Nutrition Journal

RESEARCH

Open Access

Trajectories of adherence to an obesogenic dietary pattern and changes in diet quality, food intake, and adiposity during adolescence

Jesús Martínez-Gómez[1†], Patricia Bodega[1,2†], Gloria Santos-Beneit[1,2], Amaya de Cos-Gandoy[1,2], María Beneito-Durá[1], Mercedes de Miguel[1,2], Anna Tresserra-Rimbau[3,4,5], Ana María Ruiz-León[3,5], Ramón Estruch[3,5], Rosa María Lamuela-Raventós[3,4,6], Luis A. Moreno[3,7], Juan Miguel Fernández-Alvira[1] and Rodrigo Fernández-Jiménez[1,8,9*]

Abstract

Background and Aims Contemporary longitudinal data on dietary patterns (DP) during adolescence are scarce. This study aimed to identify trajectories of adherence to an obesogenic DP and changes in diet quality (DQ), related food consumption, and adiposity markers during adolescence.

Methods A cohort of 600 adolescents (293 girls, 48.8%) attending 24 secondary schools enrolled on the SI! Program for Secondary Schools trial in Spain was assessed when participants were approximately 12, 14, and 16 years old. An energy-dense, high-fat, and low-fiber (obesogenic) DP was derived at each time point by reduced rank regression (RRR) using the percentage energy intake from fat, fiber density, and dietary energy density as intermediate variables. Based on each participant's resulting scores, trajectories of adherence to the obesogenic DP were identified by latent class trajectory modeling. Adjusted associations between trajectories, DQ and food consumption changes, and adiposity markers during adolescence were analyzed with generalized linear models.

Results Based on adherence to the obesogenic DP during adolescence, four stable trajectory groups (from lowest to highest adherence) were identified: trajectory 1 (44 participants [7.3%]), trajectory 2 (180 participants [30.0%]), trajectory 3 (292 participants [48.7%]), and trajectory 4 (84 participants [14.0%]). Overall DQ was moderate, but showed a gradient across trajectories, with trajectory 1 having the best quality. Although the identified trajectories were stable, individuals in the group with the lowest adherence to the obesogenic DP (trajectory 1) significantly improved their overall DQ over time, whereas those with the highest adherence (trajectory 4) showed the opposite trend. The group of adolescents in trajectory 4 had the least healthy central adiposity profile when ~16 years old.

Conclusion Four stable trajectories of adherence to an obesogenic DP were identified in a large cohort of adolescents, with DQ decreasing as adherence to the DP increased. Although adherence to the DP was stable, differences in food intake between trajectories widened over time, resulting in increased central adiposity in participants with the highest adherence to the pattern at the end of the study. Further research is needed to explore

† Jesús Martínez-Gómez and Patricia Bodega contributed equally to this work.

*Correspondence:
Rodrigo Fernández-Jiménez
rodrigo.fernandez@cnic.es
Full list of author information is available at the end of the article

the determinants of adherence to obesogenic DPs in adolescence and to evaluate their effects on adiposity and overall health later in life.

Trial registration ClinicalTrials.gov NCT03504059.

Keywords Teenagers, Health promotion, Reduced-rank regression, Central obesity, Overweight, Dietary patterns

Introduction

Dietary intake throughout life is one of the main modifiable factors influencing the maintenance of health and the prevention of non-communicable diseases [1, 2]. Over recent decades, dietary habits in developed countries such as Spain have shifted from traditional patterns to obesogenic dietary patterns (DP) that promote weight gain and the risk of developing obesity. These patterns are characterized by an elevated content of ultra-processed foods (fast-food, biscuits, cakes); high intake of refined grains (refined bread, pasta, rice), dairy products, and meat (mixed meat dishes); and low intake of legumes, fruits, and vegetables [3, 4]. This transition to a low-quality, energy-dense, high-fat, and low-fiber DP may be in part responsible for the currently high worldwide prevalence of overweight and obesity [5]. The study of DPs may help to understand the associations between the overall dietary intake and health outcomes [6, 7]. Understanding how DPs evolve over the life course could assist the development of strategies to improve dietary intakes and health outcomes.

Adolescence is a critical stage of life for the acquisition of lifestyle routines during which DPs start to be settled. Previous studies have reported an association between DPs in childhood and adolescence and cardiovascular diseases or metabolic disorders later in life [8]. Adolescents who have established poor DPs at 14 years are more likely to stick to them later in adolescence [9]. Moreover, adolescents are especially susceptible to environmental influences [10], and food marketing strategies targeting this population mostly promote energy-dense nutrient-poor food choices [11].

