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The bidirectional longitudinal association between academic performance and cardiovascular disease risk factors in adolescents

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Abstract

Introduction: The limited prior research examining the association between academic performance and cardiovascular disease (CVD) risk factors in youth did not explore the reciprocal association between these constructs, and analyzed CVD risk factors individually. Thus, the aim of the present study was to explore the bidirectional longitudinal association between clustered CVD risk score and academic performance in adolescents over a 24-month interval.

Methods: A total of 237 adolescents (45.6% girls), aged 13.9 ± 0.3 years old at baseline, from DADOS (Deporte, ADOlescencia y Salud) study were included in this study. A clustered CVD risk score was created by calculating the mean age- and gender-standardized *z*-scores of waist circumference, systolic blood pressure, total cholesterol to high-density lipoprotein cholesterol ratio, triglycerides, homeostatic model assessment of insulin resistance, and cardiorespiratory fitness (inversed). Academic performance was assessed through the final academic grades and the test of educational abilities.

Results: Our results showed that the clustered CVD risk score at baseline was not associated with academic performance 24 months later (all $p > .05$). Nevertheless, except for physical education, academic grades at baseline were inversely associated with clustered CVD risk score at follow-up in adolescents (β ranged from −0.140 to −0.102; all $p < .05$). No associations were found between academic abilities at baseline and clustered CVD risk score at follow-up (all $p > .05$).

Conclusion: Academic grades could help predict CVD risk 24 months later during adolescence. Education professionals should foster adolescents' academic performance not only to improve academic results but also to maximize future cardiovascular health benefits.

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1 | INTRODUCTION

Cardiovascular diseases (CVD) are heart and circulatory disorders considered as the leading cause of mortality and morbidity in adults worldwide (WHO, 2021). Although CVD clinically manifest during adulthood, strong evidence suggests that the risk factors related to their development, which usually include obesity, elevated blood pressure, dyslipidemia, hyperglycemia, or insulin resistance, begin in early life (Jacobs et al., 2022; Pool et al., 2021). Previous data have suggested that the reduction of these CVD risk factors during youth could be effective to delay progression toward the manifest of these diseases in adulthood (Hardy et al., 2015). Based on this, the implementation of strategies for CVD risk factors prevention in children and adolescents have been encouraged, which have usually focused on health-related behaviors modification (e.g., physical activity, eating habits, or smoking) (Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents, 2011). However, since CVD arise from a complex interplay of factors, the consideration of social conditions (e.g., economic status, social support, or academic performance) in prevention strategies has received increased recognition (Havranek et al., 2015).

Among the social conditions related to CVD risk factors, academic performance, which refers to educational goals that students reach in a particular period of time (Donnelly et al., 2016), has been suggested to play an important role in individuals' development and health across the life course. Indeed, previous research has reported the positive relationship between the highest educational attainment and global health outcomes in adulthood (i.e., morbidity and mortality) (Raghupathi & Raghupathi, 2020). In this line, academic grades in elementary schoolchildren predicted self-perceived physical well-being 1 year later (Degoy & Olmos, 2020). Moreover, Lê-Scherban et al. (2014) showed that higher academic performance during childhood and adolescence was associated with better self-perceived health status and lower body mass index in girls 10 years later. Thus, this study suggested that academic performance before achieving the highest level of educational attainment could also benefit future health in girls, highlighting that to analyze the opportunities generated by early academic performance could foster educational practices intended to maximize general and cardiovascular health throughout their lifespan. To our knowledge, the research performed by Lê-Scherban et al. (2014), which reported a significant association solely in girls, is the only study that analyzed the longitudinal association between academic performance during adolescence and a CVD risk factor (i.e., self-reported body mass index). In this context, a better understanding of the predictive role of academic performance on later cardiovascular health is needed, as this direction of the association has been understudied, and could also counsel future evidence-based interventions.

Conversely, a larger number of studies have focused on investigating how CVD risk factors in children and adolescents predict later academic performance. Specifically, some previous longitudinal studies have reported significant negative relationships between individual CVD risk factors, like excess of body weight, and academic outcomes (García-Hermoso et al., 2021; Larsen et al., 2014). In addition, one cross-sectional study showed that waist circumference, systolic blood pressure, insulin resistance, and dyslipidemia, individually and in a composite z-score, were negatively associated with the odds of high school completion and taking college entrance exams (Correa-Burrows et al., 2019). In the same line, a recent review showed that cardiorespiratory fitness, a positive indicator of cardiovascular health, was directly associated with academic performance (Álvarez-Bueno et al., 2020). Thus, taken together all this previous knowledge, a bidirectional relationship between academic performance and CVD risk factors during youth seems plausible. However, no previous studies have considered the possibility of reciprocal association between these two constructs.

