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Longitudinal relationship between cardiorespiratory fitness and academic achievement

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Abstract

Purpose—The aim was to examine the prospective associations between CRF and academic achievement in youth.

Methods—The sample included 1286 fifth-, sixth-, and seventh-grade students, aged 11 to 14 years (Mage=11.3±1.1), from 14 schools followed for 3 years. Academic achievement was assessed using students' marks at baseline and at follow-up three years apart, in Portuguese, Mathematics, Foreign Language (English) and Science. CRF was assessed by the PACER test from Fitnessgram battery. Students were classified as fit-fit, unfit-fit, fit-unfit, and unfit-unfit according to PACER test results at baseline and follow up. Ordinal regression analyses were performed to examine associations between CRF and academic achievement.

Results—Being persistently fit (fit-fit), compared to those classified unfit-unfit, increased the odds of having high levels of academic achievement in Portuguese (OR=3.78; 95% CI: 2.23-6.44, p<0.001), Mathematics (OR=2.95; 95% CI: 1.83-4.75, p<0.001), Foreign Language (OR=2.70; 95% CI: 1.75-3.02, p<0.001), and Science (OR=2.54; 95% CI: 1.53-4.22, p<0.001), at follow-up. Students that improved their CRF and became fit (unfit-fit) had higher odds of achieving better marks than those persistently unfit-unfit (Portuguese: OR=2.85, 95% CI: 1.68-4.82,p<0.001; Mathematics: OR=2.16, 95% CI: 1.34-3.47, p<0.01; Foreign Language: OR=1.99, 95% CI: 1.23-3.23, p<0.01; Science: OR=2.01, 95% CI: 1.21-3.34, p<0.05).

Conclusion—Consistently high and improvements in cardiorespiratory fitness are prospectively associated with better academic achievement.

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Conflict of interest
The authors declare that there are no conflicts of interest.
The results of the present study do not constitute endorsement by ACSM.

Keywords

physical activity; exercise; children; school; follow-up study

Introduction

Cardiorespiratory fitness (CRF) and physical activity (PA) appears associated with young people's cognition (31, 33). CRF is identified as a factor that might be related with cognitive control (3, 5, 25, 27), brain plasticity (24), better cognitive abilities (6, 22, 26), and memory improvement (23, 34). Thus, improving neurocognitive functions might result in better academic achievement, as has been demonstrated in several studies (7, 14, 31, 38).

Although several studies have analysed the relationship between CRF and academic achievement, most studies have been limited by cross-sectional designs (18, 20, 28, 37, 42). Results from these cross-sectional studies generally suggest a positive association between CRF and academic achievement, even when analyses were controlled for PA and for the linear and nonlinear relations between PA and CRF with academic achievement (20).

However, cross-sectional design does not allow inferences of temporality or a possible causal relationship between CRF and academic achievement. A longitudinal design addresses the issue of directionality by allowing an examination of changes over time in CRF and the effect of these changes on academic achievement and allows stronger inference about causality. So far few studies have examined the prospective associations between CRF and academic achievement (8, 9, 32, 45). The results from these studies indicated that persistently cardiorespiratory fit students have better academic achievement than those who are persistently unfit (8, 9, 32, 45). In contrast, others have failed to demonstrate associations between CRF with academic skills or academic achievement (19, 29, 34, 40).

Additional large-scale studies are therefore needed to understand the impact of CRF on the current and future students' academic achievement from different cultural settings to inform future interventions aimed at improving academic achievement in youth. To the best of our knowledge, no previous study has investigated the influence of CRF on academic achievement in a comprehensive sample of students using a three-year prospective study design. Therefore the aim was to examine the prospective associations between CRF and academic achievement in youth.

Methods and methods

Study design and participants

Participants were part of the Physical Activity and Family-based Intervention in Paediatric Obesity Prevention in the School Settings (PESSOA Project). This project was applied to students from fourteen public schools, in the Oeiras Municipality, between 2009 and 2011. Detailed information about the PESSOA project is described elsewhere (37). For the purpose of this study only those children and adolescents who provided data on both CRF and academic grades at both baseline and follow-up were included (N=1286). Participants were between 9 to 14 years (M_{age}=11.3±1.1) at baseline and between 12 to 17 years

(M_{age}=13.9±1.2) three years later at follow up. Data were analysed as a cohort analysis combining the intervention and control schools.

Participants were informed about the objectives of the study and written informed consent was obtained from the legal guardians. The study received approval from the Scientific Committee of the Faculty of Human Kinetics at the University of Lisbon, the Portuguese Minister of Education, and the principals of each school surveyed. The study was conducted in accordance to ethical standards in sport exercise research (21).

