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Physical Fitness Predicts Subsequent Improvement in Academic Achievement: Differential Patterns Depending on Pupils' Age

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Abstract: We investigated the longitudinal relationship between physical fitness (flexibility, functional strength, and running speed-agility components) and subsequent change in academic achievement across one school year. We also examined whether this longitudinal relationship differed as a function of pupils' age, controlling for sex, body mass index, and socioeconomic status. Academic achievement in terms of marks in Portuguese and mathematics was recorded from 142 pupils ($M = 14.59$ years; $SD = 1.99$, range 11–18), between autumn 2017 and summer 2018. The physical fitness components, including flexibility, functional strength, and running speed-agility, were assessed at the baseline (i.e., at the beginning of the school year). Latent change score modelling revealed that higher physical fitness level at baseline significantly predicted a subsequent improvement in academic achievement across the school year. This longitudinal relationship was significantly stronger in younger compared to older pupils. Physical fitness and its interaction with age predicted 45.7% of the variance in the change in academic achievement. In conclusion, a better physical fitness profile including flexibility, functional strength, and running speed-agility explains a subsequent improvement in academic achievement. This longitudinal relationship seems to be age-dependent.

Keywords: physical conditioning; academic success; youth; physical education

1. Introduction

Physical fitness is a set of individual's attributes related to the ability to perform physical activity and exercise [1] that have been associated with healthy physical and mental conditions throughout the lifespan [2,3]. Despite the fact that there is a remarkable amount of studies reporting a positive relationship between physical fitness and physical health in children and adolescents [3–5], much more

detailed research is still needed to better understand the impact of a healthy physical fitness profile on brain development, functioning, plasticity, and cognition, which could finally also determine children's and adolescent's academic achievement [6–8]. From this framework, physical fitness has a beneficial effect on academic achievement due to a complex network phenomenon based on the effects of neural substrates that are linked to improvements in brain structure, brain function, and brain connectivity [9–11].

Yet, only very few longitudinal studies so far have approached the relationship between physical fitness and academic achievement, defined as the extent to which each student achieves a particular learning objective [12]. One further gap in the existing literature is that research so far has focused on cardiorespiratory fitness alone as global physical fitness indicator [4,5,12]. Although cardiorespiratory fitness is considered an important general health indicator that estimates the capacity of the cardiovascular and respiratory systems [3], it seems reasonable that other physical fitness components such as flexibility, speed, and muscular fitness may also play an important role for academic outcomes [13–15]. This is based on the assumption that physical fitness is a good summative measure of the body's ability to perform different physical activities and exercises. However, those relationships between flexibility, speed, and muscular fitness on children's and adolescents' cognitive development and consequently also their academic achievement is still under debate [8,16–18]. Therefore, a more fine-grained empirical investigation is of particular importance at the community level, namely in school settings, because interventions to promote academic achievements could target other physical fitness components, besides cardiorespiratory fitness only.

Moreover, the most recent comprehensive review on this topic [12] highlights another important gap in the existing literature. Overall, the role of pupils' age in the relationship between physical fitness and academic achievement has been neglected so far. Therefore, a detailed investigation to identify differential patterns depending on pupils' age is relevant to better understand how age can affect the relationship between physical fitness and subsequent change in academic achievement. This information is relevant to help physical educators in developing and implementing age-tailored physical fitness interventions in the school context.

To contribute to a deeper understanding of these relationships, in the present longitudinal study, we investigated the relationship between physical fitness (in terms of flexibility, functional strength, and running speed-agility components) and subsequent change in academic achievement across one school year. We also examined whether this longitudinal relationship differed as a function of pupils' age.

2. Materials and Methods

2.1. Study Design and Participants

The sample comprised 142 pupils from the 5th to the 12th year that participated in the research project entitled "Physical Education in Schools from the Autonomous Region of Madeira" (EFERAM-CIT; <https://eferamcit.wixsite.com/eferamcit>) in Funchal, Portugal, between autumn 2017 (Wave 1; W1) and summer 2018 (Wave 2; W2). Mean age in W1 was 14.59 years (SD = 1.99, range 11–18). Participants were informed about the objectives of the study and written informed consent was obtained from their legal guardians. The study received Ethical approval from the Scientific Committee of the Faculty of Physical Education and Sports at the University of Madeira (Reference: ACTA N.77–12.04.2016). This study was also approved by the Regional Secretary of Education and the school's headmaster. The study was conducted in accordance to ethical standards in sports exercise research [19].

