Cardiorespiratory fitness and dietary intake in European adolescents: the Healthy Lifestyle in Europe by Nutrition in Adolescence study

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Abstract
The present study investigated the association between cardiorespiratory fitness (CRF) and dietary intake in European adolescents. The study comprised 1492 adolescents (770 females) from eight European cities participating in the HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescence) study. CRF was assessed by the 20 m shuttle run test. Adolescents were grouped into low and high CRF levels according to the FITNESSGRAM Standards. Dietary intake was self-registered by the adolescents using a computer-based tool for 24 h dietary recalls (HELENA-Dietary Assessment Tool) on two non-consecutive days. Weight and height were measured, and BMI was calculated. Higher CRF was associated with higher total energy intake in boys \((P=0.003)\). No association was found between CRF and macronutrient intake (as percentage of energy), yet some positive associations were found with daily intake of bread/cereals in boys and dairy products in both boys and girls \((P<0.003)\), regardless of centre, age and BMI. CRF was inversely related to sweetened beverage consumption in girls. These findings were overall consistent when CRF was analysed according to the FITNESSGRAM categories (high/low CRF). A high CRF was not related to compliance with dietary recommendations, except for sweetened beverages in girls \((P=0.002)\). In conclusion, a high CRF is associated with a higher intake of dairy products and bread/cereals, and a lower consumption of sweetened beverages, regardless of centre, age and BMI. The present findings contribute to the understanding of the relationships between dietary factors and physiological health indicators such as CRF.

Key words: Physical fitness; Dietary recommendations; Diet; Food consumption

Abbreviations: CRF, cardiorespiratory fitness; CSS, Cross-Sectional Study; DIAT, Dietary Assessment Tool; FBDG, food-based dietary guidelines; HELENA, Healthy Lifestyle in Europe by Nutrition in Adolescence; YANA-C, Young Adolescents’ Nutrition Assessment on Computer.

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Both physical fitness and diet influence the risk of CVD (1–4). Cardiorespiratory fitness (CRF) is one of the most important components of health-related fitness (3). High levels of CRF are associated with a healthier cardiovascular risk profile already in children (5) and when they become adults (50). In this context, FITNESSGRAM Standards (developed by the Cooper Institute) established sex- and sex-specific CRF cut-off values for adolescents known as Healthy Fitness Zones (7). The Healthy Fitness Zones are designed to represent the level of fitness (e.g. from the Institute of Medicine) (12) and food-based dietary guidelines (FBDG, e.g. food pyramids) (13,14).

The importance of the independent relationship of healthy CRF level and diet in the prevention and treatment of CVD is well established, but little is known about the interaction between these two factors. In fact, dietary patterns have been associated with the overall cause of mortality, but the diet–disease relationship was largely confounded by CRF (15). Few studies have examined the association between CRF levels and dietary intake in young (16) and older adults (17). The results observed in older adults showed that people with higher fitness levels are more likely to meet the dietary recommendations than their less fit peers (17). However, this relationship is not clear in young adults (16) and data are lacking in adolescents.

Although physical fitness is in part genetically determined (18), it is also influenced by environmental factors, particularly physical activity, and it is unknown how it is associated with nutrition. The FITNESSGRAM Standards have been associated with CVD risk factors in children and adolescents (19,20), and identifying which dietary behaviours are related to or co-exist with high levels of CRF is of both clinical and public health relevance. The present study investigated the association between CRF and dietary intake in a large sample of European adolescents.

