

## Muscular fitness, adherence to the Southern European Atlantic Diet and cardiometabolic risk factors in adolescents



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### KEYWORDS

Metabolic syndrome;  
Muscle strength;  
Diet pattern;  
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**Abstract** *Background and Aim:* Muscular fitness and an adherence to the Southern European Atlantic Diet (SEADiet) have been inversely associated with cardiometabolic risk. Our aim was to assess the independent and combined associations of muscular fitness and adherence to the SEADiet on cardiometabolic risk in adolescents.

*Methods and Results:* A total of 467 Portuguese adolescents (275 girls) participated in this cross-sectional study. Sum of the Z-Scores of Curl-Up and Push-Up tests was used to create a muscular fitness score. Adherence to SEADiet was obtained using a food frequency questionnaire. A cardio-metabolic risk score was computed from sum of Z-score of triglycerides, systolic blood pressure, total cholesterol/HDL ratio, HOMA-IR and waist circumference. Adolescents with low muscular fitness and low adherence to the SEADiet had the poorest cardiovascular profile  $F_{(5, 452)} = 5.074$  ( $p < 0.001$ ) and the highest odds of having a high cardiometabolic risk score (OR = 4.5; 95% CI: 2.1–14) when compared to those with High muscular fitness/High adherence to the SEADiet after adjustments for age, sex, pubertal stage, socioeconomic status, total energy intake, low-energy reporter and cardiorespiratory fitness.

*Conclusions:* Our findings seem suggest that improving muscular fitness as well as an adherence to the SEADiet could be an important strategy to reduce clustered cardiometabolic risk in youth.

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### Background

Cardiovascular disease (CVD) is the leading cause of mortality in developed countries [1]. The precursors of cardiovascular diseases have their onset in childhood [2]. The

most recognised cardiovascular risk factors in paediatric age are blood pressure, triglycerides, total cholesterol (TC), high-density lipoprotein cholesterol (HDL), insulin resistance, and waist circumference [3,4].

Unhealthy lifestyles are linked to metabolic and CVD [5], inducing endothelial dysfunction, accelerating progression of atherosclerosis, and increasing mortality [5–7]. There is an unequivocal association between poor physical fitness and cardiovascular risk factors in childhood and adolescence [8]. However, recently there has also been an

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increased interest on the effects of muscle strength on metabolically healthy subjects [9]. In adults, muscular fitness is inversely and independently associated with all-cause mortality, even after adjusting for several potential confounders [10]. Epidemiological studies show that higher muscle strength is associated with ideal cardiovascular health in adolescents [11] and is inversely associated with cardiovascular disease and cardiometabolic risk factors [9,12–14].

Dietary habits also play an important role in the development and progression of CVD. The Southern European Atlantic Diet (the SEADiet) is the traditional diet of northern Portugal and northwest Spain, characterized by high a consumption of fish, red meat, dairy products, vegetables and legumes, vegetable soup, potatoes, whole wheat bread, and wine [15]. The adherence to SEADiet has been associated with decreased myocardial infarction risk due to its association with lower concentrations of inflammatory markers, reduced triglycerides, insulin, insulin resistance, and systolic blood pressure [16].

Some studies have investigated the combined effect of cardiorespiratory fitness and dietary pattern on cardiovascular risk factors [17,18]. However, the combined association of diet and muscular fitness on cardiovascular risk factors among adolescents is largely unknown. Nevertheless, it is known that skeletal muscle is the largest organ in the human body, which expresses and releases several cytokines in response to muscle contractions, acting as an endocrine organ [19]. In this line, it seems important to understand the interplay between muscular fitness, diet, and cardiovascular risk factors.

Therefore, the present study aimed to assess the impact of the independent and combined associations of muscular fitness and adherence to the SEADiet on the clustering of cardiometabolic risk factors in adolescents.