Measures and procedures

Academic achievement was assessed using students' marks at the end of the academic year at baseline and at follow up three years later, in Portuguese (mother tongue), Mathematics, Foreign Language (English) and Science. In Portuguese elementary school (from grade 5 to 9) students marks range from 1 to 5 (1 = very poor, 2 = poor, 3 = average, 4 = good, and 5 = very good). For data analysis in the current study, students were grouped into low (marks 1 and 2), average (mark 3), and high academic achievement (marks 4 and 5). Students' marks were available from the administrative services of each school at the end of academic years.

CRF was assessed by the Progressive Aerobic Cardiovascular Endurance Run (PACER) from Fitnessgram test battery (11). The PACER is an incremental running test comprising 20 meters shuttle run with progressively less time to complete each shuttle. CRF was estimated as the number of stages completed. Participants were classified into fit and unfit according to the Fitnessgram cut points based on sex- and age-related criteria. The cut points are related with the minimum level of fitness that is assumed to prevent diseases from low fitness (11). Body weight was assessed to the nearest 0.1 kg wearing minimal clothes and without shoes, and height was measured to the nearest 0.1 cm. Body mass index (BMI) was calculated by the Quetelet index [weight (kg)/height (m)^2]. CRF, weight and height were collected during physical education classes within one week at the end of each academic year.Fitness tests were administered by research trainees supervised by physical education teachers to ensure an accurate and reliable Fitnessgram administration.

Data analysis

Descriptive statistics (means, standard deviation, and percent) were used to characterize the sample. To capture changes in CRF over three year time, we examined children and adolescents' cardiorespiratory fitness results trajectories, stratified into 4 groups as follows; 1) fit at both baseline and follow up (fit-fit); 2) unfit at the baseline and fit at the follow up (unfit-fit); 3) fit at baseline and unfit at the follow up (fit-unfit); and finally, 4) unfit at both baseline and follow up (unfit-unfit). Bivariate relationships between academic achievement for each academic subject and CRF trajectory were tested by the chi-square test. Several ordinal regressions were performed to analyse associations between CRF and academic achievement (low, average and high) at baseline, at follow up and through the trajectory (baseline*follow up). Parameter estimates from these analyses were transformed into odds ratio (OR) of being at a higher level of academic achievement [exp(estimates)]. The OR was calculated using unfit at both time points as the reference. The analyses were adjusted for sex and BMI. Data analysis was performed using SPSS 22. For all tests statistical significance was set at $p<0.05$.

Results

The sample characteristics and academic achievement at baseline and follow up are presented in table 1. The proportion of students categorised as high according to their grades in Portuguese, Mathematics, Foreign language and Science decreased over follow-up and the proportion of students categorised as fit increased from baseline to follow up.

Academic achievement according to CRF trajectory is presented in table 2. For mathematics ($X^2(6)=16.51$, $p=0.011$) and foreign language ($X^2(6)=15.81$, $p=0.015$) children and adolescents persistently fit (fit-fit) and those unfit at baseline and fit at follow up (unfit-fit) had significant better academic results at follow-up than those classified as unfit at both time points and those who deteriorated (fit-unfit) between baseline and follow-up.

Table 3 presents the results of the ordinal regression analyses. High CRF at baseline was related to higher levels of academic achievement at the follow-up in Portuguese (OR=1.62, 95% CI: 1.17-2.23, $p<0.01$), Mathematics (OR=1.55, 95% CI: 1.15-2.09, $p<0.01$), Foreign Language (OR=1.51, 95% CI: 1.11-2.06, $p<0.01$), and Science (OR=1.43, 95% CI: 1.04-1.95, $p<0.05$). Being categorised as consistently fit, substantially increased the likelihood of having high levels of academic achievement in Portuguese (OR=3.78, 95% CI: 2.23-6.44, $p<0.001$), Mathematics (OR=2.95, 95% CI: 1.83-4.75, $p<0.001$), Foreign Language (OR=2.70, 95% CI: 1.75-3.02, $p<0.001$), and Science (OR=2.54, 95% CI: 1.53-4.22, $p<0.001$) compared to those classified as consistently unfit. Those that were unfit at baseline and improved their CRF and became fit at follow-up had higher odds of achieving better marks than those classified as consistently unfit (Portuguese: OR=2.85, 95% CI: 1.68-4.82, $p<0.01$; Mathematics: OR=2.16, 95% CI: 1.34-3.47, $p<0.01$; Foreign Language: OR=1.99, 95% CI: 1.23-3.23, $p<0.01$; Science: OR=2.01, 95% CI: 1.21-3.34, $p<0.01$).

Discussion

We examined the relationship between academic achievement and cardiorespiratory fitness among children and adolescents in a comprehensive sample of young people followed for three years. The main findings were that high cardiorespiratory fitness at baseline was associated with higher academic achievement at follow up, and that those who become fit, achieved better school marks compared with those who were unfit at both time points.

