

Longitudinal Associations of Healthy Behaviors on Fitness in Adolescents: DADOS Study



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Introduction: This study aims to investigate the individual and combined associations of physical activity, sedentary time, diet, and sleep at baseline on cardiorespiratory fitness at 24-month follow-up in adolescents.

Methods: The DADOS (Deporte, ADOlescencia y Salud) prospective cohort study was performed between 2015 and 2017. Analyses were conducted in 2020 and included 189 adolescents aged 13.9 (SD=0.3) years at baseline. Vigorous physical activity, total sedentary time, and sleep duration were evaluated by GENEActiv accelerometer. Sleep quality and adherence to a Mediterranean diet were evaluated by questionnaires. Cardiorespiratory fitness was assessed by the 20-meter shuttle run test. A healthy lifestyle index was created by including positive scores for each individual behavior, and 3 categories of achievement (≤ 1 , 2, ≥ 3) were established.

Results: Performing high vigorous physical activity and low screen time at baseline were individually associated with the likelihood of achieving high cardiorespiratory fitness at follow-up (OR=3.33 and 3.09, respectively). ANCOVA indicated that adolescents with a healthy lifestyle index ≥ 3 at baseline showed higher cardiorespiratory fitness at follow-up than those with a healthy lifestyle index of 2 and ≤ 1 (74.4 [SE=1.5] vs 68.9 [SE=1.4] and 67.8 [SE=1.5] laps, respectively; $p < 0.01$). Adolescents with a healthy lifestyle index ≥ 3 at baseline were more likely to have high cardiorespiratory fitness at follow-up (OR=3.10) than their peers with ≤ 1 .

Conclusions: The results showed a cumulative impact of baseline health-related behaviors on cardiorespiratory fitness at 24-month follow-up in adolescents. These findings underline the key role of promoting a healthy lifestyle to improve adolescents' health.

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INTRODUCTION

Cardiorespiratory fitness (CRF) during youth is considered an important indicator of current and future health.^{1,2} High levels of CRF are favorably associated with healthy cardiovascular and metabolic profiles³ as well as with mental health⁴ and cognition.⁵ Despite these data, the percentage of youth meeting the standards for healthy CRF appears to decrease with age.⁶ Thus, identification of factors contributing to CRF improvement later in life should be a health priority.

An individual's CRF is highly determined by unmodifiable factors such as genetic heritability, sex, age, and pubertal status.^{7,8} Yet, current research suggests that

modifiable lifestyle behaviors may also impact CRF in adolescents.^{9–16} For instance, physical activity, particularly vigorous-intensity physical activity (accelerometer derived), has been positively associated with CRF in longitudinal studies.^{9,15} Regarding the impact of total sedentary time, higher durations of accelerometer-derived

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sedentary time were significantly associated with lower CRF in children and adolescents,¹⁶ but longitudinal data in these age groups are scarce.¹⁰ Results about healthy dietary patterns are derived from cross-sectional studies, which showed that adolescents adhering to a Mediterranean diet presented higher CRF than their nonadhering peers.^{11,12} With respect to sleep, limited data exist in adolescents; yet, cross-sectional research reported a positive association between CRF and sleep quality in adolescent girls.¹³ However, data regarding sleep duration showed conflicting results because both positive¹² and null¹⁴ associations between sleep duration and CRF have been reported.

In addition to the studies mentioned earlier that have explored the individual association between health-related lifestyle behaviors and CRF among adolescents, previous research has suggested that people do not adopt single lifestyle behaviors in isolation but a series of them, which may inter-relate with each other.¹⁷ Indeed, several studies performed on different age populations have reported associations between the number of healthy lifestyle factors achieved and indicators such as academic achievement, weight status, physical functioning, or mortality.^{18–21} Previous research in adolescents has also identified different patterns of lifestyle behaviors related to high CRF.^{22–25} However, to the authors' knowledge, no study has examined the longitudinal impact of all of these lifestyle behaviors on CRF in adolescents, leaving unknown the magnitude of association of these behaviors, both individually and in combination.

Therefore, because lifestyle factors could synergistically interact with each other to impact health status, it is relevant to investigate the influence of concurrently adhering to several modifiable lifestyle factors on CRF during adolescence. Hence, the aim of this study is to investigate the individual and combined associations of physical activity, sedentary time, sleep, and diet at baseline on CRF at 24-month follow-up in adolescents.