## Methods

### *Study design and sample*

Data for the present study derived from a school-based study, the Azorean Physical Activity and Health Study II, aimed to evaluate physical activity (PA), physical fitness, and prevalence of overweight/obesity, dietary intake, health-related quality of life and related factors. The study was carried out in six of the nine Azorean Islands – Portugal (S. Miguel, Terceira, Faial, Pico, S. Jorge, and Graciosa) where 95% of the population lives. Details on the study design and sampling strategy are reported elsewhere [20]. For this study, we only considered the 467 adolescents with metabolic data evaluated in 2009 and that have completed all interest variables (275 girls and 192 boys) aged 15 to 18 (mean age 16.5). All participants in this study were informed about the objectives of the work, and parents or guardians provided written informed consent. The study was approved by the Faculty of Sport at the University of Porto and the Portuguese Foundation for Science and Technology ethics committee and was conducted in accordance to the declaration of

Helsinki for Human Studies of the World Medical Association.

## Measures

### *Muscular fitness*

The Curl Up and Push Up tests were used to evaluate the muscular fitness. All tests were conducted according to the Fitnessgram measurement procedures [21]. The curl-up test was used to evaluate abdominal strength and endurance. Participants lie down with knees bent and feet unanchored. Set to a specified pace, adolescents complete as many repetitions as possible to a maximum of 75.

The push-up test was used to evaluate upper body strength and endurance. Participants lower the body to a 90° elbow angle and push up. Set to a specified pace, adolescents complete as many repetitions as possible.

The results of the Push up and Curl up tests (number of repetitions) were transformed into standardized values (Z-scores) [(participant's value - mean value of the sample)/SD] by age and sex. Then the sum of Z-Scores of the two tests was performed to create an overall muscular fitness score. Participants were divided in three groups (by tertiles of muscular fitness score, by age and sex): low, medium and high muscular fitness [13,14]. Thus, in according of SEADiet profile and muscular fitness level, six exclusive groups were created.

### *Southern European Atlantic Diet score*

Dietary intake was obtained using a self-administered, semi-quantitative food frequency questionnaire (FFQ) regarding the previous 12 months, validated for Portuguese adults [22,23]. The FFQ was adapted for adolescents by including foods more frequently eaten by this age [23,24] comprising 91 food items or beverage categories [25]. Food intake was calculated by weight in one of the nine possibilities of frequency of consumption (from never or less than once per month, to six or more times a day), by the weight of the standard portion size of the food-item. Energy and nutritional intake were estimated with consideration of the respondents' ratings of frequency, portion, and seasonality of each item, using the software Food Processor Plus (ESHA Research Inc, Salem, OR, US). This program uses nutritional information from the United States that has been adapted for use with typical Portuguese foods and beverages. The Cronbach's  $\alpha$ , to test FFQ inter-item consistency, was ( $\alpha = 0.892$ ).

The adherence to the traditional Southern European Diet was assessed by the SEAD index as reported by Oliveira et al. [15]. Briefly, the SEADiet score was originally constructed based on the intake of nine food groups, namely fresh fish (excluding cod), cod, red meat and pork products, dairy products, legumes and vegetables, vegetable soup, potatoes, whole-grain bread and wine. Each component (except wine) was measured as grams per 1000 kcal per day. Using the sex-specific median of the study's participants as a cut-off value for each of the

components, 1 point was given when intake  $\geq$  median and 0 points for intakes below median for all items except for wine ( $\leq 1$  glass/d in women and  $\leq 2$  glasses/d in men = 1 point). In the present study, we adapted this score by attributing 0 points to any wine consumption, since ethanol consumption is not recommended for children and adolescents. If participants met all the characteristics of SEADiet, their score was the highest (nine points), reflecting maximum adherence. If they met none of the characteristics, the score was minimum (zero), reflecting no adherence. Based on these results, participants were categorized into two groups: low ( $\leq 4$  points) and high ( $\geq 5$  points) adherence accordingly with the sample's median.

### **Cardiorespiratory fitness**

Cardiorespiratory fitness (CRF) was assessed with the 20 m Shuttle Run Test (20 m SRT) [26]. This test requires participants to run back and forth between two lines set 20 m apart. Running speed started at 8.5 km/h and increased by 0.5 km/h each minute, reaching 18.0 km/h at minute 20. Each level was announced on a tape player. The participants were instructed to keep up with the pace until exhausted. The test was finished when the participant failed to reach the end lines concurrent with the audio signals on two consecutive occasions. Otherwise, the test ended when the subject stopped because of fatigue. The participants received verbal encouragements from the investigators to achieve maximum performance, to keep running as long as possible. Number of shuttles performed by each participant was recorded.