In view of the available scientific evidence, there is a need for further research exploring the relationship between CVD risk factors and academic performance to understand the reverse causality between these variables. In this context, although previous studies investigated CVD risk factors individually, analyzing them as a continuous clustered CVD risk score may better represent CVD risk in youth. This is supported by the fact that these risk factors tend to occur together and their combination has been considered a stronger predictor of CVD than individual risk factors (Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents, 2011; Jacobs et al., 2022). Altogether, expanding this evidence would guide the design of forthcoming CVD prevention strategies for adolescents, who are experiencing a biological transition and rapid changes that may shape CVD risk (Hardy et al., 2015). Therefore, the present study intended to explore the bidirectional association between clustered CVD risk score and academic performance during adolescence between two timepoints with a 24-month interval.

2 | MATERIALS AND METHODS

2.1 | Study design and sample selection

This study is part of the DADOS (Deporte, ADOlescencia y Salud) research project, which was designed in

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accordance with the ethical guidelines of the Declaration of Helsinki 1964 (last revision of Fortaleza, Brazil, 2013) and approved by the Research Ethics Committee of the Universitat Jaume I of Castellon in Spain (UJI-28/04/2014). This was a 3-year longitudinal project aimed to examine the influence of lifestyle behaviors on health and academic performance during adolescence. A convenience sampling technique was used to recruit participants. For that purpose, advertising leaflets about the research project were sent to secondary schools and sport clubs located in the province of Castellon (Spain), which included the main information about the study aim and protocol. The inclusion criteria were to be in the second year of secondary school (13–14 years) and not to be diagnosed with any physical (i.e., locomotor system injury) or neurological (i.e., intellectual disability) impairment. Volunteers who met the inclusion criteria were included in the study. The participation rate of DADOS study was formed by a total of 274 participants, who were studying the second year of secondary school. From them, 237 participants completed the baseline assessments (between February and May of 2015). During the course of DADOS study, there was a drop-out of 67 participants and a total of 170 students completed the assessments 2-years later (between February and May of 2017). These participants voluntarily decided to quit the study without stating the reasons. Before participating in the study, both adolescents and their parents or guardians were informed of the nature and characteristics of the study and provided a written informed consent.

2.2 | CVD risk factors

2.2.1 | Waist circumference

Waist circumference was measured to the nearest 1 mm with a non-elastic tape applied horizontally midway between the lowest rib margin and the iliac crest, at the end of gentle expiration with the adolescent in a standing position in line with recommended guidelines (Stewart et al., 2011). Two measures were taken and the mean value was used unless those values differed by more than 10%, whereby a third measure was taken and the average of the two closest values was used for analysis.

2.2.2 | Resting blood pressure

Systolic and diastolic blood pressure were measured using automated sphygmomanometry (Omron HEM-7321-E, Omron Healthcare, Co., Ltd., Kyoto, Japan). Trained nurses took measurements and all adolescents were required to sit and rest for at least 5 min prior to the first blood pressure measurement. Two measurements were taken with a 1-min pause in between, and subsequently the mean of these two measurements was used for analysis. If the two measurements differed by >10 (mmHg), a third measure was taken and the first one discarded (McCrindle, 2010).

2.2.3 | Blood sampling

Blood samples were drawn from the antecubital vein after an overnight fast of at least 10 h (at 8:00 a.m.) and collected in two test tubes containing ethylenediaminetetraacetic acid (Greiner bioone, Kremsmünster, Austria). One tube was kept refrigerated at 4°C for immediate analyses in whole blood, whereas the other tube was centrifuged to obtain serum (3500 rpm for 10 min at 4°C). Subsequently, serum concentrations of low-density lipoprotein cholesterol (LDL), high-density lipoprotein cholesterol (HDL), total cholesterol (TC), triglycerides, glucose, and insulin were measured. The TC:HDL-ratio was calculated as a marker of dyslipidemia. The homeostatic model assessment of insulin resistance (HOMA-IR) was estimated with the following formula: [insulin (pmol/L) * glucose (mmol/L)]/135 (Matthews et al., 1985).

2.2.4 | Cardiorespiratory fitness

Cardiorespiratory fitness was assessed using the 20-m shuttle run test (Léger et al., 1988). Each participant ran straight between two lines 20 m apart at a pace established by recorded audio signals. The initial speed was 8.5 km/h and it increased 0.5 km/h each minute. The test was completed when participants could not reach the end lines at the pace of the audio signals for two consecutive times or when they stopped. The last stage completed was recorded and transformed into maximal oxygen consumption (VO_2max, mL/kg/min) using the Léger et al. (1988) equation: [31.025 + (3.238 × (8 + 0.5 × last stage completed)) − (3.248 × age) + (0.1536 × (8 + 0.5 × last stage completed) × age)].