Most studies examining the association between DPs and adiposity markers in adolescence have been cross-sectional or focused on specific foods [12, 13], and there is a lack of information on DP trajectories during adolescence and their association with adiposity markers. The aims of the present study were as follows: 1) to derive an obesogenic DP by reduced rank regression (RRR) and to determine the main food groups contributing to the pattern in three cross-sectional time points [baseline, 2-year and 4-year follow-up (FU)] in a large cohort of adolescents in Spain with a mean age of 12 years at cohort entry; 2) to identify trajectories of adherence to this DP over the course of adolescence; 3) to study the changes in food consumption according to the trajectories of adherence to the DP; and 4) to determine the longitudinal association of identified trajectories with adiposity markers determined when study participants were approximately 16 years old.

Methods

Study design and population

This study used longitudinal data collected as part of the SI! (*Salud Integral-* Comprehensive Health) Program for Secondary Schools trial in Spain, which enrolled 24 secondary schools (7 in Madrid and 17 in Barcelona). This trial, launched in 2017 and finalized in 2021, was designed as a cluster-randomized controlled intervention trial to test the impact of a comprehensive lifestyle program on the cardiovascular health of adolescents and enrolled a total of 1326 individuals with a mean [standard deviation (SD)] age at recruitment of 12.5 (0.4) years. Assessments were scheduled during the academic year at baseline (October 2017–February 2018), 2-year FU (February 2019–June 2019, when the adolescents were approximately 14 years old), and 4-year (final) FU (January 2021–June 2021, when the adolescents were approximately 16 years old).

For inclusion in the trial, the education agencies of the Madrid and Catalonia regional government invited the head teachers from all eligible schools ($n=146$) located in Madrid and Barcelona metropolitan areas to a presentation of the study. Eligible schools had to meet the following inclusion criteria: public schools located in the metropolitan areas of Madrid or Barcelona providing education from the first through the fourth secondary school grades, with 3 to 5 classes in the first grade. No exclusion criteria were established and participants did not receive financial compensation. Finally, 24 secondary schools (7 in Madrid and 17 in Barcelona) were enrolled. Within each school, all 1st grade students and their families were invited to participate, and the study included only those ones who signed the informed consent form. Additional details of the study design and data collection procedures are described elsewhere [14, 15]. The present work included all adolescents with data available for dietary assessment in all three assessment periods.

The study is registered at ClinicalTrials.gov number NCT03504059 and was approved by the Committee for Ethical Research (CEI) of the *Instituto de Salud Carlos*

III in Madrid (CEI PI 35_2016), the CEI of the *Fundació Unió Catalana d'Hospitals in Barcelona* (CEI 16/41), and the University of Barcelona Bioethics Committee (IRB00003099). Data were collected and handled according to Spanish Law 15/1999 on the Protection of Personal Data, ensuring the confidentiality of all participant data. Parents and caregivers provided written informed consent at the beginning of the study.

The reporting of the results of this trial adheres to the Strengthening The Reporting of OBservational studies in Epidemiology (STROBE) guidelines for cross-sectional and cohort studies (Supplemental Table 1).

Dietary assessments

A validated 157-item semi-quantitative food frequency questionnaire (FFQ), excluding questions regarding alcohol intake, was filled out by caregivers at each of the three assessment time points [16]. The questionnaire was considered valid if fewer than 50% of the answers were missing. Because some responses may result in implausibly high or low values, participants were also excluded if their reported energy intake was below 803 kcal/day (boys) or 502 kcal/day (girls), or above 4013 kcal/day (boys) or 3511 kcal/day (girls), based on previous studies in Spanish population [16, 17]. Any missing values in a valid FFQ were interpreted as no intake.

Food intake data were collapsed into 40 groups based on usage or differences in energy density, fat, and fiber content (Supplemental Table 2) [18, 19]. Average absolute and standardized (to 2000 kcal) intakes (g/day) were computed for each food group. We also calculated the percentage energy intake from fat, the fiber density (FD) (g/kcal), and the dietary energy density (DED) (kcal/g). DED, excluding drinks, was calculated by dividing total food energy (kcal) by total food weight (g), and FD was calculated by dividing the intake of non-starch polysaccharides (NSP) (g) by total energy intake (MJ). Diet quality was calculated using the validated Diet Quality Index for Adolescents (DQI-A), ranging from −33 to 100% [20–22]. This index measures adherence to food-based dietary guidelines and takes into account three basic principles for a healthy and balanced diet: dietary quality, dietary diversity and dietary equilibrium. Dietary quality (−100 to 100%), expresses the optimal food quality choices within a food group classified as *preference group*, *intermediate group*, or *low-nutrient, energy-dense group* (Supplemental Table 3). Dietary diversity (0 to 100%) is an indicator of the degree of variation in the diet, with points ranging from 0 to 9 when at least one serving of food of a recommended food group was consumed. Finally, dietary equilibrium (0 to 100%), represents the difference between the adequacy component and the excess component as defined in Spanish food intake recommendations [23]. The total score was calculated as the average of the three components.