### **Anthropometrics**

Height was measured to the nearest millimeter (0.1 cm) in bare or stocking feet with the adolescent standing upright against a stadiometer (Holtain Ltd., Crymmych, Pembroke shire, UK). Weight was measured to the nearest 0.10 kg, with adolescents lightly dressed using a portable electronic weight scale (Tanita Inner Scan BC 532). Waist Circumference (WC) measurement was taken in a standing position, to the nearest 0.1 cm, with a tape measure midway between the lower rib margin and the anterior superior iliac spine at the end of normal expiration. WC measurements were taken as described by Lohman [27].

### **Pubertal stage**

Participants self-assessed their pubertal stage of secondary sex characteristics (breast and pubic hair development for girls, genital and pubic hair development for boys; ranging from stage I to V), according to the criteria of Tanner and Whitehouse [28].

### **Parental education level**

The highest level of parental education (in completed years of education) was considered as a proxy of

socioeconomic status. Similar procedures have also been applied in the Portuguese context [29].

### **Resting blood pressure**

Blood pressure was measured using a Dynamap vital signs monitors (model BP 8800, Critikon, Inc., Tampa, Florida). 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. Participants were in a seated, relaxed position with their feet resting flat on the ground. Two measurements in the non-dominant arm were taken, after five and 10 min of rest. The mean of these two measurements was used for statistical analysis. If the two measurements differed by two mmHg or more, a third measure was taken [30].

### **Blood sampling**

Blood samples were obtained from each subject early in the morning, following a 10 h overnight fast by venipuncture from the antecubital vein. The samples were stored in sterile blood collection tubes in refrigerated conditions (4–8 °C) for no longer than 4 h during the morning of collection and then sent to an analytical laboratory for testing according to standardized procedures, as follow: Serum glucose, triglycerides (TG), total cholesterol (TC), and HDL-cholesterol (HDL-C) were determined by colorimetric methods using the Cobas Integra 400 Plus (ROCHE Diagnostics, Indianapolis, IN, USA). The fasting blood insulin was measured using chemiluminescence immunoassay (Immulite 2000, Diagnostic Products Corporation, Los Angeles, CA). The ratio of TC to HDL-C was calculated as an index of atherogenic lipid profile. All assays were performed in duplicate according to the manufacturers' instructions.

### **Data management**

The homeostatic model assessment (HOMA-IR), calculated as the product of basal glucose (mmol/L) and insulin ( $\mu$ U/mL) levels divided by 22.5, was used as a proxy measure of insulin resistance [31]. A continuous score representing a composite cardiometabolic risk score was derived by summing the standardized values [Z-score = (participant's value – mean value of the sample)/(standard deviation)] by age and sex, of triglycerides, systolic blood pressure, ratio total cholesterol/HDL-cholesterol, HOMA-IR and waist circumference as already proposed for adolescents [4,32]. Participants above 1 standard deviation (SD) of this score were classified as having a high cardiometabolic risk.

### **Statistical analysis**

Descriptive data are presented as means and standard deviation. Independent Two-tailed *t*-Tests for continuous variables and Chi-square for categorical variables, respectively, were used to examine sex differences. Since no

significant interaction was observed between sexes (e.g., sex  $\times$  muscular fitness score), all the statistical analysis was performed with both sexes together, to increase statistical power.

Partial correlations were performed to examine the associations between SEADiet, cardiovascular risk factors and muscular fitness measures adjusted for sex, age and pubertal stage. The SEADiet index correlations were additionally adjusted for total energy intake.

Linear regression models were performed to determine the associations between muscular fitness score and cardiovascular risk score, adjusted for age, sex, pubertal stage, socioeconomic status, SEADiet and cardiorespiratory fitness. Unstandardized regression coefficients were used to express the B coefficients in the regression analyses.