2.2.5 | Clustered CVD risk score

A continuous clustered risk score was created by calculating the mean age- and gender-standardized *z*-scores of waist circumference, systolic blood pressure, TC:HDL-ratio, triglycerides, HOMA-IR, and cardiorespiratory fitness (inversed) as recommended by Stavnsbo et al.

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(2018). These authors calculated reference values for the most commonly used cardiometabolic risk variables from data from 22 479 children and adolescents aged 6–18 years (48.7% from Europe and 51.3% from the United States) (Stavnsbo et al., 2018). A lower value denoted a healthier cardiometabolic profile. The use of a clustered *z*-score approach was suggested as a better identifier of CVD risk in youth compared with other cardiometabolic risk screening criteria such as using individual CVD risk variables (Andersen et al., 2015). Moreover, this approach facilitates comparison across studies and over time, by increasing standardization of calculations and definitions used to identify CVD risk in youth (Stavnsbo et al., 2018).

2.3 | Academic performance

Academic performance was assessed using the final academic grades from the second (13–14 years) and the fourth (15–16 years) academic year of secondary school, provided by each school's secretary office. They were based on a 10-point scale (0 indicating the lowest achievement and 10 indicating the highest achievement). Individual grades for natural sciences, social sciences, math, language, and physical education, as well as grade point average were included in the analyses. Grade point average was defined as the single average for the scores achieved by students in all subjects.

The Spanish version of the Science Research Associates Test of Educational Ability (TEA) was used to measure academic abilities (Thurstone & Thurstone, 2004). This test provides general measures of three areas of intelligence and skills of learning: verbal (i.e., command of language), numeric (i.e., speed and precision in performing calculations with numbers and quantitative concepts), and reasoning (i.e., the skill to find logical order in sets of numbers, figures, or letters). Scores for the three areas were obtained by adding the number of correct answers. An overall score was calculated by adding the three areas scores (i.e., verbal, numeric, and reasoning). Based on the age range of our sample, the third level of the TEA questionnaire was used (reliability: verbal $\alpha = 0.74$, numeric $\alpha = 0.87$, reasoning $\alpha = 0.77$, and overall score $\alpha = 0.89$).

2.4 | Covariates

Sex, pubertal stage, socioeconomic status, and moderate-to-vigorous physical activity at baseline were included as covariates in the statistical analyses because of their relationship with the study variables (Donnelly et al., 2016; Renninger et al., 2020). Specifically, socioeconomic status (Havranek et al., 2015) and physical activity of at least moderate intensity (Renninger et al., 2020) have been linked to CVD risk factors. Moreover, Donnelly et al. (2016) stated the importance of considering socioeconomic status and physical activity when analyzing academic outcomes.

2.4.1 | Pubertal stage

Pubertal stage was self-reported according to the five stages described by Tanner and Whitehouse (1976) based on external primary and secondary sex characteristics. The degree of development was assessed through two components: pubic hair growth for girls and boys, plus breast development in girls and genital development in boys. A 5-point maturity rating (from 1 to 5) was used for each component, in which stage 1 corresponded to the prepubertal state and stage 5 to the mature state. The highest rating of the two components was used for data analyses.

2.4.2 | Socioeconomic status

The Family Affluence Scale (FAS) developed by Currie et al. (2008) was used as a proxy of socioeconomic status (ranging from 0 to 8), which is based on material conditions in the family such as car ownership, bedroom occupancy, computer ownership, and home internet access.

2.4.3 | Moderate-to-vigorous physical activity

Physical activity intensities were measured using the GENEActiv accelerometer (Activinsights Ltd, Kimbolton, UK), a waterproof device that contains a triaxial accelerometer. Participants were invited to wear the accelerometer on their nondominant wrist. Accelerometer-derived data from all participants comprised at least 4 days, including a minimum of one weekend day, with 24 h valid data. GENEActiv accelerometer has been found to be a valid measure of physical activity in young people ($r = 0.925$, $p = .001$) (Phillips et al., 2013). Devices were programmed with a sampling frequency of 100 Hz, data were stored in gravity (*g*) units, and the raw acceleration output was converted to 1 s epochs using the GENEActiv Post-Processing PC Software (version 2.2, GENEActiv). By combining all registered days for each participant and using the validated cut points established by Phillips et al. (2013), we calculated the average time spent

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(min/day) in light, moderate, and vigorous physical activity. Moderate-to-vigorous physical activity was calculated as the sum of the time spent at moderate and vigorous intensities.