**Methods**

**Study design**

Data were derived from the HELENA-CSS (Healthy Lifestyle in Europe by Nutrition in Adolescence-Cross-Sectional Study), which is a multi-centre study conducted in ten European cities (Athens in Greece, Dortmund in Germany, Ghent in Belgium, Heraklion in Greece, Lille in France, Pecs in Hungary, Rome in Italy, Stockholm in Sweden, Vienna in Austria and Zaragoza in Spain). The main aim of the HELENA-CSS was to obtain reliable and comparable data on nutrition and health-related parameters such as physical activity, physical fitness, body composition, food choices and preferences, cardiovascular risk factors, vitamins and mineral status, immunological biomarkers and genetic markers. A total of 3528 adolescents (age range 12.5–17.5 years) were assessed at schools between 2006 and 2007, all fulfilling with the general HELENA-CSS inclusion criteria (21). Details on sampling procedures and study design of the HELENA study have been reported elsewhere (21,22). The study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human participants were approved by the ethics committee of each city involved (23). Written informed consent was obtained from both the adolescents and their parents.

**Participants**

Only eight study centres could be included for the 24 h dietary recall analyses (Stockholm, Dortmund, Ghent, Lille, Athens, Rome, Vienna and Zaragoza), because incomplete information was obtained from Heraklion and Pecs. Heraklion could not be included in the 24 h recall analyses since only a minority of the study population completed two 24 h recall days due to logistic problems. Pecs was also excluded from the 24 h recall analyses because no nutrient information was available and thus the standardised data cleaning procedures could not be performed. Finally, 2084 cases (54% girls) remained eligible for the 24 h dietary recall analyses. The 20 m shuttle run test was assessed in 2814 cases, while weight and height were measured in the whole sample.

In the present study participants with complete and valid data on 20 m shuttle run test, weight and height measurement and a 2 d 24 h dietary recall were included. A total of 2018 participants (53% girls) met these criteria. Under-reporters, following previously described definition (24), were excluded from all analysis (526 cases, 58% girls). The final sample for the present study was 1492 cases (52% girls). Differences between the included and excluded groups for age, sex, weight, height and BMI z-score were analysed. No differences (all P > 0.1) were found between the included and excluded groups for age, sex and height, while weight (difference 4 kg) and BMI z-score (difference 0.41) were higher in the excluded group, which might be explained by the fact that the under-reporters excluded from the analyses had a higher BMI than the rest of the sample (data not shown). The descriptive characteristics of this sample are presented in Table 1.

**Measurements**

**Cardiorespiratory fitness assessment**. CRF was measured with the 20 m shuttle run test (25). Participants were required to run between two lines 20 m apart, while keeping pace with audio signals emitted from a pre-recoded compact disk. The initial speed is 8.5 km/h, which is increased by 0.5 km/h per min (1 min equals one stage). Participants were instructed to run in a straight line, to pivot on completing a shuttle, and to pace themselves in accordance with the audio signals. The test was finished when the participant fails to reach the end lines concurrent with the audio signals on two consecutive occasions. The test was performed once, and the last half-stage fulfilled by the adolescent was recorded.
The equations of Léger et al.\(^{25}\), previously validated in young people\(^{25,26}\), were used to estimate \(\text{VO}_{2\text{max}}\) (ml/kg per min) from the test score. Participants were classified into low and high CRF levels according to the FITNESSGRAM proposed by the FITNESSGRAM have been consistently validated in relation to CVD risk in young people\(^{20}\). The FITNESSGRAM proposed one threshold for boys for the adolescence period and three thresholds for girls based on age, since \(\text{VO}_{2\text{max}}\) (expressed in relative terms) is stable across this period in boys, but progressively decreases in girls. Boys with a \(\text{VO}_{2\text{max}}\) of 42 ml/kg per min or higher were classified as having a high CRF level. Girls aged 12 and 13 years or older with a \(\text{VO}_{2\text{max}}\) of 35 ml/kg per min or higher were classified as having a high CRF level. Girls aged 14 or older with a \(\text{VO}_{2\text{max}}\) of 37 ml/kg per min or higher were classified as having a high CRF level. Girls aged 14 or older with a \(\text{VO}_{2\text{max}}\) of 36 ml/kg per min or higher were classified as having a high CRF level. Girls aged 14 or older with a \(\text{VO}_{2\text{max}}\) of 35 ml/kg per min or higher were classified as having a high CRF level.
To calculate energy and nutrient intakes, data of the HELENA-DIAT were linked to the German Food Code and Nutrient Database (Bundeslebensmittelschlüssel, version II.3.1, 2005)(30). The usual dietary intake of nutrients and foods was estimated by the multiple source method (https://nugodifie.de/msm/)(31). The multiple source method calculates first dietary intake for individuals and then constructs the population distribution based on the individual data. This method takes into account the between- and within-person variability of the dietary intake data.