These results confirms and extends the findings of previous cross-sectional studies (2, 17, 18, 43) that observed that more fit students had better school performance. Several studies have demonstrated that cardiorespiratory fitness exhibits stronger associations with academic achievement than other physical fitness components (e.g. body composition, abdominal strength and endurance, upper body strength, and flexibility) (2, 8, 43, 44).

Our results extend previous observations in that being categorised as consistently fit (fit/fit) as well as becoming fit (unfit/fit) during the three year follow up was associated with higher

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probability of attaining higher levels of academic achievement at follow-up. Being fit at baseline increased the likelihood of achieving higher marks in Portuguese, Mathematics, Foreign Language and Science three years later by between 41% and 52% independent of sex and BMI. Similarly, Chaddock et al. (7) analysed whether childhood cardiorespiratory fitness predicted cognitive performance one year later and observed that cardiorespiratory fitness was associated with cognitive control in cross-sectional and one year prospective analyses. These findings may suggest that fit children have a better capability to allocate cognitive control processes and that this may persist over time and may determine future academic achievement (7).

When examining trajectories of cardiorespiratory fitness in relation to academic achievements, we observed that students who were persistently fit (fit-fit) had higher odds to achieve high levels of academic achievement, compared to those who were consistently unfit (unfit-unfit). While high cardiorespiratory fitness has been suggested to be associated with increased academic achievement (2, 17, 18, 43), being consistently fit over time seems to be important to obtain better academic achievement as observed previously (8, 9, 45). Nonetheless, for those who were categorised as unfit at baseline and improved their fitness status during follow-up a positive impact on their academic achievement was observed when compared to consistently unfit individuals. This suggest that improvement in cardiorespiratory fitness might be associated with better academic achievement.

Some potential mechanisms may explain the association between CRF and academic performance. Students with better academic achievement are more oriented for success, therefore, they may strive to achieve success in both academics and physical fitness (41). Another reason may be that physical fitness may enhance students’ concentration and improve classroom behaviour (39), which is directly related to academic achievement. In addition, previous studies have demonstrated that cardiorespiratory fitness stimulates neural development, increasing the density of neuronal synapses (30); increase the vasculature in the cerebral cortex (16); and it is associated with the recruitment of neural resources related to the effectiveness of adapting to task demands and fatigue (6). Moreover, cardiorespiratory fitness is also related to the microstructure of white fibre tracts in the brain during childhood, which is one pathway to improve cognitive and academic achievement (3, 4). At a biochemical level previous research have shown that physical activity and physical fitness enhance the synthesis of brain-derived neurotrophic factor (BDNF) (13, 35). An increase of BDNF is associated with increases in the volume of the hippocampus as well as improved memory (13, 15). The activity of the BDNF is also related with increased long term potentiation and neurogenesis (35).

Findings from the present study, along with others (8, 9, 32, 45), suggest that investment in children’s and adolescent’s cardiorespiratory fitness levels of children and adolescents, may indirectly contribute to an investment in their academic performance. Therefore, achieving and maintaining a healthy level of cardiorespiratory fitness should be a priority for education in general and physical education in particular.

The present study has several strengths. The longitudinal design makes it possible to analyse the relationship between academic achievement and cardiorespiratory fitness at different

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time points and to follow the cardiorespiratory fitness trajectory over three years. Cardiorespiratory fitness was assessed with PACER test, using clearly defined fitness standards aimed to differentiate students into different fitness levels. Although less accurate that measured maximal oxygen uptake by indirect calorimetry the PACER test is easily administered and provides a valid estimate of cardiorespiratory fitness (36). The academic achievement as assessed by four different disciplines reinforced the role of cardiorespiratory fitness in different academic areas.

Some limitations warrant mention when interpreting the findings from this study. We cannot exclude the possibility our results are explained by unmeasured confounders. Unfortunately, individual data of socioeconomic status, home background, and parents’ education were not available. Although high fitness levels appears positively associated with academic achievement, socioeconomic status may be the strongest correlate of academic achievement (10). Thus, future prospective studies in which additional potential confounding factors are taken into account are needed to confirm or refute our observations. Furthermore, the used of categorical marks in four subjects as a proxy for achievement rather than standardized cognitive tests may be a limitation, due the fact that students marks may be related to other factors beside their cognitive performance.

Our results suggest that those who are consistently fit or increase their cardiorespiratory fitness over a three year period have an increased odds of higher academic performance compared with those categorised as unfit. These findings support the need to modify public health and educational policy to encourage schools and physical education teachers to work in order to improve children and adolescents physical fitness. Outside school, the promotion of physical activity is also important, because does not appear to be detrimental to children and adolescence academic performance (12) and contribute to improve physical fitness.