2.5 | Statistical analysis

Descriptive characteristics were calculated for each variable and are presented as mean and standard deviations or percentages. All variables were assumed as normally distributed based on graphical procedures (normal probability plots; Figures S1 and S2) as suggested by Martínez González et al. (2020). In addition, as preliminary analyses showed no significant interactions of sex with the clustered CVD risk score in relation to academic performance indicators and vice versa (Table S1), all analyses were performed including the whole sample.

The bidirectional association between clustered CVD risk score and academic performance indicators was examined using a cross-lagged modeling approach through the Lavaan package in R (Rosseel, 2012). A depiction of the general cross-lagged panel model is presented in Figure 1. In these path analyses, all associations were adjusted for each other: analyses are adjusted for the mutual prospective associations that represent the bidirectional associations between clustered CVD risk score and academic performance indicators (the cross-lagged pathways $\beta_{CL\text{-}1}$ and $\beta_{CL\text{-}2}$), the cross-sectional path ($\beta_{CS\text{-}Baseline}$), and the underlying associations of clustered CVD risk score over time (autoregressive path, $\beta_{AR\text{-}Cardiovascular\ diseases\ risk\ score}$) and academic performance indicators over time (autoregressive path, $\beta_{AR\text{-}academic\ performance}$). Autoregressive coefficients have been included to minimize bias in the estimation of cross-lagged effects, since the autoregressive paths describe the stability of individual differences in the measured variables from baseline to follow-up. A small (closer to zero) autoregressive coefficient indicates less stability, whereas a larger (closer to 1) autoregressive coefficient indicates more stability of the variable over time (Selig & Little, 2012).

Models were assessed using several fit indexes and information criteria: the Comparative Fit Index (CFI) and Tucker–Lewis Index (TLI), which should both be close to or exceed 0.95, the root mean square error of approximation (RMSEA), which should be close to or below 0.06, and the standardized root mean square residual (SRMR), which should be close to or below 0.08 (Hu & Bentler, 1999). All models were adjusted for sex, pubertal stage, socioeconomic status, and moderate-to-vigorous physical activity.

To account for missing data (missing in baseline covariates ≤1%) within these models, the full information maximum likelihood estimator was implemented in order to preserve all available data (Rosseel, 2012). This estimator is considered a standard approach to prevent listwise deletion of participants with missing data (Rosseel, 2012). Moreover, in these analyses, we used false discovery rate based on the Benjamini–Hochberg method to adjust the cross-sectional and cross-lagged paths for multiple comparisons. Briefly, this method uses ranked *p*-values to determine the cut-off at which point the Type-I error rate is below 0.05 (Benjamini & Hochberg, 1995). Lastly, to ensure that the results were not biased because of the estimation of missing data from the second timepoint, analyses were conducted only including the participants with complete clustered CVD risk score and academic performance data at both timepoints ($N = 170$). All the statistical analyses of this study were performed using SPSS v. 27 (IBM Corp., Armonk, NY) and R version 3.6.0 using the Lavaan package (The

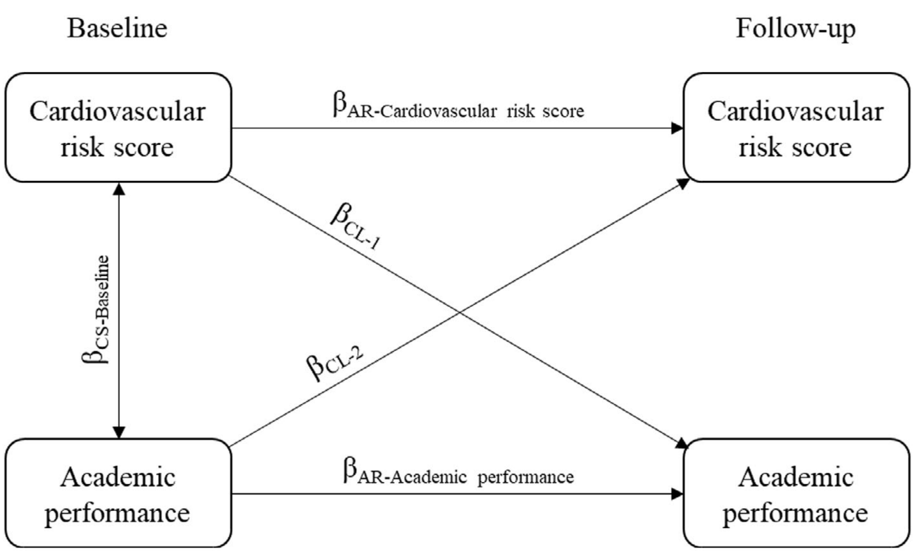

FIGURE 1 Visualization of cross-lagged panel modeling approach. AR, autoregressive, CL, cross-lagged path, CS, cross-sectional path.