Average energy intake was estimated in kJ and the intake of carbohydrates, saccharides (monosaccharides and disaccharides), polysaccharides, proteins, total fat and saturated fat was adjusted for total energy intake (as percentage of energy). Cholesterol intake was expressed in mg. To compare differences were tested using the t test. Statistical significance for t test was considered with P≤0.05. All analyses were stratified by sex.

To examine the relationship between CRF and dietary intake, we used multilevel analysis(35). Dietary intake was considered as the outcome variable and CRF as the independent variable, first, in the continuous form and, second, as the dichotomous variable (high/low CRF according to the FITNESSGRAM definition). For the multilevel analysis, the study centre was included as a random intercept and current

Table 2. Multilevel analysis examining the associations between cardiorespiratory fitness (VO2max) and dietary intake

<table>
<thead>
<tr>
<th></th>
<th>Boys</th>
<th></th>
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<th>Girls</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β</td>
<td>95% CI</td>
<td>P*</td>
<td>P†</td>
<td>β</td>
<td>95% CI</td>
<td>P*</td>
<td>P†</td>
</tr>
<tr>
<td>Energy (kJ)</td>
<td>42.739</td>
<td>14.258, 71.221</td>
<td>0.003</td>
<td>0.006</td>
<td>17.418</td>
<td>7.960, 42.797</td>
<td>0.182</td>
<td>0.741</td>
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<tr>
<td>Macronutrients</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Carbohydrate (% E)</td>
<td>0.021</td>
<td>0.042, 0.085</td>
<td>0.513</td>
<td>0.677</td>
<td>0.011</td>
<td>0.094, 0.072</td>
<td>0.790</td>
<td>0.624</td>
</tr>
<tr>
<td>Saccharides (% E)</td>
<td>0.012</td>
<td>0.059, 0.082</td>
<td>0.744</td>
<td>0.717</td>
<td>0.020</td>
<td>0.107, 0.068</td>
<td>0.659</td>
<td>0.314</td>
</tr>
<tr>
<td>Polysaccharides (% E)</td>
<td>0.009</td>
<td>0.041, 0.058</td>
<td>0.734</td>
<td>0.407</td>
<td>0.004</td>
<td>0.060, 0.067</td>
<td>0.910</td>
<td>0.647</td>
</tr>
<tr>
<td>Protein (% E)</td>
<td>-0.008</td>
<td>-0.036, 0.020</td>
<td>0.565</td>
<td>0.787</td>
<td>0.021</td>
<td>-0.014, 0.056</td>
<td>0.247</td>
<td>0.150</td>
</tr>
<tr>
<td>Fat (% E)</td>
<td>0.014</td>
<td>0.037, 0.066</td>
<td>0.589</td>
<td>0.581</td>
<td>0.008</td>
<td>0.060, 0.076</td>
<td>0.814</td>
<td>0.853</td>
</tr>
<tr>
<td>Carbohydrate (% E)</td>
<td>0.028</td>
<td>0.001, 0.054</td>
<td>0.041</td>
<td>0.079</td>
<td>0.027</td>
<td>-0.007, 0.062</td>
<td>0.123</td>
<td>0.264</td>
</tr>
<tr>
<td>Cholesterol (mg)</td>
<td>1.854</td>
<td>0.444, 3.265</td>
<td>0.010</td>
<td>0.013</td>
<td>1.497</td>
<td>0.116, 2.877</td>
<td>0.034</td>
<td>0.204</td>
</tr>
</tbody>
</table>

β, estimated value; % E, percentage of energy.