2.2. Measures and Procedures

Academic achievement was assessed using pupils' marks in Portuguese (mother tongue) and mathematics in W1 (end of the first semester, December 2017) and in W2 (end of the second semester, June 2018). For both subjects, pupils' marks were provided by administrative school services and were based on the pupils' achievement throughout the year, considering written exams and papers as well

as oral class participation. Analysed scores of pupils’ marks represented a five-point scale ranging from 1 (“very poor”) to 5 (“very good”).

The flexibility component of pupils’ physical fitness was assessed using the sit and reach test [20]. For analyses, we calculated the mean score of the left and the right body part. The functional strength component of pupils’ physical fitness was assessed using the bent arm hang test and the running speed-agility component by the shuttle run test [21]. The three physical fitness tests were administered during physical education classes in W1. For analyses, we calculated a composite score of the three physical fitness scores (which were standardized before) as a broader physical fitness indicator [18,22].

We simultaneously controlled for sex, body mass index (BMI) in W1, and highest level of parents’ occupation as an indicator of socioeconomic status in W1 [23,24]. Body mass index was calculated from weight and height (kg/m²). The highest level of parents’ education was used as an indicator of socioeconomic status. The following categories were considered: 0 = 4 years or less of education; 1 = 6 years of education; 2 = 9 years of education; 3 = 12 years of education; 4 = professional degree; 5 = graduation.

2.3. Data Analysis

We conducted latent change score modelling [25] using the R package lavaan [26]. The specification of our latent change score model is illustrated in Figure 1.

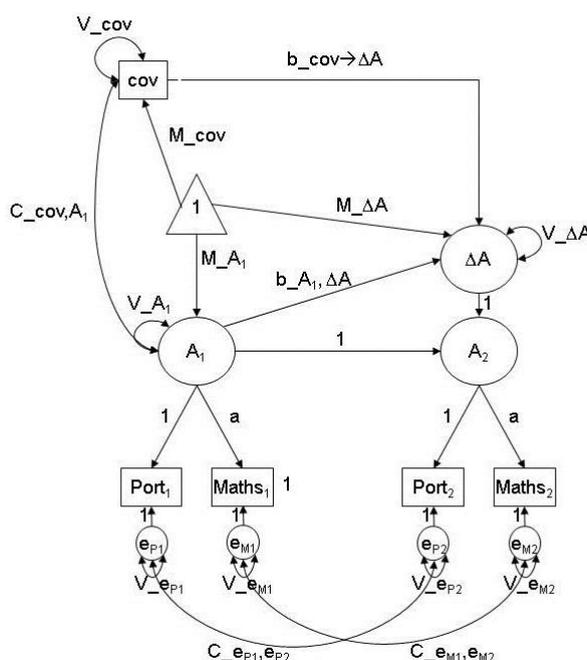


Figure 1. Specification of the tested latent change score model. A_1 and A_2 represent the latent factors of academic achievement in Wave 1 (W1; constructed from marks in Portuguese [$Port_1$] and mathematics [$Maths_1$] in W1) and Wave 2 (W2; constructed from marks in Portuguese [$Port_2$] and mathematics [$Maths_2$] in W2), respectively. ΔA represents the latent change variable regarding change in academic achievement from W1 to W2. Note that for clarity purposes the illustration is simplified. We enforced strong factorial invariance on the factor loadings, with intercepts of all indicators being fixed to zero to assure that the same latent factor of academic achievement was assessed at both waves. For simplification purposes, arrows from the triangle to the observed indicator variables (Portuguese and mathematics) that would indicate that intercepts of all indicators being fixed to zero are not displayed. cov represents all covariates that predicted latent change and were correlated to the latent factor of academic achievement in W1: Physical fitness in W1, age in W1, sex, body mass index in W1, socioeconomic status in W1, and the interaction of physical fitness with age (including interrelations of all covariates, which are not displayed here for a better overview).

