the German motor test, which examines strength, power, speed, agility, flexibility, balance and cardiorespiratory endurance. Cognitive ability was assessed via the “draw-a-man” test and teacher rated students’ academic performance based on work ethic, motivation, concentration and in-class performance. **Results:** Physical fitness was associated with better cognitive ability and teacher-rated academic performance. Specifically, higher scores on sit ups, standing longjump, sideways jumping and balance were positively associated with cognitive ability and academic performance, while the association with cardiorespiratory endurance, speed and flexibility was limited. **Conclusion:** The results of this pilot study along with previous research emphasizes the beneficial association of physical fitness with cognitive abilities and academic performance. Accordingly, schools should provide opportunities for PA that promote physical fitness as this could contribute to sustainable positive trajectories of cognition, academic performance and general health in children.

Key Words: Muscular strength; Endurance; Agility; Cognition; Brain function; Youth

Introduction

Physical activity (PA) is an important contributor to physical and psychological well-being [1]. Sufficient PA during childhood and adolescence, which is associated with improved physical fitness, facilitates weight management and reduces the risk for various chronic diseases [2]. The pressure to increase academic performance, mainly indicated by standardized tests, however, has led to reductions in physical education and opportunities for PA during the school day [3, 4]. This reduction in PA may also have contributed to a decline in physical fitness in children and adolescents [5-7].

A restriction of PA in lieu of academic study time, however, may actually hinder cognitive development during childhood and adolescence as there is accumulating evidence for beneficial associations between the physical and cognitive domain. Research in neuroscience has shown beneficial associations of PA and physical fitness with brain structure and function [8,9]. Particularly moderate-to-vigorous PA and cardiorespiratory fitness have been shown to upregulate several growth factors (e.g. brain-derived neurotrophic factor/BDNF) and neurotransmitters (e.g. dopamine), which facilitate changes in structure and function in the frontal and parietal brain regions that are associated with executive function and learning [8,10,11]. These changes contribute to a beneficial association between physical fitness and retention of learned material [12] as well as improved academic performance in mathematics, language and reading [13,14]. Accordingly, high fit children have shown better attention, faster cognitive processing and better task performance compared to their low-fit peers [14-16]. Longitudinal studies further showed that adolescents in the healthy fitness zone or those improving their cardiorespiratory fitness showed a better academic achievement during the observation period compared to their less fit peers [17-19].

Available studies, however, predominantly focused on cardiorespiratory fitness. As physical fitness has been defined as a set of characteristics necessary to perform various forms of PA [20], other components such as muscular strength and power, flexibility or skill-related fitness, including speed and agility, should be considered as well. Accordingly, additional research on the association between cognitive abilities, academic performance and various components of physical fitness is warranted if physical fitness is to be considered a viable option to improve academic performance, particularly in low-achieving students. This pilot study, therefore, examined the association of cognitive ability and academic performance with various components of physical fitness, including, strength, power, speed, agility, flexibility, balance, and endurance in Austrian elementary school children.

Methods

Data from 22 Austrian elementary school children in third grade (50% male; 9.1 ± 0.6 years) were used to examine the association of academic performance and cognitive ability with motor competence. The study was performed in accordance with the Declaration of Helsinki and the study protocol was approved by the school board of the participating school. Parents provided written informed consent prior to data collection and participants provided oral assent at the time of data collection.

Academic performance and cognitive ability

Academic performance was determined based on teacher evaluations between October 2018 and February 2019. Specifically, classroom teachers evaluated work ethic, motivation, concentration and in-class performance using a 3-point scale for each item (below average, average, above average). Work ethic referred to how students handled materials provided to them and the timeliness of completion of assigned tasks. Motivation referred to the students' ability to incorporate their own ideas into the educational setting and overall engagement in the classroom. Concentration referred to attention to detail and the amount of careless mistakes during classroom assignments and homework. In-class performance referred to the quality of completed assignments along with performance on subject-related tests. The average score across all 4 categories was used to classify the students' academic performance as below average, average or above average.

In addition, students completed the "draw-a-man" test as an indicator for cognitive ability during a regular school lesson [21]. For this test students are asked to draw a human being. Drawings are analyzed based on 52 criteria that examine various details provided. For each criterion present 1 point is assigned. Subsequently a "draw-a-man age" (Mann-Zeichen-Alter, MZA) can be calculated (MZA=Total score/4+3). The MZA is subsequently put in relation to the chronological age via a "draw-a-man quotient" (Mann-Zeichen-Quotient, MZQ; MZQ = [MZA/chronological age]* 100), which was used in the statistical analysis.

