Cardiorespiratory Fitness and Academic Performance Association is Mediated by Weight Status in Adolescents: DADOS Study

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Abstract

The aim of our study was to examine the mediation effect of weight status on the association between cardiorespiratory fitness (CRF) and academic performance (AP). 269 adolescents (140 boys) aged 13.9±0.3 years old from the DADOS study were included in this cross-sectional analysis. CRF was assessed by the 20-m shuttle run test and estimated maximum oxygen uptake was used in the analysis. AP was assessed through the final academic grades and the Science Research Associates Test of Educational Abilities for assessing reasoning, verbal and numeric abilities. Weight status was assessed by body mass index (kg/m^2). Boot-strapped mediation procedures were performed and indirect effects (IE) with confidence intervals (CI) not including zero were considered statistically significant. Mediation analysis revealed that weight status acted as a mediator of the relationship of CRF with reasoning ability (IE=0.039; CI=0.001;0.091) and the final grades in Math (IE=0.011; CI=0.002;0.025), Language (IE=0.013; CI=0.004;0.027) and GPA (IE=0.011; CI=0.003;0.023). Conclusions: Our data show that the influence of CRF on academic performance is mediated by weight status in adolescents. We suggest that our data could be considered by educators, families and policy makers, so that active lifestyles might be promoted when designing programs aimed to improve AP among adolescents.

Key words: adolescence; body mass index; health; school-performance.

What is Known

- Cardiorespiratory fitness is an indicator of health which influences weight status.
- Academic performance is associated with both, cardiorespiratory fitness and weight status.
- The role of weight status in the association between cardiorespiratory fitness and academic performance is poorly understood.

What is New

- We support the scarce research investigating the mediating role of weight status in the association between fitness and academic performance in youth.
- Previous knowledge is expanded by suggesting that cardiorespiratory fitness is related to weight status which in turn may positively influence academic performance in adolescents.

58

59 **Abbreviations**

60 AP: Academic Performance

61 BMI: Body Mass Index

62 CRF: Cardio-Respiratory Fitness

63 GPA: Grade Point Average

64 SD: Standard Deviation

65 SDS: Standard Deviations Scores

66 SES: Socio-Economic Status

67 VO_2max: Maximum Oxygen Uptake

68

69 **Introduction**

70 Adolescence is a period of life characterized by important changes in body and brain which shape cognition
71 and physical capacities [25]. A growing body of literature suggests that achieving optimal levels of health-related
72 markers during adolescence, such as physical fitness and weight status, may be crucial for cognition and physical
73 health across the lifespan [12].

74 Cardiorespiratory fitness (CRF) is one of the most studied physical fitness indicators. Besides its well-
75 known health-related positive association with weight control [22] and cardiometabolic disease risk factors in
76 adolescents [24], increasing evidences support that CRF is also positively associated to brain structures integrity
77 and brain vascularization [11,12], as well as better cognitive skills [13], which may result in improved academic
78 performance (AP).

79 AP refers to the student's attainment of educational goals in school and is usually assessed through the final
80 grades or standardized reading and arithmetic skills tests [5]. AP in adolescents has been positively associated with
81 CRF [27,29] and inversely associated with weight status [9,18,28]. The association with weight status is potentially
82 related to the physiological consequences derived from energy and metabolic unbalance [20], as well as to the
83 cognitive detriments linked to unhealthy weight status [13]. Active lifestyles might play a key role for weight
84 control, fitness enhancement and consequently, cognition and AP improvements [12].

Despite the fact that previous studies intended to investigate the combined or independent association of fitness, weight status and AP in adolescents, only Kantomaa et al. [14] have performed mediation analyses using weight status as a mediator variable in this association. This study revealed that obesity mediated the association between motor ability fitness capacity and academic grades in adolescents. Despite motor ability and cardiorespiratory fitness capacities seem both to be positively associated with AP [14,27], the mediating role of weight status in the association between CRF and AP has been poorly investigated. Although Kantomaa et al. [14] performed their prospective study in a large cohort, our study includes an objective measure of weight status and takes into account several confounders such as age, pubertal status, sex, socioeconomic status (SES) and psychological wellbeing [5].

Given the high prevalence of overweight in children and adolescents worldwide [1], and the growing body of research showing a positive association between CRF and AP [27], further comprehending of the relationship of these key factors and its potential impact on AP is needed. Based on the previous knowledge, we hypothesized that CRF positive association with AP could be mediated weight status. Thus, the aim of our study was to examine whether weight status exerts a mediation effect on the association between CRF and AP in adolescents.