Specifically, we modelled latent factors of academic achievement in W1 (constructed from marks in Portuguese and mathematics in W1) and W2 (constructed from marks in Portuguese and mathematics in W2) as well as a latent change variable regarding change in academic achievement from W1 to W2. We enforced strong factorial invariance on the factor loadings, with intercepts of all indicators being fixed to zero to assure that the same latent factor of academic achievement was assessed at both waves [22,27]. We included several covariates that predicted latent change and were correlated to the latent factor of academic achievement in W1: Physical fitness in W1, age in W1, sex, BMI in W1, socioeconomic status in W1, and the interaction of physical fitness with age. We also included interrelations of all covariates to take the dependencies among them into account.

To evaluate model fit, we used the following criteria: χ^2 test (good models: p value > 0.10), Comparative Fit Index (good models: CFI > 0.95), Incremental Fit Index (good models: IFI > 0.95), Root Mean Square Error of Approximation (good models: RMSEA < 0.06), and Standardized Root Mean Square Residual (good models: SRMR < 0.08) [28]. For analyses, we standardised the continuous variables age, physical fitness, BMI, and socioeconomic status so that the reported raw estimates (b) can be interpreted in terms of SDs. We did not standardize pupils' marks so that the reported raw estimates can be interpreted with regard to their common scaling.

3. Results

3.1. Descriptive Statistics

Table 1 shows descriptive statistics for sample description.

Table 1. Descriptive statistics.

Variable	M (SD)/Sample Proportions
Portuguese (W1) [marks 1–5]	3.46 (0.71)
Mathematics (W1) [marks 1–5]	3.46 (0.91)
Portuguese (W2) [marks 1–5]	3.54 (0.74)
Mathematics (W2) [marks 1–5]	3.42 (0.95)
Sit and reach test (W1) [cm]	26.89 (8.78)
Bent arm hang test (W1) [seconds]	9.34 (11.71)
Shuttle run test (W1) [seconds]	21.78 (1.98)
BMI (W1) [kg/m ²]	21.92 (4.30)
Socioeconomic status (W1) [rating]	4.01 (2.32)
Age (W1) [years]	14.59 (1.99)
Sex	boys: 50.0% girls: 50.0%

Note: Descriptive statistics for academic achievement in terms of marks in Portuguese and mathematics in Wave 1 (W1) and Wave 2 (W2), the three physical fitness tests, body mass index (BMI), socioeconomic status, age, and sex in terms of means (standard deviations are given in parentheses) as well as sample proportions.

3.2. Latent Change Score Modelling

The latent change score model provided a very good statistical account of the data ($\chi^2 = 20.82$, $df = 15$, $p = 0.143$, CFI = 0.99, IFI = 0.99, RMSEA = 0.05, SRMR = 0.03). Higher physical fitness in W1 significantly predicted a subsequent improvement in academic achievement from W1 to W2 ($b = 0.10$, $p = 0.004$, corresponding $\beta = 0.63$). Older age in W1 significantly predicted a worsening in academic achievement from W1 to W2 ($b = -0.10$, $p = 0.003$, corresponding $\beta = -0.62$). Sex, BMI, and socioeconomic status did not predict change in academic achievement ($ps > 0.302$). Notably, there was a significant interaction of physical fitness with age. Specifically, the relationship between higher physical fitness in W1 predicting a subsequent improvement in academic achievement from W1 to W2 was significantly stronger in younger compared to older pupils ($b = -0.12$, $p < 0.001$, corresponding $\beta = -0.71$; cf. Figure 2). In this model, physical fitness, age, sex, BMI, socioeconomic status, and the interaction of physical fitness with age predicted a total of 87.2% of the variance

in the latent change in academic achievement (in comparison, 80.2% in a model only considering physical fitness, age, sex, BMI, and socioeconomic status (thus omitting the interaction of physical fitness with age); and only 41.5% in a model only considering age, sex, BMI, and socioeconomic status (thus omitting physical fitness as a whole and also the interaction of physical fitness with age)).