Adiposity markers

All participants were instructed to fast overnight before measurements. Trained nutritionists measured participants' body weight and fat mass (OMRON BF511 body composition scale), height (Seca 213 stadiometer), and waist circumference (WC) (Holtain non-elastic tape). Body mass index (BMI) was calculated as body weight divided by height squared (kg/m^2); fat mass index (FMI) was calculated by dividing body fat mass by height squared (kg/m^2); and waist-to-height ratio (WHtR) was calculated by dividing WC by height. Age- and sex-adjusted z-scores were calculated using validated cutoff points from the Centers for Disease Control (CDC) for BMI [24] and from the Third National Health and Nutrition Examination Survey (NHANES III) for WHtR [25]. The FMI-specific z-scores were calculated based on our sample as previously described [26]. Briefly, participants were grouped according to their age at each time point, and age- and gender-specific FMI z-scores were calculated.

Covariates

Moderate-to-vigorous physical activity (MVPA) was estimated with an Actigraph wGT3X-BT accelerometer placed on the participant's non-dominant wrist for seven consecutive days. Records were considered valid if they provided data from a minimum of four consecutive or non-consecutive days, with at least 600 min per day of wear time. MVPA was calculated according to specific cutoff points for adolescents [27]. Sleep time was estimated with the same device. Records were considered valid if they provided data from at least four consecutive or non-consecutive days of wear time with a maximum of 960 min of sleep per 24 h and were classified according to Cole-Kripke cutoff points [28, 29]. Smoking status was assessed with a standard questionnaire [30]. Sexual maturity status was self-reported by participants according to Tanner and Whitehouse pictograms on a scale from I to V [31].

Families, here represented by parents or caregivers, completed a survey collecting sociodemographic information (educational level and migrant status). Parental educational level was stratified according to the International Standard Classification of Education (ISCED) as low (no studies, primary studies, or secondary studies; 0–3 ISCED score), intermediate (post-secondary non-tertiary education or short-cycle tertiary education; 4–5 ISCED score), or high (university studies; 6–8 ISCED score) [32]. If more than one parental or caregiver educational level was reported, the highest level was used for analysis. A migrant background was assumed if at least one parent/caregiver was born outside Spain. The information on migrant status and parental educational level used for analysis was that obtained at baseline; if this information was unavailable at baseline but was collected at any subsequent FU, the earliest reported information was considered.

Statistical analysis

For descriptive data, continuous variables are presented as mean and SD and categorical variables as frequencies and percentages.

DPs were determined using RRR, a statistical technique that identifies linear combinations of predictor variables (in this case food intake groups) that maximize the explained variation in a set of intermediate variables (DED, the percentage of energy intake from fat, and FD in this study) that are hypothesized to be on the pathway between the predictor variables and a health outcome of interest (adiposity parameters in this study). The main difference between RRR and other common methods for deriving DPs is that RRR is partly hypothesis-driven based on previous knowledge and thus tailored to specific research questions about diet-outcome relationships [33]. Separate RRR analyses were conducted using dietary data from baseline and 2- and 4-year FU. As the number of DPs extracted using RRR analysis is determined by the number of intermediate variables included, we obtained three DPs at each time point. DP scores were calculated for each adolescent at every time point as a linear combination of all food group intakes. The first DP from each RRR analysis explained the greatest variation in all three intermediate variables (~60% at each of the three time points), whereas the second and third patterns explained ~18% and ~7.5%, respectively. Therefore, only the first DP, named the obesogenic pattern, was considered for further analysis.