Materials and Methods

Study design and participants

The present study is part of the DADOS (Deporte, ADOlescencia y Salud) research project, a 3-year longitudinal study (from 2015 to 2017) aimed to analyze the influence of competitive physical activity on health, academic performance and psychological wellbeing through adolescence. All participants were volunteers recruited from secondary schools and sport clubs of Castellon (Spain), and met the general DADOS inclusion criteria: born in 2001, enrolled in 2nd grade of secondary school, and free of any chronic disease. The results presented in this cross-sectional analysis belong to baseline data obtained between February and May of 2015. A total of 269 adolescents (140 boys) aged 13.9±0.3 years with valid data for CRF, body mass index (BMI), final grades, pubertal and socioeconomic status were included in the analysis. Adolescents and their parents or guardians were informed of the nature and characteristics of the study, and all provided a written informed consent.

Anthropometric measurements

Measures were assessed in duplicate by trained researchers and average measures were used for the analyses. Body weight was measured to the nearest 0.1 kg using an electronic scale (SECA 861, Hamburg, Germany). Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (SECA 213, Hamburg,

Germany). BMI was calculated as weight/height square (kg/m2). The BMI values were transformed into standard deviation scores (SDS) according to WHO reference population for sex and age [21], and they were used as weight status.

Cardiorespiratory fitness

CRF was assessed using the 20m Shuttle Run Test as described by Léger [17]. Each participant run straight between 2 lines 20m apart at a pace established by recorded audio signals. The initial speed was 8.5 km/hour and it was increased 0.5 km/hour each minute. The test was completed when participants could not reach the end lines at the pace of the audio signals for 2 consecutive times or when they stopped because of fatigue. The maximum oxygen uptake was estimated. The last stage number completed was used to predict maximal oxygen uptake (VO2max, ml/kg/minute) using the following equation reported by Léger [17]: VO2max = 31.025 + (3.238 x (8 + 0.5 x last stage number completed) – (3.248 x age) + (0.1536 x (8 + 0.5 x last stage number completed) x age).

Academic performance

AP was assessed by two components: 1) the final academic grades from the 1st course of secondary school provided by each school's secretary office on a ten-point scale. Individual grades for Math and Language (Spanish), and grade point average score (GPA) were included in the analyses. GPA score was defined as the single average grade for Geography and History, Natural Science, Math, Spanish, Catalan, English and Physical Education. 2) the Spanish version of the Science Research Associates Test of Educational Abilities [31]. This test measures verbal ability (command of language), numeric ability (speed and precision in performing operations with numbers and quantitative concepts) and reasoning ability (aptitude to find logical ordination criteria in sets of numbers, figures or letters). Direct scores were obtained for each of these specific abilities, and an overall ability (range, 0-110) was calculated by summing the 3 direct scores. This battery test provides three complexity levels based on the age range of the sample. The present work used the level 3 designed for adolescents aged 14 to 18 years (reliability: verbal α=0.74, numeric α=0.87, reasoning α=0.77 and overall ability α=0.89) [31].

Covariates

The statistical analyses were controlled for sex, age, pubertal status, SES and psychological wellbeing. These are relevant cofounders given the association of SES and psychological wellbeing with AP, fitness and weight status in adolescents [3,8]. Since adolescence is a period of developmental changes at different pace, age, pubertal status and sex were also considered as covariates [23].

Pubertal status was self-reported according to the 5 stages defined by Tanner and Whitehouse (1976). It is based on external primary and secondary sex characteristics, which are described by the participants using standard pictures according to Tanner instructions. SES was self-reported by the parents using the Family Affluence Scale developed by Currie et al. [4] based on material conditions in the family such as car ownership, bedroom occupancy, computer ownership and home internet access. Psychosocial wellbeing was assessed by the Spanish version of the Behavior Assessment System for Children, using the level-3 form for 14 years old participants [26]. The psychological wellbeing indicators included in the present study as covariates were: anxiety, interpersonal relations, self-esteem, social stress, depression and sense of inadequacy.

