Original Article

Longitudinal associations of physical fitness and body mass index with academic performance

Antonio García-Hermoso\textsuperscript{1,2} | David Martínez-Gomez\textsuperscript{3,4} | Jorge del Rosario Fernández-Santos\textsuperscript{5,6} | Francisco B. Ortega\textsuperscript{7} | José Castro-Piñero\textsuperscript{5,6} | Charles H. Hillman\textsuperscript{8,9} | Oscar L. Veiga\textsuperscript{10} | Irene Esteban-Cornejo\textsuperscript{7}

\textsuperscript{1}Navarrabiomed, Complejo Hospitalario de Navarra (CHN)-Universidad Pública de Navarra (UPNA), IdiSNA, Pamplona, Spain
\textsuperscript{2}Facultad de Ciencias Médicas, Laboratorio de Ciencias de la Actividad Física, el Deporte y la Salud, Universidad de Santiago de Chile, USACH, Santiago, Chile
\textsuperscript{3}Department of Preventive Medicine and Public Health, Universidad Autónoma de Madrid/IdiPaz, CIBER of Epidemiology and Public Health (CIBERESP), Madrid, Spain
\textsuperscript{4}IMDEA Food Institute, CEI UAM + CSIC, Madrid, Spain
\textsuperscript{5}Faculty of Education Sciences, Department of Physical Education, University of Cádiz, Puerto Real, Spain
\textsuperscript{6}Biomedical Research and Innovation Institute of Cádiz (INIBICA), Cádiz, Spain
\textsuperscript{7}Faculty of Sport Sciences, PROFITH “PROmoting FITness and Health through physical activity” research group, Sport and Health University Research Institute (iMUDS), Department of Physical Education and Sports, University of Granada, Granada, Spain
\textsuperscript{8}Department of Psychology, Northeastern University, Boston, MA, USA
\textsuperscript{9}Department of Physical Therapy, Movement, & Rehabilitation Sciences, Northeastern University, Boston, MA, USA
\textsuperscript{10}Department of Physical Education, Sport and Human Movement, Autonomous University of Madrid, Madrid, Spain

Correspondence
Antonio García-Hermoso, Navarrabiomed, Complejo Hospitalario de Navarra (CHN)-Universidad Pública de Navarra (UPNA), IdiSNA, Pamplona, Spain.
Email: antonio.garciah@unavarra.es

Funding information
The UP&DOWN Study was supported by the DEP 2010-21662-C04-00 grant from the National Plan for Research, Development and Innovation (R+D+i) MICINN. AGH is a Miguel Servet Fellow (Instituto de Salud Carlos III-FSE—CP18/0150). DM-G is supported by a “Ramón y Cajal” contract (RYC-2016-20546). IE-C is supported by the Spanish Ministry of Economy and Competitiveness (RTI2018-095284-J-100) and a grant from the Alicia Koplowitz Foundation.

No studies have analyzed the longitudinal associations of change in physical fitness components and obesity with academic performance. The aim of the study was to examine longitudinal associations of changes in physical fitness components and body mass index with academic performance among youth, and whether the physical fitness components are moderators of the longitudinal association between obesity and academic performance in youth. Longitudinal analyses (2 years) included 1802 youths. Physical fitness components were assessed following the ALPHA health-related fitness test battery. Academic performance was assessed via school records. Youth in the persistently high cardiorespiratory fitness and motor ability categories (i.e., fit at baseline and at 2-year follow-up) had higher academic performance at follow-up than those in the persistently low category. Further, youth with normal weight at baseline and overweight/obesity at follow-up had lower academic performance scores at follow-up compared to those with normal weight. Also, cardiorespiratory fitness may ameliorate the negative influence of excess body mass index on academic performance at follow-up. Promoting physical activity programs at school that include both aerobic exercise and motor tasks to improve physical fitness and reduce body mass index may not only improve physical health, but also contribute toward successful academic development.
1 | INTRODUCTION

Physical fitness is an important health-related marker across the lifespan.\(^1\) Attaining a high level of physical fitness has benefits for physical and mental health,\(^2,3\) as well as for brain health and executive function during youth.\(^4\) Executive function encompasses inhibition, working memory, and cognitive flexibility, three aspects of cognition that are fundamental for academic abilities.\(^5\) The main components of physical fitness, including cardiorespiratory, motor ability, and muscular strength, have also been related to executive function and academic performance (among youth aged 6-18 years),\(^6,7\) albeit with differential findings across the various aspects of physical fitness.