Analysis of covariance (ANCOVA) with Bonferroni post-hoc multiple comparison tests were used to assess the differences of cardiometabolic risk score across groups with different levels of muscular fitness score by adherence to SEADiet. For this analysis, adolescents were categorized as having a low or high adherence to SEADiet and as having a low, medium and high muscular fitness score. Covariates included were age, sex, pubertal stage, socioeconomic status, total energy intake and cardiorespiratory fitness. Furthermore, we adjusted by under-reporting energy intake, which was estimated using the ratio between reported energy intake and predicted basal metabolic rate [31,32]. The thresholds that defined low-energy reporters (under-reporters) were 1.70 and 1.71 for girls and boys between 15 and 17 years old, and 1.67 and 1.81 for girls and boys aged 18. 'Low-energy reporter' (a categorical variable) was included in the model as a confounding. Finally, binary logistic regressions were performed to assess odds ratios (OR) and 95% CI predicting high cardiometabolic risk according to the combined groups of muscular fitness and adherence to SEADiet; covariates included age, sex, pubertal stage, socioeconomic status, total energy intake, low-energy reporter and cardiorespiratory fitness.

A *p* value less than 0.05 was regarded as significant. Data analysis was performed using the Statistical Package for the Social Sciences for Windows (Version 21.0 SPSS Inc., Chicago, IL).

## Results

Descriptive characteristics of the participants are presented in Table 1. Boys were heavier and taller than girls and showed higher levels of muscular fitness ( $p < 0.01$  for all). Girls presented lower values of WC, TC/HDL-C, systolic blood pressure and higher TC and HDL-C than boys ( $p < 0.01$ ).

Table 2 shows partial correlations for muscular fitness variables, SEADiet index and individuals cardiovascular risk factors. Muscular fitness score was negatively associated with all metabolic risk factors, and positively associated with SEADiet index. When we analysed the individual measures of muscular fitness, Curl Up was positively correlated with SEADiet and negatively correlated with all single metabolic risk factors measures and cardiovascular risk score. Push Up was also positively correlated with SEADiet, and negatively correlated with systolic blood pressure, HOMA-IR, WC and cardiovascular risk score. SEADiet index was negatively associated with systolic blood pressure, WC and cardiovascular risk score ( $p < 0.05$  for all).

Regression analyses showed a significant inverse association between muscular fitness score and cardiometabolic risk score ( $B = -0.464$ ;  $p < 0.001$ ) after adjustments for age, sex, pubertal stage, socioeconomic status, SEADiet index, total energy intake, low-energy reporter and cardiorespiratory fitness (Table 3).

ANCOVA showed a significant difference between the Low muscular fitness/Low adherence to SEADiet group and the High muscular fitness/Low adherence to SEADiet and High muscular fitness/High adherence to SEADiet groups

**Table 1** Participants' characteristics.

Characteristics	Mean (SD)		
	All (n = 467)	Girls (n = 275)	Boys (n = 192)
Age (year)	16.50 ( $\pm 0.90$ )	16.51 ( $\pm 0.91$ )	16.50 ( $\pm 0.86$ )
Weight (Kg)	63.17 ( $\pm 12.60$ )	58.83 ( $\pm 10.23$ )	69.46 ( $\pm 13.05$ ) <sup>a</sup>
Height (cm)	165.6 ( $\pm 0.8$ )	160.05 ( $\pm 0.6$ )	172.93 ( $\pm 0.7$ ) <sup>a</sup>
Waist circumference (cm)	79.35 ( $\pm 10.82$ )	78.3 ( $\pm 10.40$ )	80.9 ( $\pm 11.16$ ) <sup>a</sup>
Systolic blood pressure (mm Hg)	115.45 ( $\pm 32.36$ )	112.53 ( $\pm 13.4$ )	119.63 ( $\pm 15.92$ ) <sup>a</sup>
Total cholesterol (mg/dl)	162.38 ( $\pm 10.40$ )	169.86 ( $\pm 33.53$ )	151.06 ( $\pm 27.38$ ) <sup>a</sup>
Triglycerides (mg/dl)	71.29 ( $\pm 37.9$ )	74.38 ( $\pm 37.70$ )	76.03 ( $\pm 37.86$ )
HDL-cholesterol (mg/dl)	55.62 ( $\pm 13.1$ )	59.35 ( $\pm 12.87$ )	50.27 ( $\pm 12.87$ ) <sup>a</sup>
Total cholesterol/HDL-C ratio	3.03 ( $\pm 0.75$ )	2.96 ( $\pm 0.76$ )	3.13 ( $\pm 0.74$ ) <sup>a</sup>
HOMA-IR	1.95 ( $\pm 1.35$ )	1.96 ( $\pm 0.76$ )	1.93 ( $\pm 0.74$ )
Cardiovascular risk score	0.03 ( $\pm 3.10$ )	0.07 ( $\pm 3.02$ )	-0.01 ( $\pm 3.22$ )
SEADiet score	4.74 ( $\pm 1.88$ )	4.77 ( $\pm 1.94$ )	4.68 ( $\pm 1.80$ )
Total energy intake	2368.2 ( $\pm 900$ )	2219.9 ( $\pm 870$ )	2577.3 ( $\pm 950$ )
Curl up (# of curl ups)	35.71 ( $\pm 22.52$ )	30.45 ( $\pm 21.2$ )	43.45 ( $\pm 21.2$ ) <sup>a</sup>
Push up (# of push ups)	14.71 ( $\pm 10.7$ )	11.91 ( $\pm 11.2$ )	18.71 ( $\pm 8.7$ ) <sup>a</sup>
Muscular fitness score	0.00 ( $\pm 1.65$ )	-0.48 ( $\pm 1.65$ )	0.69 ( $\pm 1.39$ ) <sup>a</sup>