METHODS

Study Sample

This study is part of the DADOS (Deporte, ADOlescencia y Salud) prospective cohort study, which aimed to investigate the impact of lifestyle behaviors on health and academic achievement in adolescents. A convenience sampling technique was used to recruit participants. For that purpose, advertising leaflets about the research project were sent to secondary schools and sports clubs located in the province of Castellón (Spain), which included basic information and the general inclusion criteria of the DADOS study (i.e., to be enrolled in the second grade of secondary school and without any diagnosis of physical or mental disease). Volunteers who met the inclusion criteria contacted the research group and were included in the study. Baseline data were collected between

February 2015 and May 2015 for 274 participants, and 205 were re-evaluated at follow-up in the same period of 2017 (2-year follow-up). A total of 189 adolescents (91 girls) aged 13.9 (SD=0.3) years at baseline with valid data on the variables of interest at baseline (2015) and at follow-up (2017) were included in the analyses. Adolescents and their parents were informed of the nature and characteristics of the study, and they all provided written informed consent. The study was performed following the ethical guidelines of the Declaration of Helsinki 1961 (revision of Fortaleza 2013), and the study protocol was approved by the Research Ethics Committee of the University Jaume I (UJI-28-07-2014).

Measures

Physical activity and sedentary time were measured using the GENEActiv accelerometer (Activinsights Ltd, Kimbolton, UK), a waterproof device that contains a triaxial microelectromechanical accelerometer that records both motion-related and gravitational acceleration and has a linear and equal sensitivity along the 3 axes. Although the GENEActiv accelerometer offers a body temperature sensor to detect wear and nonwear time, participants kept a daily physical activity and sedentary time log in which they registered wear and nonwear time to check possible inconsistencies. Accelerometer-derived data from all the participants comprised ≥ 4 days, including weekends and weekdays, with 24-hour valid data. The GENEActiv accelerometer has been found to be a reliable²⁶ and valid measure of physical activity and sedentary time in young people.²⁷ Devices were programmed with a sampling frequency of 100 Hz, and data were stored in gravity (g) units (1 g=9.81 m/s²). The raw acceleration output was converted to 1-second epochs using the GENEActiv Post-Processing PC Software, version 2.2. According to Phillips et al.,²⁷ a GENEActiv cut off point for vigorous-intensity physical activity in adolescents was established for values >60 g, and sedentarism was established for values <7 g. Vigorous physical activity and sedentary time were expressed as the average (minutes/day) by combining all the registered days for each participant. Vigorous physical activity was chosen to be included in the analyses owing to its stronger relationship with CRF than moderate and low physical activity intensities.^{9,15} Regarding physical activity, participants above the sex-specific 75th percentile were categorized as having high levels of physical activity, which corresponded to ≥ 17 minutes of vigorous physical activity. With regard to sedentary time, participants under the sex-specific 25th percentile were categorized as having low sedentary time, which corresponded to ≤ 660 minutes of sedentary time.

The Spanish version of the Pittsburgh Sleep Quality Index (PSQI) questionnaire was used to assess sleep quality over the last month.²⁸ Lower scores in overall PSQI represent better sleep quality. The PSQI provides a sensitive measure to identify poor sleep quality if the total PSQI score is >5 and good sleep quality if the total PSQI score is ≤ 5 .²⁹

Daily sleep duration was objectively measured by the GENEActiv accelerometer, a reliable device to examine sleep ($\kappa=0.85$ [SD=0.06]).³⁰ Sleep duration was calculated by the algorithm included in GENEActiv Post-Processing PC Software, version 2.2. Although the GENEActiv accelerometer offers body temperature and luminosity sensors to establish sleep duration, participants kept a daily sleep time log in which they registered their sleep/wake schedule. All participants included data of ≥ 4 complete

days, including weekends and weekdays, with 24-hour valid data. According to National Sleep Foundation, good sleep duration was defined as ≥ 8 hours of sleep per day.³¹

Adherence to the Mediterranean diet was assessed using KIDMED, a questionnaire based on the Mediterranean dietary guidelines for children and adolescents that provides an overall indication of their dietary patterns. The score for the subjects' adherence to the Mediterranean diet ranges from 0 to 12. Levels of adherence were classified into 2 groups: poor (0–7) and optimal. (8–12).³²

A healthy lifestyle index ranging from 0 to 5 was defined specifically for the sample of this study according to the number of modifiable healthy lifestyle behaviors fulfilled by each adolescent. For each healthy behaviour achieved (high levels of vigorous physical activity, low sedentary time, good sleep quality, good sleep duration, or optimal adherence to the Mediterranean diet) participants scored 1; hence, a higher index indicated healthier lifestyle.