A growing body of evidence suggests physical fitness may play a key role in academic performance in youth; however, the majority of evidence thus far has relied on cross-sectional studies.\(^8,9\) Few longitudinal studies have examined the association between changes in different physical fitness components and academic performance, with most studies mainly focusing only on cardiorespiratory fitness.\(^10-15\) Overall, studies reported inconsistent results. For example, Raine et al\(^12\) suggest that changes in cardiorespiratory fitness may modulate changes in academic achievement in a sample of 55 children. In contrast, McLoughlin et al\(^13\) reported that cardiorespiratory fitness was not associated with academic achievement 2 years later among 5735 youth. The only study including several components of physical fitness found that a combination of physical fitness components predicted improvements in academic performance; yet, this study was performed by summing the number of fitness tests that youth passed, which hindered the possibility of differentiating the specific physical fitness components important for enhancing academic performance.\(^15\) Another study included cardiorespiratory fitness and muscular strength, showing that adolescents who increased cardiorespiratory fitness, but not muscular strength (assessed with the bent-leg curl-ups test, ie, a muscular endurance test), improved their academic performance.\(^14\) However, no longitudinal study included motor ability, a key physical fitness component related to cortical structures involved in reading and language processing, such as the inferior frontal gyrus and the superior temporal gyrus, and in turn with academic performance.\(^7\)

Similarly, body mass index (BMI) has been inversely associated with academic performance in children and adolescents in the majority of previous studies.\(^5,16\) However, not all studies are in agreement, as some have failed to demonstrate a relationship.\(^17,18\) For example, Haapala et al\(^19\) suggest that an inverse association of body fat with academic achievement is largely explained by motor ability. In this context, a recent systematic review concluded that there is no strong evidence to support the association between obesity (OB) and poorer academic performance in school-age children relative to their normal-weight peers, and suggests that longitudinal studies with adequate power are required.\(^20\)

To the best of our knowledge, the field has not yet investigated the longitudinal associations of change in the three components of physical fitness (ie, cardiorespiratory, motor ability, and muscular strength) and OB with academic performance. Importantly, examining whether changes in physical fitness may moderate the negative effects of OB in academic performance during childhood and adolescence is important to understand how these health factors influence one another. Such information would help to develop targeted interventions early in childhood for individuals at risk of low physical fitness or with overweight (OW)/OB to ameliorate, in part, lower academic performance. Hence, the aim of the study was to examine (a) longitudinal associations of change in the physical fitness components (ie, cardiorespiratory, motor ability, and muscular strength) and change in BMI with academic performance among youth; and (b) whether the physical fitness components are moderators of the association between BMI and academic performance in youth.

2 | METHODS

2.1 | Subjects

Participants were enrolled in the UP&DOWN Study. Briefly, the UP&DOWN Study was a 2-year follow-up study designed to assess the relation of physical activity and sedentary behaviors on health indicators (physical fitness, metabolic and cardiovascular disease risk factors, inflammation-immunity biomarkers, and mental health) over time, as well as to identify the psycho-environmental and genetic determinants of physical activity in a cohort of Spanish children and adolescents.\(^21\) Children and adolescents were recruited from schools in Cadiz and Madrid (Spain), respectively. Data were collected from September 2011 (baseline) to June 2014 (second post-test). A total of 2263 youth aged 10.4 ± 3.4 years participated. The present analyses included 1802 children and adolescents (46.8% girls) with complete baseline and 2-year follow-up data on physical fitness, BMI, peak height velocity (PHV), maternal education level, and academic performance. Youth
included in this study did not differ at baseline from those not included regarding height, weight, BMI, PHV, maternal education, physical fitness, and academic performance data (all $P > .10$).