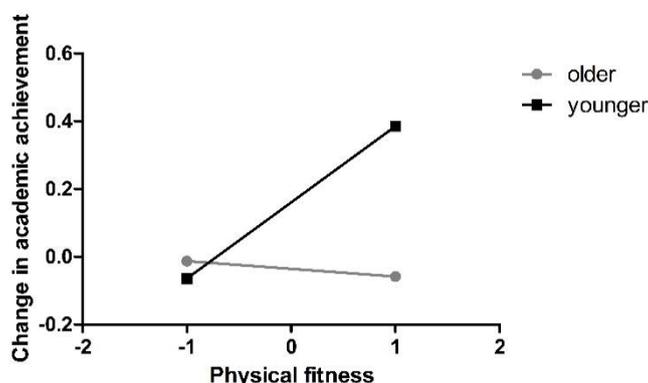


Figure 2. Estimated mean change in academic achievement from Wave 1 (W1) to Wave 2 (W2) at low and high physical fitness in W1 (i.e., -1 and $+1$ SD, respectively) as a function of age in W1 (younger vs. older, i.e., -1 and $+1$ SD, respectively), controlling for sex, body mass index, and socioeconomic status. Positive values represent an improvement in academic achievement, while negative values represent a worsening in academic achievement.

3.3. Additional Analyses

We repeated the latent change score modelling approach separately for the three fitness measures. The pattern of results remained identical. Specifically, better performance in the three fitness measures in W1 significantly predicted a subsequent improvement in academic achievement from W1 to W2 (sit and reach test: $b = 0.10$, $p = 0.002$, corresponding $\beta = 0.67$; bent arm hang test: $b = 0.09$, $p = 0.033$, corresponding $\beta = 0.60$; shuttle run test: $b = 0.08$, $p = 0.037$, corresponding $\beta = 0.58$). Again, the relationship between better performance in the three fitness measures in W1 predicting a subsequent improvement in academic achievement from W1 to W2 was significantly stronger in younger compared to older pupils (sit and reach test: $b = -0.07$, $p = 0.036$, corresponding $\beta = -0.44$; bent arm hang test: $b = -0.12$, $p < 0.001$, corresponding $\beta = -0.82$; shuttle run test: $b = -0.08$, $p = 0.020$, corresponding $\beta = -0.58$).

4. Discussion

The first main purpose of this longitudinal study was to examine the relationship between a broader spectrum of physical fitness components and the subsequent change in academic achievement. It seems well accepted in the literature that cardiorespiratory fitness is positively associated with academic achievement in the majority of the subjects [4,12,17,18,29], even after controlling for several covariates that can moderate these relationships. Nevertheless, much less consistent are the relationships between flexibility, muscular strength, muscular endurance, and running speed-agility with academic achievement [14,17,18]. For example, some studies have demonstrated a positive association between abdominal strength and academic achievement, with greater abdominal strength relating to enhanced performance in several academic areas such as mathematics and reading [16,30]. However, when those relationships are controlled for potential covariates such as age, the associations were weakened [16,30]. With respect to the relationship between muscular flexibility and academic achievement, it seems even less consistent. The majority of the studies failed to find any association between muscular flexibility and academic achievement [16,30,31].

One novel aspect of the present study is that we demonstrated, from a broader multifaceted approach of physical fitness in contrast to the usual unidimensional approach (e.g., focused on

cardiorespiratory fitness alone), that a healthier physical fitness profile in W1 significantly predicted a subsequent improvement in academic achievement across an academic year (from W1 to W2). In other words, this composite measure of fitness that includes flexibility, functional strength, and running speed-agility might have the potential to explain positive changes in academic achievement. This analysis allows us to further speculate on the relevance of this broad spectrum of physical fitness for academic achievement and makes a stronger and more effective message in the school context to make children and adolescents becoming and staying more active. These results are convergent with those reported by London and Castrechini [15] indicating that overall fitness (the combination of the six components of physical fitness) is far more predictive of academic achievement than any one test.

The possible mechanisms supporting the association between physical fitness and academic achievement could be explained from several perspectives. First of all, a better physical fitness profile is a direct result of an increase in physical activity level, and both have been positively correlated with cognitive function and academic achievement in children and adolescents [13]. From a neuroscience perspective, the benefits from this interrelationships are linked to improvements in brain structure [9], brain function [10], and brain connectivity (e.g., exercise-induced neurogenesis and angiogenesis) [11]. No less important is the strong possibility that students with better academic achievement may be better oriented for success, and therefore might attempt to achieve success in both academics and physical fitness [12,32]. However, we acknowledge that more evidence is needed to better understand this complex network phenomenon to pin down the detailed mechanisms involved.