Participant's CRF was assessed by research staff using the 20-meter shuttle run test as described by Léger and colleagues.³³ Each participant ran straight between 2 lines 20 meters apart at a pace established by recorded audio signals. 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 number of laps completed (20 m) was used in the analyses. As indicated in the study by Tomkinson et al.,⁶ participants above the sex-specific 80th percentile according to European normative values were categorized as having high CRF.

Owing to the impact of sex, pubertal stage, body fat percentage, and parents' educational level on CRF levels, all models controlled for the baseline scores of these variables.⁷ Pubertal status was self-reported according to the 5 stages described by Tanner and Whitehouse.³⁴ Skinfold thicknesses were measured at the left side of the body at the triceps and subscapular areas to the nearest 0.2 mm using a Holtain skinfold caliper following standardized procedures.³⁵ Total body fat percentage was calculated by the equation described by Slaughter and colleagues.³⁶ Parents or legal guardians reported their educational level, which was categorized into 2 groups using the highest educational level obtained by the mother or the father: (1) below university education and (2) university education.

Statistical Analysis

Study sample characteristics are presented as mean (SD) for continuous variables and as frequencies and percentages for categorical variables. Because preliminary analyses did not show a significant interaction of sex with the study variables in relation to CRF (all $p > 0.10$), all analyses were performed with the total sample. Differences between the baseline and follow-up time points were assessed using *t*-tests for continuous variables and chi-square tests for nominal variables. Binary logistic regression was used to assess the association between baseline health-related behaviors and CRF at follow-up. CRF at follow-up was entered as the dependent variable, and each health-related behavior was entered as an independent variable in separate models.

One-way ANCOVA with a Bonferroni posthoc test was performed to investigate whether CRF at follow-up differed

depending on the number of healthy lifestyle behaviors achieved at baseline. In addition, logistic regression was conducted to examine the likelihood of achieving high CRF at follow-up depending on the number of healthy lifestyle behaviors attained at baseline (i.e., ≤ 1 , 2, and ≥ 3). All analyses were adjusted for sex, pubertal stage, body fat percentage, parents' educational level, and CRF at baseline. No multicollinearity was identified in the model (variance inflation factors < 3). The analyses were performed using SPSS, version 22.0. The level of significance was set to $p < 0.05$.

RESULTS

Descriptive characteristics of the population at baseline and at 24-month follow-up are shown in Table 1. Overall, participants showed higher levels of vigorous physical activity and spent less time in sedentary activities, reported better sleep quality and duration, and reported lower levels of CRF at baseline than at 24-month follow-up (all $p < 0.01$).

The individual associations of healthy lifestyle behaviors at baseline with CRF at follow-up are shown in Table 2. Performing high vigorous physical

Table 1. Characteristics of Participants at Baseline and at 24-Month Follow-Up (N=189)

Variables	Baseline	Follow-up
Age, years	13.9 (0.3)	15.8 (0.3)
Tanner stage (I–V), %	0/8/33/49/10	0/0/10/54/36
Total body fat mass, %	21.4 (7.5)	24.4 (9.1)
Parents with university educational level, %	91 (48)	—
Healthy lifestyle behaviors		
Vigorous physical activity (minutes/day)	12.4 (8.3)	7.0 (7.6)
Sedentary time (minutes/day)	699.1 (78.8)	741.2 (64.3)
Sleep quality score (0–21)	4.6 (2.5)	5.2 (2.8)
Good sleep quality, %	127 (67)	119 (63)
Sleep duration, hours	8.0 (0.9)	7.8 (1.0)
Good sleep duration, %	96 (51)	70 (37)
Adherence to the Mediterranean diet score (0–12)	7.1 (2.2)	7.2 (2.2)
Optimal adherence to Mediterranean diet, %	89 (47)	83 (44)
Cardiorespiratory fitness, laps	66.3 (24.5)	70.4 (26.9)
High cardiorespiratory fitness, %	106 (56)	110 (58)

Note: Boldface indicates statistical significance ($p < 0.01$). Statistical significance differences between baseline and follow-up were tested by paired *t*-test.