Before participation in the UP&DOWN Study, parents and school supervisors were informed by letter about the purpose of the study and written informed consent was obtained. The UP&DOWN Study was approved by the Ethics Committee of the Hospital Puerta de Hierro (Madrid, Spain) and the Bioethics Committee of the National Research Council (Madrid, Spain).

### 2.2 Physical fitness

Physical fitness was assessed following the ALPHA (the Assessing Levels of PHysical Activity and fitness) health-related fitness test battery for youth.1,22

Cardiorespiratory fitness was assessed via the 20-m shuttle-run test. This test is an excellent tool for population-based surveillance and monitoring because it demonstrates strong-to-very strong test-retest reliability and moderate-to-strong validity.23 Participants were required to run between two lines 20 m apart, while keeping pace with a pre-recorded audio CD. The initial speed was 8.5 km/h, which was increased by 0.5 km/h each minute (1 min = 1 stage). Participants were instructed to run in a straight line, to pivot on completing a shuttle (20-m), and to pace themselves in accordance with the audio signals. The test was finished when the participant failed to reach the end lines concurrently with the audio signals on two consecutive occasions. The score was the number of stages completed.24 The test was performed once and at the end of the fitness testing session. The last stage completed was recorded and transformed to maximal oxygen consumption ($\text{VO}_{2}\text{max}$, ml/kg/min) using the Léger Equation.25

Motor ability was assessed with the $4 \times 10$-m shuttle-run test of speed of movement, agility, and coordination. Participants were required to run back and forth twice between two lines 10 m apart. Youth were instructed to run as fast as possible and every time they cross any of the lines, and they were to pick up (the first time) or exchange (second and third time) a sponge that was been placed behind the lines. The test was performed twice, and the fastest time was recorded in seconds.24 The variable expressed in seconds was inverted by multiplying by $-1$, so that a higher score indicated better performance (ie, the person is faster and more agile).

Muscular strength was assessed using maximum handgrip strength (isometric strength) and the standing long jump (lower limb explosive strength) tests. A hand dynamometer with an adjustable grip was used (TKK 5101 Grip D; Takey, Tokyo Japan) for the handgrip strength test. The grip span of the dynamometer was adjusted according to the hand size of the youth. The participant squeezed the dynamometer continuously for at least 2 s in standing position, alternating between the right and left hands, with the elbow in full extension.26 The test was performed twice, and the maximum score for each hand was recorded in kilograms. The average score of the left and right hands was calculated. The standing long jump test was performed from a starting position behind a line, standing with feet approximately shoulder's width apart. Participants jumped as far forward as possible, landing with feet together. The test was performed twice, and the longest distance was recorded in centimeters. To account for differences in body size, handgrip strength was expressed per kilogram of body weight. This variable and the standing long jump were then standardized as follows: standardized value $= (\text{value} - \text{mean})/\text{standard deviation} (SD)$. A muscular fitness score was computed by summing up the standardized values of handgrip strength and standing long jump.

Each physical fitness component was grouped into two categories (fit/unfit). For cardiorespiratory fitness, youth were classified as fit or unfit based on the sex and age cut points established by Ruiz et al.27 For motor ability and muscular strength, participants were categorized as fit or unfit in each component according to the sex- and age-specific 20th percentile in the present sample. For each participant, change scores for each physical fitness component were calculated as follows: (a) persistently high, which consisted of fit youth at baseline and follow-up; (b) increasing, which consisted of unfit youth at baseline but fit at follow-up; (c) decreasing, which consisted of fit youth at baseline but unfit at follow-up; and (d) persistently low, which consisted of unfit youth at baseline and follow-up.

### 2.3 Body mass index

Height and weight were measured with participants having bare feet and wearing light underclothes. Height was measured to the nearest 1 mm and weight to the nearest 0.05 kg using a standard beam balance with a stadiometer (SECA 701; SECA, Hamburg, Germany). The measurements were performed twice, and averages were recorded. BMI was calculated as weight in kilograms divided by height in meters squared ($\text{kg/m}^2$). Overweight and obesity (OB) categories derived from BMI values were defined according to Cole et al.28 Youth were categorized in four groups as follows: (a) remaining OW/OB, consisting of youth with OW/OB at baseline and follow-up; (b) normal weight (NW) to OW/OB, consisting of youth with NW at baseline but with OW/OB at follow-up; (c) OW/OB to NW, consisting of youth with OW/OB at baseline but with NW at follow-up; and (d) remaining NW, consisting of youth with NW at baseline and at 2-year follow-up.
2.4 Academic performance