Physical fitness

Physical Fitness was assessed with the "Deutsche Motorik Test" (German Motor Test, DMT 6-18) during a regular physical education class. The DMT 6-18 is a commonly used and validated test that consists of 8 test items, which assess strength, power, speed, agility, flexibility, balance and endurance [22]. Specifically, participants performed push ups, sit ups, standing longjump, 20 m sprint, sideways jumping, a stand-and-reach-test, backwards balancing and a 6-minute run. All tests were completed in a single session during a regular physical education class following the specifications (e.g. number of practice trials) detailed in the test manual. The tests were performed in random order except for the 6-minute run, which was performed at the end of the session. In addition to raw performance scores, the DMT 6-18 provides sex- and age-standardized values for each test item based on a German reference sample with a score of 100 indicating average performance for the respective age and sex [22]. The mean of these standardized scores is used as an indicator for total fitness. In order to avoid the impact of sex on the results, standardized scores were used in the analysis.

In addition, anthropometric measurements were taken with participants wearing gym clothes and being barefoot. Body weight (kg) was measured to the nearest 0.1 kg with an electronic scale (Grundig PS2010, Grundig AG, Nürnberg, Germany). Height (cm) was measured to the nearest 0.1 cm with a portable stadiometer (SECA® 217, Seca, Hamburg, Germany). Body mass index (BMI, kg/m^2) was calculated and converted to BMI percentiles (BMIPCT) using the German reference system [23]. The 90^{th} percentile was used as cutpoint to differentiate between overweight/obese and non-overweight participants.

Statistical analysis

Descriptive statistics were calculated and data was checked for normal distribution. MANOVA, was used to examine differences in total physical fitness and the individual test items across below average, average and above average students (based on teacher evaluation). The congruence between teacher evaluation and cognitive ability as indicated by the MZQ was determined via ANOVA. The association between cognitive ability, indicated by the MZQ, and physical fitness was examined via Pearson correlation analysis. The strength of the associations, for positive and negative associations, was defined as strong ($r>0.5$), moderate ($0.5 \geq r \geq 0.3$), or weak ($0.3>r>0.1$) [24].

Results

The sample consisted of 11 boys and 11 girls between 8 and 10 years of age. Boys were significantly older than girls ($p=0.01$). Three boys were overweight/obese while all girls were considered normal weight. Mean BMIPCT, however, did not differ between boys and girls and there were no sex differences in physical fitness (Table 1). Further, no sex differences in MZQ and teacher-rated academic performance were observed.

Based on teacher ratings 8 students (63% male) were considered below average, 11 students (55% male) were considered average and 4 students (25% male) were considered above average. Students classified as below average in their academic performance had significantly lower total fitness scores than those classified as average or above average ($p \leq 0.01$). Even though, there was no significant difference between average and above average students, there was a significant linear trend across all three groups (p for trend <0.01) with better fitness scores being associated with better teacher-rated academic performance.

	Total Sample (N = 22)	Girls only (N = 11)	Boys only (N = 11)
Age (years)	9.1 ± 0.6	8.8 ± 0.3	9.4 ± 0.6
Height (cm)	135.6 ± 6.6	133.7 ± 5.8	137.5 ± 7.1
Weight (kg)	32.1 ± 11.5	28.6 ± 5.4	35.6 ± 14.9
BMIPCT	44.0 ± 31.1	39.0 ± 29.5	49.0 ± 33.7
MZQ (score)	99.0 ± 18.6	103.1 ± 18.0	94.8 ± 19.0
Sprint (sec)	4.3 ± 0.5	4.4 ± 0.4	4.3 ± 0.6
Push Ups (repetitions)	11.4 ± 3.6	10.9 ± 3.9	11.9 ± 3.4
Sit ups (repetitions)	15.5 ± 4.3	15.1 ± 2.2	15.8 ± 5.6
Longjump (cm)	124.5 ± 19.5	124.9 ± 13.2	124.2 ± 25.4
Side Jumps (repetitions)	29.2 ± 9.1	31.4 ± 7.5	26.9 ± 10.2
Balance (steps)	27.5 ± 11.3	31.2 ± 8.2	4.3 ± 0.5
Flexibility (cm)	3.7 ± 7.2	3.1 ± 7.6	4.3 ± 7.1
6-Min Run (m)	692.4 ± 181.5	756.0 ± 102.5	628.4 ± 223.0
Total Fitness (z-score)	99.7 ± 6.9	102.4 ± 5.3	97.1 ± 7.5
BMIPCT… BMI Percentile; MZQ…man-drawing quotient			

Table 1: Descriptive Characteristics of the total sample and separately for girls and boys. Values are Means ± SD.