Data are shown as mean (SD) or frequency (percentage). Good sleep quality was measured by the Pittsburg sleep quality index of ≤ 5 . Good sleep duration indicates ≥ 8 hours of sleep per day. Optimal adherence to the Mediterranean diet indicates a score ≥ 8 . High cardiorespiratory fitness indicates performing ≥ 80 th sex-specific percentile according to European normative values.

activity (≥ 75 th sex-specific percentile) and low sedentary time (≤ 25 th percentile) at baseline were positively associated with the likelihood of achieving high CRF (≥ 80 th percentile of normative values) at 24-month follow-up.

Figure 1 shows the differences in CRF at follow-up according to the healthy lifestyle index at baseline. Overall, adolescents with a healthy lifestyle index of ≥ 3 at baseline showed higher CRF at follow-up than those with a healthy lifestyle index of 2 and ≤ 1 (mean=74.42 [SE=1.5] laps vs 68.9 [SE=1.4] and 67.8 [SE=1.5] laps, respectively; $p < 0.01$).

The healthy lifestyle index at baseline predicting high CRF at follow-up is shown in Figure 2. Logistic regression analysis showed that adolescents with a healthy lifestyle index ≥ 3 at baseline were more likely to have high CRF at 24-month follow-up than their peers with a healthy lifestyle index ≤ 1 . In terms of ORs, adolescents with a healthy lifestyle index ≥ 3 at baseline were 3.1 times more likely of having high CRF 24 months later (OR=3.10, 95% CI=1.10, 8.73).

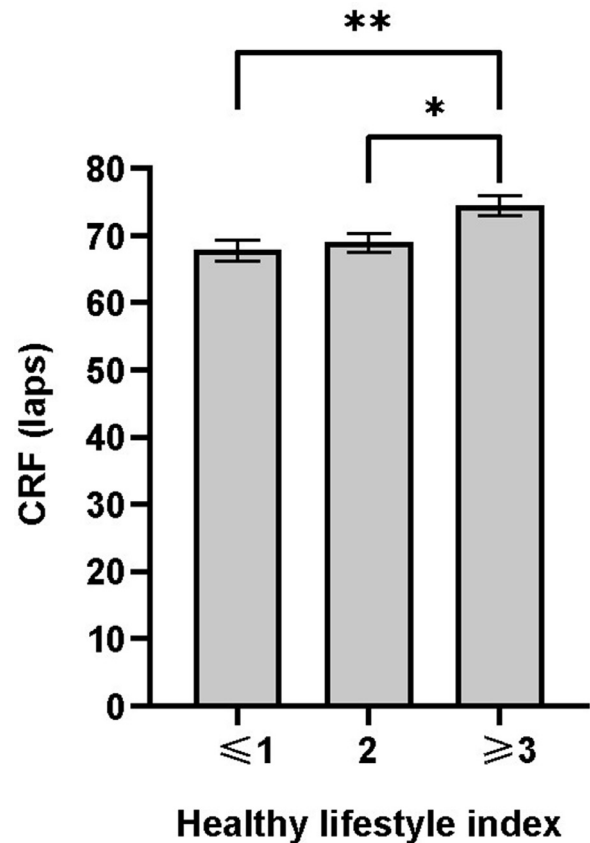


Figure 1. Differences in CRF at 24-month follow-up according to the healthy lifestyle index at baseline, after adjustment for sex, pubertal stage, body fat percentage, parents' educational level, and cardiorespiratory fitness at baseline.

Note: Estimated marginal means and SEs are presented. The single asterisk (*) indicates significant differences, $p < 0.05$; double asterisks (**) indicate significant differences, $p < 0.01$. For healthy lifestyle index ≤ 1 , $n = 56$; for healthy lifestyle index = 2, $n = 69$; and for healthy lifestyle index ≥ 3 , $n = 64$.

CRF, cardiorespiratory fitness.

Table 2. Logistic Regression Analyses Examining the Individual Influence of Healthy Lifestyle Behaviors at Baseline on High Cardiorespiratory Fitness at 24-Month Follow-Up in Adolescents (N=189)

Healthy lifestyle behavior	High cardiorespiratory fitness
Vigorous physical activity	
Low	1 (ref)
High	3.33 (1.18, 9.41)
Sedentary time	
High	1 (ref)
Low	3.09 (1.13, 8.48)
Sleep quality	
Poor	1 (ref)
Good	1.58 (0.68, 3.69)
Sleep duration	
<8 hours	1 (ref)
≥ 8 hours	1.27 (0.57, 2.81)
Adherence to the Mediterranean diet	
Poor	1 (ref)
Optimal	1.89 (0.86, 4.12)

Note: Boldface indicates statistical significance ($p < 0.05$). OR (95% CI) represent increased odds of achieving high cardiorespiratory fitness. Analyses were adjusted for sex, pubertal stage, body fat percentage, parents' educational level, and cardiorespiratory fitness at baseline.