Academic performance was assessed via school records at the end of the academic year. Five indicators were used to define academic performance at baseline and at the 2-year follow-up: individual grades for the core subjects (mathematics and language), an average of mathematics and language, foreign language, and grade point average (GPA) score. GPA score was standardized by calculating a single average for each of the subjects in each grade. For analytic purposes, individual letter grades were converted to numeric data: A = 5, B = 4, C = 3, D = 2, and E = 1.

2.5 Covariates

2.5.1 Biological maturation

Peak height velocity is a common indicator of maturity in children and adolescents. Anthropometric variables (weight, height, and seated height) were used to estimate PHV according to Moore's Equation. Years from PHV were calculated by subtracting the age of PHV from the chronological age. The difference in years was defined as a value of maturity offset.

2.5.2 Maternal education

Maternal education was self-reported by parents as completion of elementary school, middle school, high school, and university. Responses were dichotomized as below university education or university education.

2.6 Statistical analysis

Descriptive statistics at baseline and follow-up are presented as means (standard error) or percentages. Preliminary analyses showed no significant interactions between sex, age, and physical fitness variables in relation to academic performance (all P > .10); therefore, all analyses were performed with boys and girls as well as children and adolescents together. All model assumptions were checked (ie, normality and homoscedasticity).

The change in academic performance from baseline to follow-up for each physical fitness component and BMI (persistently low, decreasing, increasing, and persistently high) was examined by analysis of covariance. For physical fitness components, we used three models: Model 1: Analysis was adjusted by sex, city (Cadiz/Madrid), PHV (years) at baseline, maternal education (university level/below university level), and academic performance at baseline; model 2: model 1 factors plus all physical fitness components at baseline; and model 3: model 2 factors plus BMI at baseline. For BMI, we used two models: model 1: analysis adjusted by sex, city (Cadiz/Madrid), PHV (years) at baseline, maternal education (university level/below university level), and academic performance at baseline; and model 2: model 1 factors plus all physical fitness components at baseline. We repeated all the analyses between physical fitness with allometric scaling and academic indicators, and results were virtually the same (data not shown).

Finally, regression and moderation analyses were conducted using the PROCESS macro 2.16. PROCESS utilizes ordinary least squares regression analysis when predicting continuous variables (academic performance in the current study) and a bias-corrected bootstrap method (with 5000 bootstrapped samples) to estimate the conditional (moderated) effects. To probe significant interactions, simple slope analysis at low (−1 SD), average (mean), and high (+1 SD) levels of the moderator was used with the Johnson-Neyman technique to assess whether the change in BMI (follow-up − baseline) values moderated the relationship between the change in physical fitness (follow-up − baseline) and academic performance at follow-up to indicate regions of significance. In contrast with the traditional simple slopes technique, which tests for a significant relationship between the predictor and outcome at the mean + 1 SD of the moderator, the Johnson-Neyman technique tests for significance along a continuum of moderator values and delineates the slope of the relationship at each value. The Johnson-Neyman technique thus provides greater resolution for clarifying interactions than traditional techniques. In the context of the current study, the technique highlights specific physical fitness cut points in which the significant relationship between BMI and academic performance disappears, as well as how that relationship varies based on the changes in physical fitness. The moderator analyses were adjusted by sex, city (Cadiz/Madrid), PHV (years) at baseline, maternal education (university level/below university level), academic performance at baseline, and all physical fitness components at baseline according to dependent and independent variable included in the model, respectively. All statistical analyses were performed using Statistical Analysis IBM SPSS Statistics version 22.0 (Chicago, IL, USA).