We believe that this perspective offers important practical contributions at different levels at school that should be taken into consideration by schools' administrators and teachers. For example, there is commonly only little time in schools allocated to sports activities due to the pressure for academic achievement (also with respect to e.g., school's rankings; competition; grades competition to access specific Universities/courses), as well as to greater quantity of lesson for studying the subjects [6]. Our results support that school policies that aim to develop the overall concept of physical fitness may increase academic achievement. Finally, at the physical education level, teachers should be aware that a large variability of types of physical activities that cover all physical fitness components may be more effective to improve the overall cognitive achievements. On the other hand, many children and adolescents dislike spending much time in aerobic activities only. Hence, this further underlines the urgent need to apply a broader multifaceted approach of physical fitness, integrating enjoyable and diversified physical activities targeting a broad spectrum of physical fitness components such as flexibility, functional strength, and running speed-agility.

The second main and novel purpose of this study was to investigate whether the relationship between physical fitness and subsequent changes in academic achievement differed as a function of pupils' age. We found a significant interaction of physical fitness with age. Interestingly, the relationship between higher physical fitness in W1 predicting a subsequent improvement in academic achievement from W1 to W2 was significantly stronger in younger compared to older pupils.

Although several studies have considered age as a covariate [16,18,30], to the best of our knowledge, no prior study has integrated a detailed investigation to disentangle age-differential patterns in the relationship between physical fitness and subsequent academic achievement. From our innovative perspective, the pupils' age is highly relevant and needs to be considered in this relationship. It could be crucial for helping school communities to develop and implement age-tailored physical fitness interventions to promote physical fitness and, as consequence, may improve better academic achievement. We advocate that gaining good physical fitness already early in life seems crucial as this may establish an important basis for the pathways of later development.

On the other hand, the weaker relationship found between physical fitness and academic achievement in the older pupils might be explained by important modifiable extrinsic and intrinsic factors. First of all, adolescence is a critical period for the development and establishment of long-term behaviours and attitudes [33]. Furthermore, this period is characterized by several psychological well-being instabilities that could affect those behaviours [34]. Secondly, at this age, these students

were faced with many intrinsic and social pressures for better academic achievement in order to access specific universities or courses, so, as consequence, less time is dedicated to moderate and vigorous physical activities per day [35]. Finally, a high prevalence of sedentary behaviour (i.e., spending many hours sitting) at this age has been recognized [36]. Altogether, we can expect that all these factors can weaken the relationship between physical fitness and academic achievement in older pupils.

Some issues warrant a mention when interpreting the findings from this study. First, we assessed physical fitness using field-based tests. However, such field-based tests allow an excellent feasibility in applied environments such as the school context and have been shown to capture inter-individual differences comparably to using gold standard laboratory fitness tests [20,21]. Second, the academic achievement was based on the grades of two subjects only (i.e., mother tongue and mathematics) and in some way partly includes a subjective evaluation from teachers. We acknowledge that those two subjects do not represent a comprehensive examination of educational outcomes. Yet, grades in mother tongue and mathematics have been considered across many studies as key predictors of vocational and university education attainment and job success in later life [37,38].

Besides that, the present study has several strengths. The longitudinal design makes it possible to analyse the effect of a healthy physical fitness profile on subsequent changes in academic achievement over one school year. The applied latent change score modelling approach allowed a measurement-error-free estimation of these changes over time. Furthermore, we included school-aged children and adolescents with a broad age range from 11 to 18 years, which represents middle and secondary education in most countries. This also denotes a critical phase for the development of children and adolescents, where different approaches should be taken into consideration in order to promote a more physically healthy lifestyle.

5. Conclusions

This study reinforces that a healthier physical fitness profile, including flexibility, functional strength, and running speed-agility, significantly predicts a subsequent improvement in academic achievement. Moreover, this longitudinal relationship was stronger in younger compared to older pupils. We conclude that gaining good physical fitness already early in life seems particularly crucial as this may establish an important basis for the pathways of later development.

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