DISCUSSION

The main finding of this longitudinal study revealed that a combination of modifiable health-related lifestyle behaviors (denoted by a healthy lifestyle index), including high vigorous physical activity, low sedentary time, good sleep quality, good sleep duration, and optimal adherence to the Mediterranean diet at baseline was associated with higher CRF at 24-month follow-up in adolescents. Indeed, adolescents adhering to a healthy lifestyle index ≥ 3 at baseline were more likely to have high CRF at 24-month follow-up than those adhering to ≤ 1 , considering potential cofounders. These results complement the scarce current literature investigating the individual and combined longitudinal relationships

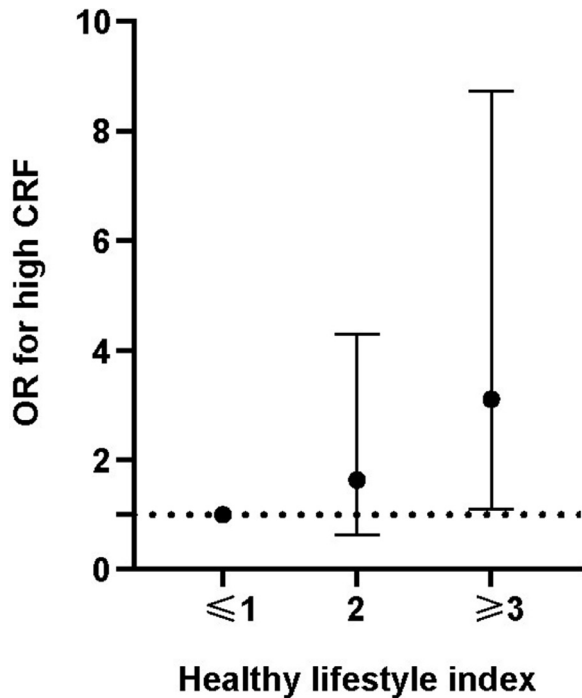


Figure 2. Logistic regression model predicting high CRF at 24-month follow-up according to the healthy lifestyle index at baseline.

Note: Analysis adjusted for sex, pubertal stage, body fat percentage, parents' educational level, and cardiorespiratory at baseline. Reference (OR=1.00): adolescents with a healthy lifestyle index ≤ 1 . For healthy lifestyle index ≤ 1 , $n=56$; for healthy lifestyle index=2, $n=69$; and for healthy lifestyle index ≥ 3 , $n=64$. CRF, cardiorespiratory fitness.

between modifiable health-related behaviors and CRF in adolescents and contribute to a better understanding of the complexity of their interaction.

The results about the individual associations of the studied healthy lifestyle behaviors with CRF in adolescents concur with the results of previous longitudinal research showing that CRF was associated positively with vigorous physical activity⁹ and negatively with sedentary time.¹⁰ Conversely to previous knowledge,^{11–13} in this study, sleep patterns and adherence to the Mediterranean diet were not individually associated with CRF.

The association between high levels of vigorous physical activity and CRF may be explained by the fact that intensity seems to be a key element in physical fitness enhancement in adolescents because previous research has observed that increased levels of vigorous physical activity rather than lower intensities are associated with higher CRF in children and adolescents.^{9,15} These results could be explained by the physiologic and mechanical stress that vigorous physical activity exerts on the

cardiorespiratory and the muscular systems leading to specific adaptations such as greater oxidative capacity.³⁷ Concerning total sedentary time, its association with CRF might be due to specific physiologic changes, such as reduced muscle blood flow or endothelial function, which may occur during prolonged common sedentary activities such as sitting or lying.^{38,39}

Although optimal adherence to the Mediterranean diet and good sleep patterns were not associated with CRF through adolescence on an individual level in this study, some previous cross-sectional studies reported positive associations of these variables with CRF in adolescents.^{11–13} To the authors' knowledge, no longitudinal study to date has investigated the impact of adherence to the Mediterranean diet and sleep patterns on CRF, which hinders the direct comparability with the findings of this study. Nevertheless, because health-related lifestyle behaviors seem to not act in isolation,¹⁷ it is likely that on a combined level, diet and sleep patterns may also contribute to improved CRF. For instance, the inter-relationship of physical activity and sedentary behaviors with a Mediterranean diet⁴⁰ and sleep⁴¹ have been previously reported in the literature, which together may influence adolescents' energy balance and nutrient supply⁴² as well as endocrine system regulation.⁴³ The combination of these physiologic responses may impact cardiometabolic system functioning and ultimately CRF. Thus, these factors were included in the healthy lifestyle index to examine the combined associations with CRF at follow-up.