<sup>a</sup> Significantly different from girls,  $p < 0.01$  (Independent Two-tailed *t*-tests for continues variables or Chi-square for categorical variables); SEADiet, Southern European Atlantic Diet; HOMA-IR, Homeostasis model assessment – insulin resistance.

**Table 2** Partial correlations (*r*) between SEADdiet, muscular fitness measures and cardiovascular risk factors.

	SEADdiet	SBP <sup>a</sup>	TG <sup>a</sup>	TC/HDL <sup>a</sup>	WC <sup>a</sup>	HOMA-IR <sup>a</sup>	CRS score
SEADiet <sup>b</sup>		-0.116*	-0.009	-0.035	-0.106*	-0.029	-0.100*
Muscular fitness	0.155*	-0.214**	-0.100*	-0.156**	-0.352**	-0.170**	-0.319**
Curl up <sup>a</sup>	0.127*	-0.123**	-0.098*	-0.190**	-0.206**	-0.088*	-0.226**
Push up <sup>a</sup>	0.125*	-0.224**	-0.064	-0.063	-0.366**	-0.188**	-0.292**

Partial correlation (*r*, adjusted for age, sex and pubertal stage).

CRS: cardiovascular risk score.

\**p* < 0.01; \*\**p* < 0.001.

<sup>a</sup> Variables standardized values (Z-scores) [(participant's value – mean value of the sample)/SD] by age and sex were constructed.

<sup>b</sup> Additionally adjusted for Total Energy intake. SBP: Systolic blood pressure; TG: triglycerides; TC: total cholesterol, WC: waist circumference; SEADiet: Southern European Atlantic Diet; HOMA-IR: Homeostasis model assessment: insulin resistance.

**Table 3** Unstandardized regression coefficients examining the association of cardiovascular risk score and muscular fitness.

Muscular fitness (score)	Cardiovascular risk score			
	B	(95% CI)	<i>p</i> Value	R <sup>2</sup>
Model 1	-0.570	(-0.734: -0.406)	<0.001	0.092
Model 2	-0.608	(-0.809: -0.462)	<0.001	0.119
Model 3	-0.621	(-0.796: -0.446)	<0.001	0.121
Model 4	-0.464	(-0.645: -0.283)	<0.001	0.158

B: Unstandardized coefficients.

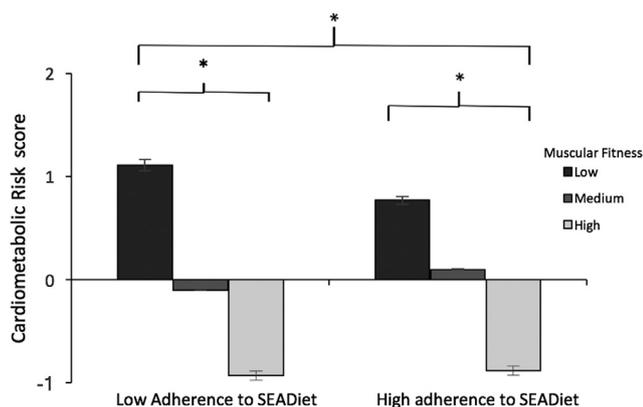
Model 1 – Unadjusted model.