3 RESULTS

The characteristics of the study sample are presented in Table 1. Table S1 shows the longitudinal association between changes in physical fitness components (persistently low, decreasing, increasing, and persistently high) and academic performance in youth at follow-up. Youth in the persistently high cardiorespiratory fitness category had higher scores...
Table 1: Characteristics of the sample (n=1802)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>2-y follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girls, %</td>
<td>48.1</td>
<td>46.8</td>
</tr>
<tr>
<td>Physical characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>10.37 (0.07)</td>
<td>12.39 (0.07)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>42.02 (0.34)</td>
<td>49.36 (0.32)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>143.78 (0.39)</td>
<td>153.40 (0.33)</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>19.51 (0.08)</td>
<td>20.44 (0.09)</td>
</tr>
<tr>
<td>Overweight and obesity, %</td>
<td>27.5</td>
<td>27.1</td>
</tr>
<tr>
<td>Peak height velocity, y</td>
<td>−1.82 (0.06)</td>
<td>−0.38 (0.06)</td>
</tr>
<tr>
<td>Maternal education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>university level, %</td>
<td>26.3</td>
<td>–</td>
</tr>
<tr>
<td>Physical fitness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiorespiratory fitness, mL/kg/min</td>
<td>45.97 (0.11)</td>
<td>45.04 (0.14)</td>
</tr>
<tr>
<td>Unfit, %a</td>
<td>8.4</td>
<td>11.2</td>
</tr>
<tr>
<td>Motor ability, s</td>
<td>13.52 (0.04)</td>
<td>12.53 (0.05)</td>
</tr>
<tr>
<td>Unfit, %a</td>
<td>19.5</td>
<td>19.0</td>
</tr>
<tr>
<td>Muscular strength, z-score</td>
<td>−0.001 (0.02)</td>
<td>0.002 (0.02)</td>
</tr>
<tr>
<td>Unfit, %a</td>
<td>20.3</td>
<td>19.7</td>
</tr>
<tr>
<td>Academic performance, score</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathematics (1-5)</td>
<td>3.28 (0.03)</td>
<td>3.17 (0.03)</td>
</tr>
<tr>
<td>Language (1-5)</td>
<td>3.31 (0.03)</td>
<td>3.28 (0.03)</td>
</tr>
<tr>
<td>Mathematics/Language (1-5)</td>
<td>3.29 (0.02)</td>
<td>3.23 (0.02)</td>
</tr>
<tr>
<td>Foreign language (1-5)</td>
<td>2.94 (0.06)</td>
<td>3.11 (0.06)</td>
</tr>
<tr>
<td>Grade point average (1-5)</td>
<td>3.51 (0.02)</td>
<td>3.45 (0.02)</td>
</tr>
</tbody>
</table>

Note: Values are means (SE), except for categorical data (%).

aCardiorespiratory fitness categories were computed using the cut points established by Ruiz et al.27 and motor ability and muscular strength were categorized according the sex- and age-specific 20th percentile in the present sample.

The findings from the present study indicate that (a) maintaining high levels of cardiorespiratory fitness and motor ability over a 2-year period was associated with higher academic performance compared with those maintaining lower levels of cardiorespiratory fitness and motor ability, even after adjustment for other physical fitness components and BMI; (b) maintaining NW status over a 2-year period was associated with higher academic performance compared with those whose status changed to OW/OB; and (c) moderation analysis suggests that the negative effect of increases in BMI on language, mathematics/language, and GPA disappeared when change in cardiorespiratory fitness was above 0.66, −1.35, and −1.06 mL/kg/min (43.38% of sample), respectively. The strength of this relationship became positive as cardiorespiratory fitness increased (see Figure 1). However, muscular strength and motor ability were not identified as moderators.

4 DISCUSSION

The findings from the present study indicate that (a) maintaining high levels of cardiorespiratory fitness and motor ability over a 2-year period was associated with higher academic performance compared with those maintaining lower levels of cardiorespiratory fitness and motor ability, even after adjustment for other physical fitness components and BMI; (b) maintaining NW status over a 2-year period was associated with higher academic performance compared with those whose status changed to OW/OB; and (c) moderation analysis suggests that the negative effect of increases in BMI on language, mathematics/language, and GPA disappeared when change in cardiorespiratory fitness was above 0.66, −1.35, and −1.06 mL/kg/min, respectively. Therefore, maintaining cardiorespiratory fitness seems to reduce the negative effects associated with change in BMI on academic performance. These findings contribute to the current knowledge by adding evidence regarding the role of physical fitness on academic performance, suggesting that cardiorespiratory fitness may ameliorate, in part, the negative influence of OB on academic performance.