The combined analyses revealed that adolescents with a healthy lifestyle index ≥ 3 at baseline showed higher CRF at 24-month follow-up than those with an index ≤ 2 . Moreover, adolescents with a healthy lifestyle index ≥ 3 at baseline had an increased likelihood of achieving high CRF at follow-up compared with their peers with a healthy lifestyle index ≤ 1 . Previous cross-sectional studies have analyzed the combined influence of some health-related behaviors on CRF in adolescents and pre-adolescents using cluster analyses.^{22–25} Although cluster analysis results are not directly comparable with the findings of this study, these previous studies also showed that health-related behaviors manifest together with a specific impact on CRF in adolescents. For instance, in boys, the cluster with the highest amount of sedentary time had the lowest CRF, even though it had the highest diet scores and showed similar physical activity levels to other clusters.²⁵ In another recent study, Cabanas-Sánchez et al.²² found that youths in the most active cluster obtained the highest score on CRF than their peers in the rest of the clusters. Similarly, Pérez-Rodrigo and colleagues²³ showed that adolescents in the most active cluster had the highest CRF scores than those in

the other clusters. Alternatively, Cuenca-García et al.²⁴ found that the most active adolescents with better dietary patterns showed better CRF. However, the studies from Cuenca-García and colleagues²⁴ and Hartz et al.²⁵ did not include sleep patterns, which hampers comparisons among studies.

The results obtained in this study reinforce the idea that the combination of different healthy lifestyle behaviors may have a notable impact on youths' health status. Indeed, no individual behavior has been proposed as being the unique predictor of poor health indicators.²² Adolescence is a crucial period in life because health-related behaviors are usually adopted during this age span and appear to moderately track into adulthood.⁴⁴

⁴⁶ Therefore, educational and public health programs promoting a healthy lifestyle should target these modifiable behaviors during adolescence given its potential influence on CRF, which is an important indicator of current and future health status.^{1,2} The lifestyle index used in this study was based on scientific evidence, which helps to give a simple and useful message for intervention and counseling purposes as well as for encouraging adolescents to follow a healthier lifestyle.

Limitations

Strengths of this study include the longitudinal design with a homogenous sample in terms of age and the consideration of several lifestyle behaviors for the analyses (physical activity, sedentary behavior, sleep, and diet). In addition, physical activity, sedentary time, and sleep duration were assessed by accelerometry, which has several advantages over questionnaires and self-report methods, although some controversies have also been reported.⁴⁷ CRF was assessed by a valid and reliable test, which is feasible and time efficient in observational studies; however, it is acknowledged that more accurate data could be obtained in laboratory settings. The analyses were controlled for several potential cofounders, but other unmeasured cofounders such as genetic, environmental, or social factors could have influenced the results of this study. Limitations of this study also include the fact that adherence to the Mediterranean diet and sleep quality results were derived from a questionnaire, which is considered a subjective method; however, both questionnaires were previously validated. Moreover, the healthy lifestyle index used in the analyses has not been validated previously. The convenience sampling technique may have biased the results because participants' healthy behaviors accomplishment could not be representative of the general population. The inclusion of smoking or alcohol consumption in the healthy lifestyle index could have broadened the insight about health behaviors linked to CRF in adolescents.

CONCLUSIONS

The results of this study suggest that although some health-related behaviors at baseline may be individually and positively associated with CRF at follow-up in adolescents, the more health-related behaviors achieved at baseline, the higher the CRF at 24-month follow-up. These findings are of paramount importance because of the increasing evidence suggesting the impact of high CRF on adolescents' overall health. Educational and public health intervention and prevention strategies addressed to improve adolescents' health should take into account the promotion of multiple health-related lifestyle behaviors throughout this age span.

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MRBV, DMU, and MAR contributed to the conception and design of the study, acquisition of data, and analysis and interpretation of data. MRBV prepared the first draft of the manuscript. DMU, JM, and MAR revised the manuscript critically for important intellectual content. All authors gave final approval and agreed to be accountable for all aspects of the work.

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