Across individual test items significant linear trends were observed for sit ups (p for trend =0.02), standing longjump (p for trend<0.01), sideways jumping (p for trend <0.01) and balance (p for trend =0.02). Further, results for the 6-minute run were borderline significant (p for trend =0.05) with better performance being associated with higher teacher-rated academic performance. No significant association was observed between teacher-rated academic performance and sprint, push ups, and flexibility (Figure 1). Teacher-rated academic performance was also associated with MZQ scores, as indicated by increasing scores from teacher-rated below average to above average students (p for trend =0.04).

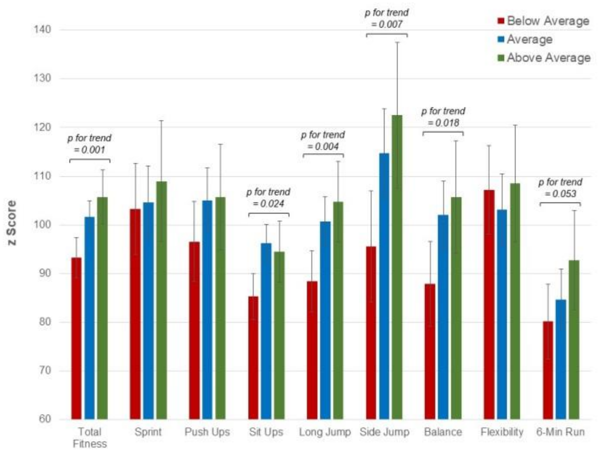

Figure 1: Differences in physical fitness across teacher-rated academic performance groups. Values are mean with 95% confidence intervals.

Using continuous MZQ scores as indicator for cognitive ability there was a strong positive association with total physical fitness (r =0.51; p=0.01) (Figure 2). Specifically, a better performance on sit ups, sideways jumping, and balance was strongly associated with a higher MZQ. In addition, there was a moderate positive significant association between MZQ and longjump. Push ups were also moderately associated with MZQ but the association was not significant. No significant associations were observed for sprint, flexibility and the 6-minute run (Table 2).

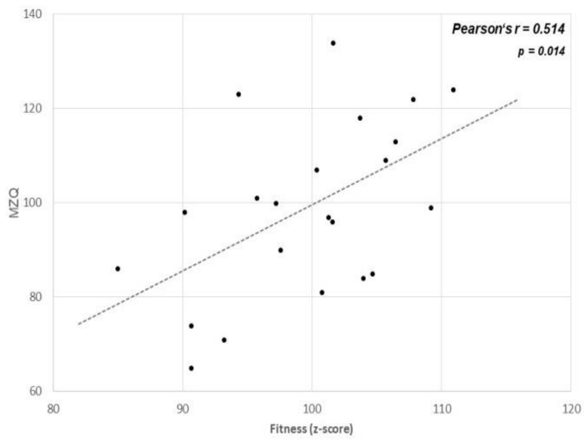

Figure 2: Association between the draw-a-man quotient (MZQ) and total physical fitness.

	Sprint	Push Ups	Sit Ups	Long Jump	Side Jump	Balance	Flexibility	6-Minute Run
Pearson's r	-0.224	0.368	0.595	0.434	0.701	0.604	-0.205	0.094
Significance	*0.316*	*0.092*	*0.003*	*0.044*	*<0.001*	*0.003*	*0.359*	*0.677*

Table 2: Associations of the draw a man quotient (MZQ) with components of physical fitness.

Discussion

Despite the small sample, this study provided several interesting insights. There was a beneficial association of overall physical fitness with cognitive ability and academic performance. Particularly, a better performance on agility and balance-related tasks along with strength and power was associated with better academic performance and cognitive ability while the association with cardiorespiratory fitness was less pronounced. As balance and agility rely on neural regulation due to the demands on movement precision and precision under a time constraint these test items have been shown to correlate more strongly with cognitive abilities compared to condition-related aspects of physical fitness (e.g. strength, endurance) [25]. Accordingly, significant differences in balance have been observed between regular students and students with learning problems [26]. Nevertheless, there was also a beneficial association between the performance on strength-related tests and academic performance while the association with cardiorespiratory fitness was less pronounced. Results of this study further showed a congruence between teacher-rated academic performance and an objective measure of cognitive ability. This may support the reliance on subjective teacher evaluations on academic performance, which could provide information beyond scores on standardized tests.