Consonant with previous longitudinal studies, the present results confirm that cardiorespiratory fitness is
FIGURE 1 Regression slope estimate and 95% confidence interval for the relationship between changes in body mass index and academic performance (A, language; B, mathematics/language; and C, grade point average) as a function of change in cardiorespiratory fitness (moderator), based on Johnson-Neyman results.
associated with academic performance in youth.\textsuperscript{10,12,14,15,17} For example, Sardinha et al\textsuperscript{10} suggested that youth aged 11-14 years who were consistently fit or increased their cardiorespiratory fitness over a 3-year period had increased odds of achieving higher academic performance in Portuguese and foreign language compared with those categorized as unfit after adjusted by BMI. Another study in adolescents reported that changes in cardiorespiratory fitness were related to higher academic performance\textsuperscript{14}; however, this study was not adjusted for any body mass indicator. Specifically, our findings suggested that maintaining high levels of cardiorespiratory fitness over a 2-year period was associated with higher academic performance compared with those who were persistently unfit at both time points. However, youth who gained cardiorespiratory fitness during a 2-year period did not increase their academic scores equal to the academic scores of youth who maintained their (higher) fitness. It is worth noting, this lack of association for those who increased their cardiorespiratory fitness over the 2-year period may be due to the small sample size, which comprised only 37 youth. Taken together, these findings indicate that being consistently fit over time could be associated with achieving greater academic performance during childhood and adolescence.

This is the first study examining the longitudinal association between motor ability and academic performance in youth independent of BMI and other physical fitness components. Interestingly, we found that maintaining a high level of motor ability was associated with higher scores in language compared with those maintaining a low level of motor ability. These results further substantiate and extend findings of previous cross-sectional studies\textsuperscript{6} showed that higher motor ability was positively associated with academic performance. The reasons explaining why motor ability might increase academic performance selectively in language cannot be elucidated in our study; yet, there are reasonable means for speculation. First, motor ability has been related to cortical structures, which have also been linked to reading and language processing.\textsuperscript{32} For example, Esteban-Cornejo et al found that motor ability was associated with greater gray matter volume in the inferior frontal gyrus and the superior temporal gyrus, two regions that are also related to verbal processing.\textsuperscript{7} Second, motor ability-related changes in the inferior frontal gyrus and the superior temporal gyrus were related to better reading skills, including language and processing of speech.\textsuperscript{7} These common links between motor ability and language with similar brain regions could partially explain the marked association in youth, independent of the other physical fitness components.

Collectively, our findings suggest that motor ability together with cardiorespiratory fitness is more important to academic performance than muscular strength. Indeed, our results revealed that changes in muscular strength were unrelated to academic performance, which is consistent with a cross-sectional study using the same sample.\textsuperscript{6} Importantly, a recent neuroimaging study examining the association between muscular strength and gray matter in children also did not find any association,\textsuperscript{7} which supports the findings from this study. However, a study in 36 870 Chilean adolescents suggested that those with high levels of muscular strength, assessed with the standing long jump, had significantly higher language and mathematics scores compared with their peers with lower and moderate fitness levels.\textsuperscript{16} While we included upper and lower muscular strength measures, the previous study only assessed lower muscular strength,\textsuperscript{16} which could partly explain this discrepancy in results.

Literature relating BMI and academic performance remains inconsistent. A recent systematic review of longitudinal studies indicated that there is insufficient evidence to support a direct link between OB and poor academic performance in children and adolescents,\textsuperscript{20} suggesting that this inconsistency may be due to a lack of adjustment for various confounding variables. Our study reveals that maintaining NW status over a 2-year period was associated with higher language performance compared with those changing from NW at baseline to OW/OB at follow-up, after adjustment for physical fitness components and other associated confounders. Consistent with our findings, Suchert et al\textsuperscript{17} observed that adolescents changing from NW at baseline to OW/OB at 1-year follow-up showed a significant decline in academic performance. However, consonant with our approach herein, the above-mentioned studies also adjusted for physical fitness components. The association between OB and academic performance may be explained, in part, by the relation of OB to reduced physical and mental health, and consequently increased absenteeism from school.\textsuperscript{33} In addition, OB has been associated with lower gray matter volume compared with NW individuals as early as childhood and adolescence.\textsuperscript{34} Specifically, gray matter reductions in prefrontal cortex have been suggested to occur in a dose-dependent manner with increasing BMI\textsuperscript{35}; within the frontal lobe, the prefrontal cortex is a key region involved in executive function, and in turn, may influence academic performance.\textsuperscript{36}