Statistical analysis

Study sample characteristics are presented as mean ± standard deviation (SD) unless otherwise stated. Differences between boys and girls were examined using independent t-test. Since we did not observe a significant interaction effect for sex (e.g. sex x main effect variables) (all $P>0.05$), all analyses were performed together for boys and girls. Partial correlations were performed to confirm the relationships between weight status, CRF and AP variables, controlling for age, pubertal status, SES, sex and psychological wellbeing. Boot-strapped mediation procedures were performed to examine whether the association between CRF and AP variables were mediated by weight status, controlling for age, pubertal status, SES, sex and psychological wellbeing. The PROCESS SPSS Macro version 2.16.3, model four, with 5.000 bias-corrected bootstrap samples and 95% confidence intervals (CIs) was used for these analyses [10]. Mediation was assessed by the indirect effect of the CRF (independent variable) on AP (variables individually entered as the dependent variable) through weight status (mediator). The total (c path), direct (c′ path) and indirect effect (a*b paths) are presented (figure 1). Indirect effects (*ab*) with CIs not including zero were interpreted as statistically significant, which can be so regardless of the significance of the total effect (the effect of CRF on AP) and the direct effect (the effect on AP when both CRF and BMI SDS are included as predictors) [10]. Percentage of mediation (PM) was calculated as (indirect effect/total effect)x100 to know how much of the total effect was explained by the mediation when the following assumptions where achieved: the total effect is larger than the indirect effect and with the same direction of the effect [10]. These analyses were adjusted by age, pubertal status, SES, sex and psychological wellbeing. All the analyses were performed using the IBM SPSS Statistics for Windows version 22.0 (Armonk, NY: IBM Corp), and the level of significance was set at $P<0.05$.

Suggested insertion Figure 1

Results

According to descriptive data of the study population (table 1), boys and girls were only significantly different in height, CRF, numeric ability and pubertal status distribution (P<0.001).

Suggested insertion Table 1

Partial correlations between CRF, weight status and AP outcomes, accounting for age, pubertal status, SES, sex and psychological wellbeing, are presented in Table 2. Overall, weight status was negatively correlated with AP whereas CRF was positively correlated to AP (P<0.05). All the academic grades were positively correlated to all the academic abilities (all P<0.001).

Suggested insertion Table 2

Simple mediation analyses results are presented in Table 3, which shows that CRF indirectly influenced some AP variables through its association with weight status, controlling for age, pubertal status, SES, sex and psychological wellbeing. There was a significant indirect relationship (path *a*b*) between CRF and all final grades as well as reasoning ability when weight status was included in the mediation analyses, indicating that weight status mediated the relationship between CRF and these AP variables. The total effect of CRF on AP explained by BMI SDS was 34% in Math, 63% in Language and 40% in GPA. CRF was negatively associated with weight status (path *a*) and weight status was negatively associated with final grades (path *b*). A significant total effect (path *c*) was observed for CRF and Math, GPA and numeric ability. The direct effect (path *c'*) of CRF on AP variables was not significant.

Suggested insertion Table 3

Discussion

Previous studies have investigated the combined or independent relationship of AP with CRF and weight status in adolescents [13,28,29]. However, to our knowledge, only one previous study has examined in adolescents the role of weight status in the relationship between CRF and AP using mediation statistical analyses. Our results suggest that, after controlling for potential confounders, weight status mediated the association between CRF and final academic grades as well as reasoning ability in healthy adolescents (PM ranging from 34% to 63%). These data strengthen the positive association between CRF and AP and adds new knowledge about the potential underlying mechanisms through weight status.

198 The findings of the present study suggest that CRF is inversely associated with weight status, which may
199 contribute to better final academic grades and better reasoning ability. These findings are consistent with previous
200 studies showing that improvements in CRF are associated with BMI reductions [22] along with better AP [9,29].
201 Our results agree with the only previous study using weight status as mediator between physical fitness (measured
202 as motor ability) and AP [14], which showed that obesity is an important factor driving the association of physical
203 fitness with AP.

204 The divergent mediation results obtained for the final academic grades and some of the academic abilities
205 for which weight status did not mediate the relationship, could be due to the fact that they rely on different forms
206 of assessment. The academic abilities test is an standardized test that evaluates specific abilities in a single time-
207 point trial while final grades are the result of the student progression for each subject evaluated by different
208 teachers and tasks [2].