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Perspectives

Cardiorespiratory fitness is a predictor of academic success. Attention to these findings should be paid, because of the implications it may have on student's education, predominantly in societies were economic development is so important. With an increasing emphasis on the so-called academic disciplines, such as mathematics, sciences and languages, decision-makers are under pressure in order to adhere to high academic standards. This may have implications on the curricula limiting time for physical activity and physical education which in turn may negatively impact on students' physical fitness. Considering the relationship between cardiorespiratory fitness and academic achievement, low levels of cardiorespiratory fitness can jeopardized students' academic future. Therefore, an investment in physical education is important, because it might play a role in the positive effect of physical activity, fitness and consequently on cognition and academic success (1). In conclusion, the main findings of the present study were that consistently high and improvements in cardiorespiratory fitness are prospectively associated with better academic achievement. High cardiorespiratory fitness at baseline was associated with higher academic achievement at follow up, and that those who become fit, achieved better school marks compared with those who were unfit at both time points.

Table 1

Characteristics of the participants.

	Baseline		Follow up	
	n	**% or M±SD**	**n**	**% or M±SD**
Sex				
Boys	627	48.8	627	48.8
Girls	659	51.2	659	51.2
Age	1286	11.3±1.1	1142	13.9±1.2
Portuguese				
Low	90	7.1	91	7.2
Average	625	49.1	769	60.8
High	559	43.9	405	32.0
Mathematics				
Low	154	12.1	304	24.1
Average	578	43.6	579	54.8
High	539	47.6	381	30.1
Foreign language[1]				
Low	111	8.7	123	9.7
Average	556	43.6	591	46.4
High	607	47.6	560	44.0
Science				
Low	74	5.8	60	4.7
Average	551	43.2	670	52.6
High	649	50.9	543	42.7
CRF				
Fit	901	70.1	1131	87.9
Unfit	385	29.9	155	12.1
BMI				
Normal weigh	873	68.6	903	76.2
Overweight/obese	400	31.4	282	23.8

Table 2

Descriptive statistic for academic achievement according to cardiorespiratory fitness between baseline and follow up

Academic achievement at the follow up	Cardiorespiratory fitness at the baseline-follow up: Fit-fit (n=865)	Unfit-fit (n=266)	Fit-unfit (n=36)	Unfit-Unfit (n=119)	*p*[1]
Portuguese					0.289
Low	7.4	5.7	8.3	8.8	
Average	60.9	57.4	63.9	67.3	
High	31.7	37.0	27.8	23.9	
Mathematics					0.011
Low	21.9	24.5	38.9	34.8	
Average	46.5	44.5	38.9	45.5	
High	31.6	30.9	22.2	19.6	
Foreign language (English)					0.015
Low	8.9	10.2	13.9	13.2	
Average	44.6	45.9	58.3	57.0	
High	46.5	44.0	27.8	29.8	
Science					0.233
Low	4.3	4.5	8.3	7.1	
Average	51.9	51.1	55.6	60.7	
High	43.8	44.4	36.1	32.1	

Fit-fit, children and adolescents fit at the baseline and follow up.

Unfit-fit, children and adolescents unfit at the baseline but fit at the follow up.

Fit-unfit, children and adolescents fit at baseline but unfit at the follow up.

Unfit-unfit, children and adolescents unfit at the baseline and follow up.

[1] Tested by Chi-square

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Table 3

Associations between academic achievement and cardiorespiratory fitness at baseline and follow up.

	Portuguese	Mathematics	Foreign language	Science
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
CRF at baseline				
Unfit	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
Fit	1.62 (1.17-2.23)**	1.55 (1.15-2.09)**	1.51 (1.11-2.06)**	1.43 (1.04-1.95)*
CRF at follow up				
Unfit	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
Fit	2.64 (1.72-4.04)***	2.31 (1.56-3.41)***	2.14 (1.44-3.18)***	2.08 (1.38-3.16)**
CRF (baseline*follow up)				
Unfit-unfit	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
Fit-unfit	2.18 (0.94-5.03)	1.44 (0.67-3.12)	1.38 (0.63-3.01)	1.40 (0.62-3.17)
Unfit-fit	2.85 (1.68-4.82)***	2.16 (1.34-3.47)**	1.99 (1.23-3.23)**	2.01 (1.21-3.34)**
Fit-fit	3.78 (2.23-6.44)***	2.95 (1.83-4.75)***	2.70 (1.75-3.02)***	2.54 (1.53-4.22)***

Abbreviations: OR, odds ratio; CI, confidence interval; CRF, cardiorespiratory fitness

Outcome variable is a 3-level ordinal variable: (1) low academic achievement, (2) average academic achievement, and (3) high academic achievement.

The table presents OR representing the association between cardiorespiratory fitness and being in the higher levels of academic achievement.

Analyses were adjusted for sex and BMI.

*$p<0.05$, **$p<0.01$, ***$p<0.001$.