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R foundation for Statistical Computing, Vienna, Austria), and the level of significance was set at $p < .05$.

3 | RESULTS

The descriptive characteristics of the study sample at baseline and at 24-month follow-up are shown in Table 1. Participants presented a mean age of 13.9 ± 0.3 at baseline ($N = 237$, 45.6% girls) and 15.8 ± 0.3 at follow-up ($N = 170$, 48.8% girls). The clustered CVD risk score of the study sample was −0.35 ± 0.41 at baseline and − 0.21 ± 0.48 at follow-up. Academic grades ranged from 6.6 ± 1.5 to 8.1 ± 1.1 at baseline and from 6.0 ± 1.9 to 8.1 ± 1.3 at follow-up.

TABLE 1 Descriptive characteristics of participants at baseline and at 24-month follow-up.

	Baseline	Follow-up
N (% girls)	237 (45.6)	170 (48.8)
Age (years)	13.9 ± 0.3	15.8 ± 0.3
Pubertal stage (II-V) (%)	8/35/47/10	0/12/54/34
Socioeconomic status (0–8)	4.2 ± 1.4	-
MVPA (min/day)	88.9 ± 28.9	75.9 ± 25.6
Cardiovascular diseases risk factors		
Waist circumference (cm)	67.1 ± 5.6	71.4 ± 6.4
Systolic blood pressure (mmHg)	107.3 ± 10.8	113.5 ± 11.4
Diastolic blood pressure (mmHg)	64.8 ± 6.9	70.1 ± 6.2
LDL cholesterol (mg/dL)	63.8 ± 18.4	72.4 ± 20.6
HDL cholesterol (mg/dL)	51.5 ± 10.9	48.6 ± 11.0
Total cholesterol (mg/dL)	152.5 ± 25.0	150.0 ± 28.2
TC:HDL-ratio	3.0 ± 0.5	3.2 ± 0.6
Triglycerides (mg/dL)	52.6 ± 26.5	51.1 ± 24.4
Glucose (mmol/L)	5.3 ± 1.1	5.3 ± 1.4
Insulin (pmol/L)	49.7 ± 24.9	60.5 ± 57.4
HOMA-IR	1.9 ± 1.2	2.5 ± 2.4
Cardiorespiratory fitness (VO_2max, ml/kg/min)	50.7 ± 6.7	49.2 ± 7.5
Clustered risk score[a]	−0.35 ± 0.41	−0.21 ± 0.48
Academic grades (0–10)		
Natural sciences	6.8 ± 1.7	6.5 ± 1.5
Social sciences	6.7 ± 1.7	6.5 ± 1.8
Math	6.7 ± 1.7	6.0 ± 1.9
Language	6.6 ± 1.5	6.4 ± 1.8
Physical education	8.1 ± 1.1	8.1 ± 1.3
Grade point average	7.0 ± 1.3	6.7 ± 1.4
Academic abilities		
Verbal ability (0–50)	19.1 ± 5.4	22.6 ± 5.5
Numeric ability (0–30)	13.9 ± 4.7	16.5 ± 5.1
Reasoning ability (0–30)	17.0 ± 5.7	21.2 ± 4.7
Overall score (0–110)	50.0 ± 12.3	60.3 ± 11.7

Note: Data are presented as mean ± standard deviation or percentages.

Abbreviations: HDL, high-density lipoprotein; HOMA-IR, homeostasis model assessment of insulin resistance; LDL, low-density lipoprotein; MVPA, moderate-to-vigorous physical activity; TC, total cholesterol; VO_2max, maximal oxygen consumption.

[a]The clustered risk score based on the age- and gender-standardized *z*-scores of six cardiometabolic risk variables: waist circumference, systolic blood pressure, TC:HDL-ratio, triglyceride, HOMA-IR, and cardiorespiratory fitness (inversed), according to Stavnsbo et al. (2018).

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Regarding academic abilities, the overall score was 50.0 ± 12.3 at baseline and 60.3 ± 11.7 at follow-up.