The level of significance is considered below the threshold after controlling for multiple testing (P≤0.003).

Model 1: after adjusting for centre and age.

Model 2: after adjusting for centre, age and BMI z-score.

†Bread, rolls and cereals.

‡Starchy roots, potatoes, flour, pasta, rice and other grain products.

§Meat, fish, pulses, eggs, meat substitutes and protein from vegetable products.

*Confectionery, chocolate, other sugar products, savoury snacks and butter—animal fat.

**Juices, carbonated, soft and isonic drinks.

Under-reporting was considered when the ratio of energy intake over the estimated BMR was lower than 0.96, as proposed by Black(24). BMR, used for estimating under-report, was calculated from age-specific FAO/WHO/UNU equations(32).

Anthropometric measurements. The protocol used to collect anthropometric data has been described previously(33). All adolescents were measured by trained researchers in a standardised way. Weight was measured with an electronic scale (type SECA 861) to the nearest 0.1 kg. Height was measured in the Frankfort plane with a telescopic height-measuring instrument (type SECA 225) to the nearest 0.1 cm. BMI was calculated as body weight divided by the square of height (kg/m²), and adjusted for age and sex to give a BMI standard deviation score (BMI z-score)(34).

Data analyses

Statistical analyses were performed using the statistical software PASW for Windows version 18 (PASW Inc., Chicago, IL, USA). Sex differences were tested with the t test. Statistical significance for t test was considered with P≤0.05. All analyses were stratified by sex.

To examine the relationship between CRF and dietary intake, we used multilevel analysis(35). Dietary intake was considered as the outcome variable and CRF as the independent variable, first, in the continuous form and, second, as the dichotomous variable (high/low CRF according to the FITNESSGRAM definition). For the multilevel analysis, the study centre was included as a random intercept and current

Table 2. Multilevel analysis examining the associations between cardiorespiratory fitness (VO2max) and dietary intake

(Estimated values and 95 % confidence intervals)
centre and age. Statistical significance was also considered when further adjusting for BMI z-score (model 2) were entered as covariates. The effect size, as estimated by Cohen's $d$, was inversely associated with sweetened beverage consumption. In addition, whether the juices were added to the sweetened beverage groups (carbonated, soft and isotonic drinks) the results remained unchanged (data not shown). Overall, the results did not materially change after further adjustment for BMI z-score.

Table 3 shows the dietary intake according to the FITNESSGRAM levels. The only difference between the two categories was that boys with a low CRF reported consuming a lower amount of bread/cereals and dairy products than those with a high CRF ($P<0.003$). In girls, those presenting low CRF also reported a lower consumption of dairy products in both boys and girls. CRF was positively related to mean daily intake of dairy products in both boys and girls. In boys, CRF was also positively associated with bread/cereals and dairy products consumption. In girls, CRF was inversely associated with sweetened beverage consumption. In addition, whether the juices were added to the sweetened beverage groups (carbonated, soft and isotonic drinks) the results remained unchanged (data not shown). Overall, the results did not materially change after further adjustment for BMI z-score.

Results

Descriptive characteristics of the study sample, and stratified by sex, can be found in Table 1. Weight, height and CRF levels were higher in boys ($P<0.001$). Mean daily total energy intake, cholesterol intake and most food group consumption (all except fruit and vegetables) were also higher in boys ($P<0.001$).