Model 2 – Adjusted, age, sex, pubertal stage and socioeconomic status.

Model 3 – Model 2 plus adjustment for SEADiet index.

Model 4 – Model 3 plus adjustment for cardiorespiratory fitness and total energy intake and low-energy reporter (Fully adjusted model).

(*p* < 0.05), after adjustments for age, sex, pubertal stage, socioeconomic status, total energy intake, low-energy reporter and cardiorespiratory fitness showed. We also found significant differences between Low muscular fitness/High adherence to SEADiet group and High muscular fitness/High adherence to SEADiet ( $F_{(5, 452)} = 5.074, p < 0.001$ ) (Fig. 1).



**Figure 1** Means values of cardiovascular risk score stratified in tertiles of muscular fitness (low, medium, and high) in Low ( $\leq 4$  points) and High ( $\geq 5$  points) adherence to SEADiet. Adjusted for age, sex, pubertal stage, socioeconomic status, total energy intake, low-energy reporter and cardiorespiratory fitness. \*Significantly different (*p* < 0.05).

**Table 4.** Binary logistic regression analysis showed that participants with a Low muscular fitness/Low SEADiet had the highest odds of having a high cardiometabolic risk (OR = 4.5; 95% CI: 2.1–14, *p* = 0.001) followed by the High SEADiet/Low muscular fitness group (OR = 3.3; 95% CI: 1.5–11.2, *p* = 0.046) when compared to those with High muscular fitness/High SEADiet, after adjustments for potential confounders.

## Discussion

Our results showed that muscular fitness was negatively associated with cardiovascular risk score even after considering potential confounders such as age, sex, pubertal stage, socioeconomic status, SEADiet, total energy intake and cardiorespiratory fitness. We also found significant differences on the cardiometabolic risk score per the different levels of muscular fitness and SEADiet groups. In addition, adolescents classified with low muscular fitness and low adherence to a SEADiet had the poorest cardiometabolic profile, which also highlights the importance of the combined effect of a healthy dietary intake and high muscle strength. Participants with low muscular fitness/low SEADiet had the highest odds of having high cardiometabolic risk, followed by the high SEADiet/low muscular fitness group, when compared to those with high muscular fitness/high SEADiet, after adjustments for potential confounders.

The relationship between metabolic risk factors and muscular fitness has been explored in adolescents.

**Table 4** Odds ratio of high cardiometabolic risk by muscular fitness levels and Adherence to SEADiet.

Parameter	High cardiometabolic risk		
	OR adjusted <sup>a</sup> (95% CI)	<i>p</i> -value	
High SEADiet	High MF	1	1
	Medium MF	1.83 (0.5–6.2)	0.334
	Low MF	3.30 (1.5–11.2)	0.046
Low SEADiet	High MF	0.8 (0.17–4.1)	0.830
	Medium MF	2.87 (0.80–9.0)	0.100
	Low MF	4.5 (2.1–14.0)	0.001

OR, odds ratios; CI, confidence intervals; 1, reference category. MF, muscular fitness.

<sup>a</sup> Adjusted for age, sex, pubertal stage, socioeconomic status, total energy intake, low-energy reporter and cardiorespiratory fitness.

Previous research has reported inverse associations between muscular fitness and individual cardiovascular risk factors [33], inflammatory biomarkers [34], and clustered cardiovascular risk factors [12,13,35,36]. Recently, a 20 years follow-up study with 737 subjects aged 9, 12, or 15 years at baseline showed that childhood muscular fitness predicted adult metabolic syndrome outcomes independently of childhood cardiorespiratory fitness [37]. In addition, a recent systematic review and meta-analysis showed strong evidence for an inverse association between muscular fitness and cardiometabolic risk factors in adolescents [9]. However, none of these studies adjusted their analyses for dietary patterns, nor considered the independent and combined effect of muscular fitness and dietary patterns on the cardiometabolic risk in adolescents. Therefore, to the best of our knowledge, this is the first study assessing the combined associations of muscular fitness and adherence to a healthy dietary pattern, namely the SEADiet, on the cardiometabolic profile in adolescents.