Bidirectional longitudinal associations between clustered CVD risk score and academic performance based on the cross-lagged panel models after adjustment for sex, pubertal stage, socioeconomic status, and moderate-to-vigorous physical activity are shown in Table 2. At baseline, after multiple comparisons correction, only physical education was cross-sectionally and inversely associated with clustered CVD risk score ($\beta = -0.196$, $p = .010$). Clustered CVD risk score at baseline was not associated with any of the academic performance indicators 24 months later (all $p > .05$). Nevertheless, natural sciences ($\beta = -0.102$, $p = .038$), social sciences ($\beta = -0.137$, $p = .005$), math ($\beta = -0.140$, $p = .005$), language ($\beta = -0.111$, $p = .023$), and grade point average ($\beta = -0.127$, $p = .002$) at baseline were inversely associated with clustered CVD risk score at follow-up. There was no association between academic abilities at baseline and clustered CVD risk score at follow-up (all $p > .05$). Autoregressive coefficients are presented in Table S2 and show that the stability between baseline and follow-up measures was greater for clustered CVD risk score (ranging from 0.766 to 0.786) than for academic performance indicators (ranging from 0.423 to 0.762).

Sensitivity analyses were conducted by performing a complete cases analysis including the sample reduced to those with complete clustered CVD risk score and academic performance data at both timepoints ($N = 170$), and results were similar (see Table S3 and Table S4).

4 | DISCUSSION

The main findings of the present study indicated for the first time that clustered CVD risk score at baseline did not predict academic performance 24 months later, whereas academic grades (but not academic abilities) at baseline predicted clustered CVD risk score at follow-up in adolescents. Specifically, natural sciences, social sciences, math, language, and grade point average at baseline were inversely associated with clustered CVD risk score 24 months later. Our findings are unique in the existing literature since they suggest that there is not a significant bidirectional relationship between a composite score of CVD risk and a wide range of academic performance indicators across time, yet they reveal a possible route to reduce adolescents' CVD risk via academic performance.

Most of the studies that have analyzed how CVD risk may influence later academic performance in adolescents have investigated this link focusing only on individual CVD risk factors. These studies showed both significant (Álvarez-Bueno et al., 2020; García-Hermoso et al., 2021; Larsen et al., 2014) and nonsignificant (Lyngdoh et al., 2013) results depending on the individual CVD risk factor analyzed, without considering other risk factors that tend to accumulate or occur altogether. In this context, this is the first study that examines the longitudinal association between a composite score of CVD risk for youth and academic performance, which hampers direct comparisons with other studies. Our findings revealed that clustered CVD risk at baseline was not associated with academic performance at 24 month follow-up. In this sense, to our knowledge, there is only one previous study that has examined the association between a composite score of CVD risk and academic performance in youth (Correa-Burrows et al., 2019). This study used a cross-sectional design and contrary to our findings concluded that cardiometabolic risk, measured through a composite *z*-score comprising indicators of waist circumference, systolic blood pressure, HDL, triglycerides, and glucose, was negatively associated with the odds of completing high school and taking college exams (Correa-Burrows et al., 2019). We speculate that the lack of association found in our study could be related to the fact that cardiovascular abnormalities may not translate into poorer executive function within a 2-year period, which is a cognitive variable closely linked to academic performance. Further longitudinal studies are needed to elucidate the developmental period at which clustered CVD risk may produce detrimental effects on academic performance in youth.

Moreover, this study revealed that adolescents' academic grades at baseline were inversely associated with clustered CVD risk score 24 months later (even when performing the sensitivity analyses only with complete cases). To our knowledge, there are no prior studies analyzing how academic grades may predict future overall cardiovascular health. Despite this, our results are partially supported by a previous scientific study which used data spanning 10 years on a national US cohort of 2546 children aged 3–14 years, showing that higher academic performance (measured over 5 years, 1997–2002) was associated with lower body mass index and lower prevalence of poor self-rated health status in 2007 (Lê-Scherban et al., 2014). Although this is the only study analyzing how academic outcomes predict a future CVD risk factor, other studies examined academic performance as a predictor of self-rated physical health. For instance, Degoy and Olmos (2020) indicated that, in a sample of 533 elementary schoolchildren aged 9–13 years from Argentina, academic performance predicted next-year self-rated physical health. Similarly, in adults, Raghupathi and Raghupathi (2020) analyzed data from 26 countries for the years 1995–2015 and reported that

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TABLE 2 Bidirectional associations between the clustered cardiovascular diseases risk score and academic performance based on the cross-lagged panel models ($N = 237$).