Table 2 shows the associations between CRF (VO$_{2\max}$) and dietary intake. In boys, but not in girls, CRF was positively associated with mean daily energy intake ($P=0.003$); this association was minimally attenuated when further adjusting for BMI z-score ($P=0.006$). CRF was not related to the percentage of energy obtained from the different macronutrients or cholesterol intake, either in boys or in girls. CRF was positively related to mean daily intake of dairy products in both boys and girls. In boys, CRF was also positively associated with bread/cereals and fat/sweet food consumption. In girls, CRF was inversely associated with sweetened beverage consumption. In addition, whether the juices were added to the sweetened beverage groups (carbonated, soft and isotonic drinks) the results remained unchanged (data not shown). Overall, the results did not materially change after further adjustment for BMI z-score.
Discussion

The results of the present study show the association between CRF and dietary intakes in a large sample of European adolescents controlling for centre, age and BMI. In both boys and girls, a high CRF is consistently associated with a higher consumption of dairy products, regardless of centre, age and BMI. A high CRF is also consistently associated with a higher intake of bread/cereals in boys, and a lower intake of sweetened beverages in girls. To the best of our knowledge, this is the first study reporting the association between CRF and dietary intakes in adolescents.

The association between CRF and dairy product intake observed in the present study is in accordance with a previous study in adults, showing that men and women in the higher fitness tertiles had higher Ca intakes (37). The magnitude of the difference in dairy product intake between adolescents with a high v. low CRF was 11 and 9% higher in boys and girls, respectively. Relatively small differences are expected since many factors influence dietary patterns. The potential benefit of milk consumption possibly due to the presence of many biologically active compounds (37) could be a possible explanation. In fact, combining consumption of high-quality

<table>
<thead>
<tr>
<th>Dietary guidelines/recommendations</th>
<th>Boys OR (95% CI)†</th>
<th>Girls OR (95% CI)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macronutrients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbohydrate †, 45–65% E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein †, 10–30% E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total fat †, 25–35% E</td>
<td></td>
<td></td>
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<tr>
<td>Saturated fat †, &lt; 10% E</td>
<td></td>
<td></td>
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<tr>
<td>Cholesterol ‡, &lt; 300 mg</td>
<td></td>
<td></td>
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<tr>
<td>Food group</td>
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<td></td>
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<tr>
<td>Bread/cereals ‡, 150–360 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grains/potatoes ††, 210–350 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruit, 250–370 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetables, 300–450 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dairy products, 450–600 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cheese, 20–40 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein food ††, 75–100 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat/sweet food ‡‡, max. 50 g</td>
<td></td>
<td></td>
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<tr>
<td>Sweetened beverages ‡‡‡, max. 300 g</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. OR and CI for presenting high cardiorespiratory fitness (CRF) and comply with dietary guidelines/recommendations. References present low CRF and comply with dietary recommendation (vertical lines indicate reference low CRF). † After adjusting for centre and age. ‡ Acceptable macronutrient distribution ranges. ‡‡ Tolerable upper intake levels according to the Institute of Medicine (12). || Acceptable ranges according to the Flemish food-based dietary guidelines (14). ‡ Bread, rolls and cereals. †† Starchy roots, potatoes, flour, pasta, rice and other grain products. ‡‡ Meat, fish, pulses, eggs, meat substitutes and protein from vegetarian products. §§ Confectionery, chocolate, other sugar products, savoury snacks and butter–animal fat. §§§ Juices, carbonated, soft and isotonic drinks. The level of significance is considered below the threshold after controlling for multiple testing (P ≤ 0.003). % E, percentage of energy; max., maximum.
(milk-based) proteins with resistance exercise\textsuperscript{(58,59)} has been shown to induce higher gains in muscle mass in young, healthy, untrained men and women\textsuperscript{(60,61)}. Dairy consumption is inversely associated with the metabolic syndrome\textsuperscript{(42,43)}, especially due to one of its components, i.e. Ca. In this line, observational studies have also shown an inverse association between the intake of Ca or dairy products and body weight, as well as total and abdominal fat\textsuperscript{(43–45)}. Since body weight and adiposity are closely related to CRF, these findings could at least partially explain the association between CRF and dairy products observed in the present study.