In this study, we further aimed to test the phenotype known as “fat but fit” in terms of academic performance. Previous cross-sectional studies using mediation analysis suggested that physical fitness may attenuate or even counteract the adverse influence of OW/OB on academic performance in adolescents.\textsuperscript{16,37} For example, García-Hermoso et al\textsuperscript{16} suggested that the effect of excess of fatness on academic performance was mediated by cardiorespiratory fitness and muscular strength. Also, Muntaner-Mas et al\textsuperscript{37} found a meditational effect on the association of excess body mass on academic performance for cardiorespiratory fitness and motor ability, but not for muscular strength. Another study suggests that motor ability may be
more important for academic performance than adiposity in boys and therefore emphasize motor skill training during early and mid-childhood (6-8 years old).19

The present study reveals through a longitudinal moderation analysis that maintaining cardiorespiratory fitness eliminates the negative influence of BMI on academic performance. Several explanations for the moderator role of cardiorespiratory fitness have been suggested: (a) cardiorespiratory fitness has been related to angiogenesis in the motor cortex and increases blood flow, improving brain vascularization which could affect cognitive performance38; (b) cardiorespiratory fitness component has been shown to play a role in spatial memory and white matter integrity39; and (c) cardiorespiratory fitness has been independently associated with greater gray matter volume in numerous cortical and subcortical brain structures (eg, premotor cortex, supplementary motor cortex, and hippocampus), which, in turn, were related to better academic performance in children with OW/OB.7

The present study has some limitations that should be considered. First, students' grades were used as a proxy for academic performance, which could be biased by subjective views or stereotypes of teachers. Second, we cannot exclude the possibility that our findings are explained by unmeasured confounders such as familial background,40 self-concept, self-esteem, or other psychological indicators. Third, an additional limitation is the use of BMI. While BMI is a useful clinical tool, it does not offer the level of specificity that is available such as the dual-energy x-ray absorptiometry, and therefore, its relationship with academic performance could be stronger.37 Fourth, we predicted VO2max and muscular strength from field tests, and standard testing methods (ie, directly measured oxygen consumption and isokinetic measures) are required to confirm our results. Sixth, we categorized participants as fit or unfit with international cutoff only for cardiorespiratory fitness, but not for motor ability and muscular strength. Regarding cardiorespiratory fitness categorization (ie, persistent low, decreasing, increasing, and persistent high), we obtained strongly heterogeneous group sizes and most of them were classified as persistent high.

The study also has several strengths, including the relatively large and heterogeneous sample of children and adolescents, the complete and standardized assessment of physical fitness components, and the longitudinal and moderation analyses.

In conclusion, maintaining higher levels of cardiorespiratory fitness and motor ability as well as NW status over a 2-year period was associated with higher academic performance compared with those maintaining lower levels of fitness or shifting/remaining their weight status at follow-up. Further, cardiorespiratory fitness may ameliorate the negative influence of excess BMI on academic performance during the school years.

5 | PERSPECTIVE

From a public health perspective, promoting physical activity programs at school that include both aerobic exercise and motor tasks to improve physical fitness and lower body mass may not only improve physical health, but also contribute toward successful academic development.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the youth, parents, and teachers who participated in this study.

ORCID

Antonio García-Hermoso [https://orcid.org/0000-0002-1397-7182]

Charles H. Hillman [https://orcid.org/0000-0002-9598-019X]

José Castro-Piñero [https://orcid.org/0000-0002-7353-0382]

Oscar L. Veiga [https://orcid.org/0000-0002-8555-5704]

REFERENCES


**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section.