	CVD risk score → AP			AP → CVD risk score			Cross-sectional			Fit measures	
	$β_{CL-1}$	p	p_{FDR}	$β_{CL-2}$	p	p_{FDR}	$β_{CS-Baseline}$	p	p_{FDR}	CFI	RMSEA
Academic grades											
Natural sciences	0.058 (−0.070, 0.186)	.375	.496	−0.102 (−0.188, −0.017)	**.019**	**.038**	−0.139 (−0.263, −0.016)	**.027**	.075	1.000	0.000
Social sciences	0.115 (−0.013, 0.244)	.078	.425	−0.137 (−0.217, −0.058)	**.001**	**.005**	−0.131 (−0.249, −0.013)	**.030**	.075	0.976	0.067
Math	0.055 (−0.065, 0.174)	.369	.496	−0.140 (−0.222, −0.059)	**.001**	**.005**	−0.095 (−0.219, 0.028)	.131	.262	0.983	0.054
Language	−0.109 (−0.233, 0.015)	.085	.425	−0.111 (−0.195, −0.027)	**.009**	**.023**	−0.050 (−0.178, 0.077)	.441	.630	1.000	0.000
Physical education	−0.032 (−0.173, 0.109)	.656	.662	−0.019 (−0.118, 0.081)	.717	.717	−0.196 (−0.315, −0.076)	**.001**	**.010**	1.000	0.000
GPA	0.042 (−0.055, 0.139)	.397	.496	−0.127 (−0.209, −0.045)	**.002**	**.007**	−0.142 (−0.264, −0.019)	**.023**	.075	1.000	0.000
Academic abilities											
Verbal ability	0.056 (−0.042, 0.155)	.263	.496	−0.050 (−0.133, 0.033)	.238	.264	0.011 (−0.111, 0.132)	.862	.862	1.000	0.000
Numeric ability	0.076 (−0.023, 0.175)	.132	.440	−0.065 (−0.151, 0.021)	.139	.194	−0.027 (−0.148, 0.094)	.660	.733	0.996	0.028
Reasoning ability	−0.026 (−0.142, 0.090)	.662	.662	−0.059 (−0.141, 0.022)	.155	.194	−0.054 (−0.158, 0.050)	.310	.517	1.000	0.000
Overall score	0.049 (−0.037, 0.136)	.265	.496	−0.073 (−0.157, 0.010)	.084	.140	−0.030 (−0.141, 0.080)	.592	.733	1.000	0.000

Note: Results showed as standardized coefficients and 95% confidence intervals. CVD, cardiovascular diseases, AP, academic performance. $β_{CL-1}$, the cross-lagged path 1, where CVD risk score at baseline predicts AP at follow-up; $β_{CL-2}$, the cross-lagged path 2, where AP at baseline predicts CVD risk score at follow-up; $β_{CS-Baseline}$, the cross-sectional association between the clustered CVD risk score and AP within baseline; p_{FDR}, *p*-values after using false discovery rate based on the Benjamini–Hochberg method. CFI, comparative fit index, RMSEA, root mean square error of approximation, GPA, grade point average. Cross-lagged models were adjusted for sex, pubertal stage, socioeconomic status, and moderate-to-vigorous physical activity. Statistically significant values are shown in bold.

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individuals with higher educational level showed better health and lifespans over a 20-year period.

The reasons underlying why academic performance at baseline was associated with clustered CVD risk score at follow-up cannot be elucidated in the present study. Nevertheless, some behavioral and psychosocial mechanisms could offer plausible explanations for the findings reported in the present study. Higher academic performance may reflect improved critical thinking skills and decision-making abilities that help adolescents to be more literate in terms of health (Cutler & Lleras-Muney, 2006). This knowledge could lead them to take more informed decisions regarding their adherence to healthy behaviors. In addition, better educated adolescents may also come from more supportive parental backgrounds who might also prioritize healthy behaviors (Cutler & Lleras-Muney, 2006). Indeed, adolescents with higher academic performance have shown greater adherence to healthy eating patterns (Li & Powdthavee, 2015), to be more physically active (Degoy & Olmos, 2020), and to spend less time in sedentary activities, as well as a later initiation of smoking (Ojembarrena Martínez et al., 2002), which may positively influence their cardiovascular health. In addition, psychosocial aspects may play an important role in this association. In fact, higher academic performance may foster higher self-esteem, a greater sense of personal control, better self-concept (-Ross & Chia-Ling, 1995), less stressful academic experiences (Anderson et al., 2008), less social rejection, and higher social support (Xu et al., 2019), which may also impact adolescents' cardiovascular health over time. In this context, socioeconomic status could be a common factor linked to all these mechanisms. Indeed, it is likely that families with higher socioeconomic status provide a greater supportive environment in terms of educational goals, adherence to healthy lifestyles, and psychosocial interactions (Havranek et al., 2015), which may influence adolescents' academic performance and health.