The association of a high CRF with a higher intake of bread/cereals in boys is in accordance with previous studies in adults\textsuperscript{(16,17)}. In these studies, a higher fitness was associated with a higher percentage of energy coming from carbohydrates\textsuperscript{(17)} and a higher consumption of rye bread\textsuperscript{(16)}. The higher intake of bread/cereals observed in boys with better CRF (13\% higher compared with those with a lower CRF) could be due to the need of carbohydrates to replenish glycogen stores.

The present study shows that girls with a lower CRF presented lower intakes of dairy products and higher intakes of sweetened beverages. This is in accordance with a previous study in young men and women\textsuperscript{(16)}, in which CRF was inversely related to the consumption of sweetened drinks. In both boys and girls, dairy product intake and the consumption of sweetened drinks are inversely related, although the association was not significant (data not shown). This can be interesting because the nutritional value of sweetened beverages compared with dairy products is very poor; in fact, it is considered as a source of energy of ‘empty calories’ (virtually no nutritional value). Sweetened beverages represent rapidly absorbed carbohydrates whose consumption has been shown to result in increases in blood glucose and insulin, and a high dietary glycaemic load, which are associated with the metabolic syndrome\textsuperscript{(46)}. Thus, high added sugar consumption in the form of sweetened beverages is associated with a constellation of cardiovascular risk factors, both independently and through the development of obesity\textsuperscript{(47,48)}.

Overall, we did not observe associations between CRF and compliance with dietary recommendations neither in energy distribution among nutrients nor in food consumption in adolescents; only girls meeting the recommendations of sweetened beverage intakes were associated with a better CRF. These results are in contrast to those observed in adults\textsuperscript{(17)}. Brodney et al.\textsuperscript{(17)} reported that adults in the higher fitness tertiles consumed diets that more closely approached national dietary recommendations in terms of percentage of energy provided from fat and saturated fat, cholesterol intake or fruit and vegetable intakes. Results on sweetened beverage consumption have not been reported in that study. The lack of association found in the present study can be explained, at least in part, by the fact that food choices of adolescents do not match with the dietary recommendations\textsuperscript{(9–15)}. We observed that most of the adolescents in the present study comply with recommendations in terms of percentage of energy from carbohydrate (73–5\% for boys, 76–8\% for girls), protein (99–6\% for boys, 98–7\% for girls) and total fat (58–4\% for boys, 56–2\% for girls). In contrast, a much lower proportion were compliant for energy derived from saturated fat (4–4\% for boys, 4–2\% for girls) and cholesterol intake (18–6\% for boys, 42–2\% for girls), with most of the people presenting higher intakes than recommended. Regarding food groups, a larger proportion of people (90\%) do not comply with recommendations particularly with regard to lower than recommended intakes of fruit and vegetables and higher intakes of protein food and fat food/sweet (data not shown).

The present study has some limitations. Self-report dietary data are prone to a variety of unintentional measurement errors. In addition, misreporting is a common problem in assessing dietary habits among adolescents\textsuperscript{(49)}. According to Biro et al.\textsuperscript{(50)}, assessment of usual intakes on the individual level should be done by repeated short-term measurements (i.e. 24 h). In the present study, dietary intake was assessed on two self-administered, computer-assisted, non-consecutive 24 h recalls. Although more measurements would be desirable, this method has shown to be appropriate in collecting detailed dietary information from adolescents\textsuperscript{(58,59)}. In order to decrease the influence that episodically consumed foods might have, dietary intake was corrected for within- and between-person variability according to the multiple source method\textsuperscript{(51)}. For CRF, several methodological studies\textsuperscript{(20–22)} and systematic reviews\textsuperscript{(5,6,51,52)} were performed by our groups and concluded that the 20 m shuttle run test is currently the best field test available to assess CRF.

Conclusion

In conclusion, in a large sample of European adolescents, a high CRF is consistently associated with higher intakes of dairy products after controlling for centre, age and BMI. A high CRF is also associated with a higher intake of bread/cereals in boys, and with a lower consumption of sweetened beverages in girls. The present findings contribute to the understanding of the relationships between dietary factors and physiological health indicators, such as CRF.

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