Our study showed that SEADiet was inversely correlated with systolic blood pressure, WC, and a cluster of cardiometabolic risk factors. Recent studies have investigated the benefits of adherence to a SEADiet. Oliveira et al. [15] showed that higher adherence to the SEADiet was associated with a lower risk of non-fatal acute myocardial infarction. Conversely, another study with 10,231 individuals – representative of the population aged 18 years and older in Spain – showed that the SEADiet was associated with a lower concentration of inflammatory markers and with reduced triglycerides, insulin, insulin resistance, and systolic blood pressure [16].

Cardiorespiratory fitness, a powerful marker of current and future health status in children and adolescents [8,38], has been positively associated with adherence to the SEADiet and inversely associated with cardiovascular risk factors [17,18]. Importantly for this discussion, in the present investigation we considered cardiorespiratory fitness, adherence to SEADiet, and socio-economic status as confounders in our analysis between muscular fitness and cardiometabolic risk score, and the results remained significant. In addition, in the present study we matched the muscular fitness status to the SEADiet groups, which allowed us to compare differences in the cardiometabolic profile of the two groups of SEADiet (low and high adherence) by levels of muscular fitness levels. We observed that adolescents with higher muscular fitness levels exhibit the lowest cardiovascular risk, regardless of their adherence to SEADiet. These results seem to suggest that muscular fitness may play a key role in the cardiometabolic profile of adolescents, independent of several confounders. Although a cross-sectional design was used, our data seem to suggest that having high muscular fitness levels may somewhat overcome the deleterious effects of low adherence to healthy dietary patterns.

Diet and physical activity have different effects on body composition, with both contributing to weight control and loss. However, the skeletal muscle is the major site of

glucose uptake [39], a highly energetic tissue that contributes substantially to basal metabolic rate [40]. Exercise training is the most potent stimulus to increase skeletal muscle GLUT4 expression, which facilitates insulin action and glucose disposal; and, consequently, insulin resistance prevention [39]. Recently, a study comparing the effects of aerobic, strength, and combined aerobic and strength training on metabolic disorders induced by a fructose-rich diet in animal models showed that hyperinsulinemia, glucose intolerance, and insulin resistance were attenuated by aerobic physical exercise, while strength training was able to restore all these parameters to control levels [41]. In this line of thought, high muscular fitness levels are associated with better skeletal muscle function, which directly affects the metabolic function and may explain the better cardiometabolic profile in our participants. Nevertheless, the prevention of cardiometabolic risk via healthy dietary patterns remains important, although future work should also focus on promoting high muscular fitness levels.

Some limitations of our study should be taken into consideration. First, we were unable to draw cause-effect conclusions because of the cross-sectional nature of our data. Second, we cannot rule out some reporting bias because we used self-reported dietary intake data. However, the FFQ was previously tested [42] and the analyses were controlled to prevent the misreporting of energy intake.

Strengths of this study include the novelty of the analyses of combined associations of muscular fitness with adherence to a healthy dietary pattern on the cardiometabolic risk of adolescents; moreover, most studies that reported the relationship between physical fitness and cardiovascular risk score were confined to cardiorespiratory fitness. To our knowledge, few studies have been conducted among adolescents assessing other health-related fitness components associated with cardiometabolic risk factors. Furthermore, the use of a valid field tests for muscular fitness assessment, which can be administered in school settings and allow a large number of participants to be tested simultaneously, is another strength. Indeed, this is a valuable tool for routinely measuring physical fitness in youth.

In conclusion, although our study used a cross-sectional design, our findings suggest that muscular fitness was inversely associated with a cluster of cardiometabolic risk in adolescents, independent of SEADiet adherence. Furthermore, adolescents with high levels of muscular fitness presented lower odds of having a high cardiometabolic profile, independent of their adherence to a SEADiet. Our study also suggests that the combination of poor dietary habits and low muscular fitness levels is associated with a poor cardiometabolic profile. From a public health perspective, our data seem to suggest that improving muscular fitness and adhering to a healthy diet could be an important strategy to reduce clustered cardiometabolic risk in youth. Therefore, the study highlights the importance of developing muscular fitness at these ages and seems to corroborate the international World

Health Organization's recommendations of strengthening muscle and bone at least 3 times per week.

### Conflict of interest

The authors have no conflicts of interest relevant to this article to disclose.

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