In the present study, academic grades, but not academic abilities, were associated with clustered CVD risk score 24 months later. These divergent results among academic performance indicators may be partially explained by the nature of these variables. Indeed, academic grades are the result of the student progression for each subject scored by different teachers through exams and tasks during an academic year, whereas academic abilities are assessed by a standardized test, which assesses specific abilities in a single timepoint trial. Moreover, unlike academic abilities' test, which mainly requires good cognitive skills, the multidimensional nature of academic grades involves several factors like school attendance, effort, motivation, or attitude (Petrides et al., 2005). In this sense, it is likely that students with higher academic grades (independently of their academic abilities) have a greater commitment to attend classes and a better attitude toward learning, which also includes health-related knowledge. Altogether, this fact could increase students' awareness about the importance of self-care, improving their health status.

Our findings have several implications from an educational and public health perspective. Based on our results, policy makers should foster adolescents' academic performance, not only to boost career and personal achievements, but also to benefit future cardiovascular health. Indeed, since CVD originate during youth, the early prevention of CVD risk factors through education could contribute to improve health trajectories and outcomes across time. Therefore, education professionals should focus on developing optimal study skills and teaching methodologies as well as favorable social and learning environments to enhance students' academic performance (Degoy & Olmos, 2020; Ojembarrena Martínez et al., 2002), and work together with health professionals to enhance cardiovascular health. In addition, considering previous evidence related to the improvement of both education and cardiovascular health in adolescents, the promotion of healthy behaviors and the avoidance of unhealthy ones should be encouraged (Adelantado-Renau, Jiménez-Pavón, et al., 2019; Adelantado-Renau, Moliner-Urdiales, et al., 2019; Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents, 2011). For instance, adolescents' academic performance has been positively related to healthy diets (Adelantado-Renau, Beltran-Valls, et al., 2019), which have shown to reduce the risk of hypercholesterolemia, obesity or hypertension (Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents, 2011). Likewise, academic performance has been negatively associated with sedentary time in adolescents (Adelantado-Renau, Moliner-Urdiales, et al., 2019), which has been strongly linked to high levels of lipid profiles, hypertension, insulin resistance, and obesity (Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents, 2011). Importantly, for a better understanding of the link between educational outcomes and cardiovascular health, future studies should extend this work by investigating the possible behavioral, psychological, and social moderators and mediators behind this association.

4.1 | Limitations and strengths

The current study has some limitations that must be mentioned. The convenience sampling technique used to

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recruit participants limits the generalizability of our findings. In this line, our analyses need replication with larger sample sizes through further longitudinal studies to elucidate the role of specific variables on the study associations, like sex or type of school, by using more complex statistical approaches (e.g., multilevel modeling). Moreover, although the analyses were adjusted by socioeconomic status, other relevant socioeconomic factors such as school neighborhood, parents' level of education, or parents' type of occupation, which could influence health and academic performance, were not considered in this study. This implies potential bias since prior evidence has shown variations in health-related habits and body mass index according to school economic status and neighborhood (Luiggi et al., 2021). Lastly, although our data span 24 months, we are conscious that the data presented in the current study were collected only at two timepoints. Future prospective studies with multiple measurement waves are needed to provide further evidence of the temporal precedence between clustered CVD risk score and academic performance. This study has several strengths, including the use of longitudinal data that enables to focus on changes over time rather than on static relations, as well as the analyses of a wide range of academic performance indicators, including individual academic grades and abilities. In addition, since risk factors tend to appear in combination (Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents, 2011), we used a continuous composite score of CVD risk calculated from age- and gender-specific reference values for individual CVD risk factors. It has been proposed by Stavnsbo et al. (2018) as an approach that increases the prospect to estimate and compare prevalence and trends of cardiometabolic risk in youth. In addition, our statistical analyses were controlled for sex, pubertal stage, socioeconomic status, and moderate-to-vigorous physical activity which are relevant given their association with cardiovascular health and academic performance (Donnelly et al., 2016; Renninger et al., 2020).

5 | CONCLUSION

The results of the present study reveal that adolescents' academic grades at age 14 were inversely associated with clustered CVD risk score 24 months later. Given the current burden caused by cardiovascular diseases worldwide, a focus on improving the social determinants related to the CVD risk factors for primordial and primary disease prevention is a key (and cost-effective) strategy. Education and health professionals could benefit from collaborating to achieve both improved academic performance and cardiovascular health in youth, which would benefit adolescent population.

AUTHOR CONTRIBUTIONS

M. Adelantado-Renau, I. Monzonís-Carda, D. Moliner-Urdiales and M. R. Beltran-Valls contributed to the data collection. M. Adelantado-Renau, M. Duncan, and M. Crotti contributed to the conception and design of this manuscript. M. Adelantado-Renau and M. R. Beltran-Valls performed the analyses and wrote the first draft of the manuscript. All authors commented on previous versions of the manuscript and have read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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