209 In our opinion, the mediating role of weight status in the association between CRF and AP might partially
210 be explained by both psychosocial and physiological mechanisms. On the one hand, research in obese adolescents
211 have shown that they are perceived by teachers to be less socially, physically and cognitively skillful, so this biased
212 perception towards obesity could also impact on AP [15]. Previous data have shown that weight status influences
213 school experience of students by increasing teasing and psychological maladjustment, which could also worsen
214 their AP [8]. Thus, we speculate that fitness improvements could positively influence weight-related psychological
215 factors, which may also shape adolescents AP. The psychological mechanisms proposed might not be reflected in
216 our results from the specific academic abilities tests. On the other hand, we suggest that CRF metabolic adaptations
217 related to weight control could influence cognitive functioning, and thus AP. This idea might be related to the fact
218 that the adipose tissue drive biological processes involved in the regulation of obesity-related indicators such as
219 adipokines, inflammatory cytokines and gut hormones which have been associated with learning, memory, and
220 general cognitive function in youth [20].

221 Although the mediation analysis used is a robust measure of statistical analyses [10], the cross-sectional
222 design of the study limits our ability to make assumptions about the causal nature of the relationship analyzed [19].
223 Thus, since mediation may occur over time, our results should be taken with caution since we did not control for
224 previous values of the variables [19]. This study has been carried out in a group of adolescents from south Europe,
225 which have shown particular cognitive and physical capacities [6], thus different results could be obtained from
226 different population. Nevertheless, the study has some strengths including the use of objective and standardized
227 measures of AP and a relatively large and homogeneous sample in terms of age. In addition, following the

recommendations of a recent review [5], the statistical analyses were controlled for age, pubertal status, SES, sex and psychological wellbeing.

In conclusion, this study suggests that weight status mediates the association between CRF and AP in healthy adolescents. Thus, if confirmed prospectively, our data point out that improvements in CRF during adolescence may contribute to better AP partially via improvements in weight status. Our findings may have significant implications from an educational and public health point of view given the high prevalence of overweight in children and adolescents [1]. Academic outcomes are of high importance to adolescents, families and society due to its relationship with future personal events such as employability [7] and health [16]. Despite the cross-sectional nature of our findings limits our ability to stablish definite conclusion, we consider that our data could be of interest to educators, families and policy makers, so that active lifestyles might be promoted when designing programs aimed to improve AP among adolescents.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest.

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Informed consent: Informed consent was obtained from all individual participants included in the study.

Ethical approval: The DADOS study protocol was designed in accordance with the ethical guidelines of the Declaration of Helsinki 1961 (last revision of Fortaleza, Brazil, 2013) and was approved by the Research Ethics Committee of the University Jaume I of Castellon.

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Table 1. Descriptive data by gender.

Variable	**All** (n=269)	**Boys** (n=140)	**Girls** (n=129)	**p value**
Age (years)	13.9 ± 0.3	13.9 ± 0.3	13.9 ± 0.3	0.39
Weight (kg)	54.1 ± 9.2	54.5 ± 9.6	53.7 ± 8.8	0.50
Height (cm)	163.0 ± 7.9	164.6 ± 8.6	131. 2 ± 6.7	**<0.001**
BMI (kg/m^2)	20.3 ± 2.1	20.0 ± 2.5	20.6 ± 2.9	0.05
BMI SDS	0.29 ± 0.89	0.27 ± 0.89	0.30 ± 0.90	0.83
Tanner (I-V) [a]	0/21/91/130/25	0/14/44/61/19	0/7/47/69/6	
VO_2max. (ml/kg/min)	50.4 ± 6.7	54.1 ± 5.3	46.4 ± 5.8	**<0.001**
Academic abilities				
Reasoning	16.6 ± 5.8	16.1 ± 5.6	16.9 ± 6.0	0.23
Numeric	13.3 ± 4.7	14.7 ± 4.5	11.9 ± 4.5	**<0.001**
Verbal	18.5 ± 5.3	19.0 ± 5.8	18.2 ± 4.6	0.19
Overall	48.4 ± 12.6	49.8 ± 12.8	47.0 ± 12.2	0.07
Academic Grades				
Math	6.8 ± 1.8	7.0 ± 1.6	6.7 ± 1.6	1.17
Language	6.9 ± 1.5	6.7 ± 7.5	7.1 ± 1.5	0.09
GPA	7.1 ± 1.3	7.1 ± 1.3	7.2 ± 1.3	0.48

Data are presented as mean ± SD. Differences between boys and girls were examined by independent t-test. Data presented as frequency, differences between boys and girls analyzed by chi-square test [a]. Values in bold font indicate significant results: $P<0.05$.