Beneficial associations of PA and physical fitness with cognitive ability and academic performance have been shown by various studies [9,14]. This may be attributed to the fact that several underlying processes such as planning, sequencing and monitoring are required for both, movement and cognitive tasks [27,28]. Accordingly, improved performance in attention tasks along with better scores on literacy and mathematics tests have been associated with higher fitness [14,29]. Specifically, physical exercise has been associated with a stimulation of new vessels (angiogenesis), endothelial cell proliferation and increased neural synapsis [30,31]. Engagement in diverse forms of PA that stimulate physical fitness may also facilitate reorganization of neural networks that contributes to neural plasticity and the ability to adapt to various task demands and learn new skills [8,32]. Accordingly, studies examining children's brain structure and function consistently showed fitness-related differences [9]. There were also differences in the activation of brain regions by fitness status, which may affect attentional control and executive function [33]. Muscular strength has further been suggested to enhance synaptogenesis in the spinal cord and alter spinal moto-neuron excitability [34]. Lima et al., for example, showed a beneficial longitudinal association between grip strength and academic performance in girls while the association was less pronounced in boys [35]. It may, however, also be possible that students displaying higher academic achievement are more goal oriented and thrive for success in both academics and physical fitness [36].

Prior studies, however, predominantly focused on cardiorespiratory fitness and emphasized the beneficial association with cognitive ability and academic performance [14,37]. This discrepancy with the results of the present study may be explained by the generally poor cardiorespiratory fitness in the present study; a mean sex- and age-standardized z-score of 84.7 is considered far below the average endurance performance and only 2 participants displayed average endurance performance. It may be possible that there is a minimum threshold of cardiorespiratory fitness that needs to be achieved in order to induce changes in the central nervous system that would affect cognitive ability and academic performance as previous research did show a dose-response relationship between PA and cognitive ability [9]. Further, Marques et al. argue that socio-economic status and parental education are the main contributors to academic performance at younger ages while the association between academic performance and physical fitness becomes more pronounced during late childhood and adolescence [13]. The beneficial association of overall physical fitness with cognitive ability and academic performance, nevertheless, has been shown in elementary school children [38]. Even though the magnitude may be less pronounced at the individual level at younger ages, it could still have important implications at the population level. Accordingly, PA that contributes to the enhancement of physical fitness has been emphasized as important component in the promotion of cognitive function and memory in the school environment [35,39].

Some limitations of the present study, however, need to be considered when interpreting these results. As this research was conducted as a pilot study the sample size is small. Further, the "draw-a-man" test, which was used as an indicator for cognitive ability should not be considered an intelligence test; rather it reflects visual perception and self-concept of a child [21]. Additionally, subjective teacher evaluations were used as indicator for academic performance. As teachers were asked to evaluate work ethic, concentration, motivation and in-class performance, this may, however, provide a better overview of academic performance than a reliance on standardized tests. The results also indicated reasonable congruence between the MZQ and teacher ratings. An additional strength of the study is the utilization of a validated fitness battery that assesses cardiorespiratory fitness, strength, power, agility, balance and flexibility. The availability of sex- and age-standardized reference values also allows for the calculation of an overall fitness score in addition to information on performance on the individual test items.

Conclusion

In conclusion, the present study along with previous studies emphasizes the beneficial association between physical fitness and cognitive ability as well as academic performance. Despite an increasing pressure to improve academic performance, the value of physical education classes should not be questioned as reductions in time devoted to PA and physical fitness may hinder cognitive development and academic performance [14, 40]. In fact, longitudinal and cohort studies suggest that higher fitness and PA may be predictive of better cognitive ability and academic performance [9] and de Bruijn et al. argue that interventions targeting physical fitness may improve academic performance in low-achieving students [15]. Further it has been shown that the implementation of PA programs in schools did not interfere with academic achievement [9]. Accordingly, PA that enhances physical fitness should be encouraged within the school setting and during leisure time as this may promote beneficial trajectories of health, cognition and academic performance towards sustainable positive health outcomes.

Disclosure

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