BMI: body mass index. SDS: standard deviations scores using the WHO 2007 reference values [21]. GPA: grade point average.

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Table 2. Partial correlation among academic performance variables, weight status and cardiorespiratory fitness controlling for sex, pubertal status, socioeconomic status and psychological wellbeing (n=269).

	CRF	Math	Language	GPA	Reasoning	Numeric	Verbal	Overall
BMI SDS	**-0.30*** **	**-0.17** **	**-0.19** **	**-0.20** **	0.12	**-0.14***	-0.08	**-0.14***
CRF	-	**0.13***	0.09	**0.14***	0.25	**0.14***	0.10	0.11
Math		-	**0.74*** **	**0.85*** **	**0.38*** **	**0.46*** **	**0.30*** **	**0.47*** **
Language			-	**0.87*** **	**0.37*** **	**0.36*** **	**0.34*** **	**0.45*** **
GPA				-	**0.39*** **	**0.43*** **	**0.33*** **	**0.48*** **
Reasoning					-	**0.56*** **	**0.36*** **	**0.83*** **
Numeric							**0.41*** **	**0.80*** **
Verbal							-	**0.75*** **

Data are presented in the correlation coefficient *R*. Values in bold font indicate significant results: **P*<0.05, ***P*<0.01, ****P*<0.001

BMI SDS: body mass index standard deviations scores used as measure of weight status; CRF: cardiorespiratory fitness evaluated by estimated VO_2max. GPA: grade point average score. Reasoning, verbal, numeric and overall refers to the test of academic abilities. Overall: Sum of Academic Abilities

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Table 3. Total, direct and indirect effects, *a* and *b* pathways, of the simple mediation analyses investigating weight status as a mediator between cardiorespiratory fitness and academic performance outcome variables (n=269).

Outcome	Total effect (*c*)	Direct effect (*c'*)	Path *a*	Path *b*	Indirect effect (*ab*)	BC 95% CI		P_M (%)
						Lower	Upper	
Academic Grades								
Math	0.034 (0.017)#	0.022 (0.018)	-0.047 (0.009)#	-0.247 (0.114)#	**0.011 (0.006)***	0.002	0.025	34
Language	0.021 (0.016)	0.001 (0.018)	-0.047 (0.009)#	-0.281 (0.106)#	**0.013 (0.006)***	0.004	0.027	63
GPA	0.028 (0.014)#	0.017 (0.014)	-0.047 (0.009)#	-0.245 (0.090)#	**0.011 (0.005)***	0.003	0.023	40
Academic Abilities								
Reasoning	0.021 (0.068)	-0.017 (0.071)	-0.047 (0.009)#	-0.829 (0.452)	**0.039 (0.022)***	0.001	0.091	N/A
Verbal	0.095 (0.061)	0.080 (0.064)	-0.047 (0.009)#	-0.334 (0.411)	0.016 (0.021)	-0.024	0.059	
Numeric	0.113 (0.051)#	0.087 (0.054)	-0.047 (0.009)#	-0.548 (0.344)	0.026 (0.017)	-0.005	0.064	
Overall	0.230 (0.143)	0.150 (0.149)	-0.047 (0.009)#	-1.712 (0.953)	0.080 (0.047)	-0.001	0.192	

Results showed as unstandardized coefficients (Standard Error, SE) and BC 95%CI based on 5000 bootstrap. All analyses were adjusted for sex, pubertal status, socioeconomic status and psychological wellbeing.

CRF: cardiorespiratory fitness; AP: academic performance; BC: Bias corrected; CI: confidence interval; P_M: percentage of mediation; GPA: grade point average score. N/A: non-applicable according to statistical assumptions specified previously.

* indicates that 0 is not in the 95% CI of the indirect effect, thus reflecting significant indirect effect. # P=0.05.

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Fig. 1 Simple mediation model of cardiorespiratory fitness (independent variable) on academic performance variables (dependent variable) through weight status measured by body mass index standard deviations scores (BMI SDS) (mediator variable).

Path *a*: association between independent and mediator variables; Path *b*: association between mediator and dependent variables; Path *c*: overall association between independent and dependent variables; Path *c'*: unmediated direct effect of independent variable on dependent variable.