DP scores for each adolescent at each time point were used to identify trajectories by latent class growth modeling (LCGM). LCGM is a longitudinal approach used to identify distinct subgroups (or "latent classes") within a population that follow similar trajectories over time. When applied to derive trajectories of obesogenic DPs, LCGM uncovers groups of individuals with similar patterns of change and adherence to them over the given time period [34]. LCGM was performed with the user-written Stata command 'traj', which is based on the SAS PROC TRAJ macro and fits semiparametric (discrete mixture) models for longitudinal data using the maximum likelihood method [35]. Given the use of continuous DP scores, a censored normal distribution approach was used. The optimal number and shape of trajectories was determined as previously described [36]. Briefly, models between one and six trajectories were tested, and the model with the number of trajectories that best fitted the data (lowest absolute Bayesian information criterion (BIC) value; BIC = −2877.80) was finally selected. A maximum probability assignment rule was applied to allocate each participant to the trajectory for which he or she exhibited the highest posterior probability of belonging [37].

Statistical differences between identified trajectory groups were determined by chi-square test with the Cochran-Mantel–Haenszel extension test for variables with ordered categories and by analysis of variance (one-way ANOVA) for continuous variables.

For the study of longitudinal associations between trajectory groups and changes in food consumption over the course of adolescence, we applied multilevel linear mixed-effects models that account for the hierarchical cluster design. As fixed effects, adjusted models included trajectory group, age, gender, randomization group, parental educational level, migrant background, MVPA, sleep time, smoking, sexual maturity status, and food group consumption at baseline. Region (Madrid or Barcelona) and schools within each region were handled as random effects. To study the longitudinal association between trajectory groups and adiposity markers, similar models were constructed using as outcomes the adiposity markers at 4-year FU. The adjustments for these models were the same as above, but with the exclusion of age, gender, and food group consumption variables and the addition of baseline values for the adiposity markers and adherence to the obesogenic pattern. Post-estimation testing of the linear hypothesis across sleep recommendation categories over time was performed using coefficients of orthogonal polynomials. Missing values were not imputed.

Statistical significance was set at $p < 0.05$ two-sided. Analyses were performed with data from the SI! Program for Secondary Schools trial's database dated July 17th, 2023. All statistical analyses were conducted with Stata version 17 (StataCorp, College Station, Texas).

Results

This analysis included 600 adolescents (293 girls, 48.8%) enrolled on the SI! Program for Secondary Schools trial in Spain, with a median age at cohort entry of 12.5 years (SD = 0.4 years). The obesogenic DP was positively correlated with DED (~0.61) and with the percentage of energy from fat (~0.48) and was inversely correlated with FD (~−0.62). This energy-dense, high-fat, and low-fiber DP was characterized by positive factor loadings of margarine and vegetable oils, cheese, nuts and seeds, biscuits and cakes, processed meat, and mixed meat dishes and negative factor loadings of fresh fruit, vegetables, and legumes (Fig. 1).

Based on adherence to the obesogenic DP during adolescence, four stable trajectory groups were identified (Fig. 2): trajectory 1 (44 participants [7.3%]), trajectory 2 (180 participants [30.0%]), trajectory 3 (292 participants [48.7%]), and trajectory 4 (84 participants [14.0%]), with trajectory 1 having the lowest adherence to the obesogenic pattern over time. No associations were found at baseline with parental educational level, but the healthiest trajectories (1 and 2) included higher proportions of girls and individuals from families with a migrant background (Table 1). Moreover, the mean DQI-A score was highest in trajectory 1 and decreased with increasing adherence across trajectories 2–4; this pattern was especially pronounced for the dietary quality component. No associations were found with MVPA, sleep time, or smoking status. Overall, adolescents allocated to trajectory 4 had healthier values for adiposity markers at baseline, especially BMI and FMI z-scores (Table 1).

Food group consumption and changes during adolescence

Although the food trajectories identified were stable over the study period, there were specific changes in terms of food-group intake, producing more differences in food consumption between trajectories. Detailed information on standardized food-group intake expressed in g/day is presented in Supplemental Table 4. Between baseline and 4-year FU, individuals in trajectory 1 significantly increased their consumption of healthy choices (high-fiber bread: 14.5; 95% CI: 7.9 to 21.0 g/day, vegetables: 120.5; 95% CI: 91.3 to 149.7 g/day, legumes: 29.2 95% CI: 18.9 to 39.5 g/day, and fresh fruits: 309.1; 95% CI: 242.0 to 376.2 g/day) and significantly decreased their consumption of unhealthy foods (low-fiber bread: −17.3; 95% CI: −30.9 to −3.8 g/day, biscuits and cakes: −12.6; 95% CI: −19.7 to −5.5 g/day, processed meat: −10.6; 95% CI: −16.6 to −4.6 g/day, and sugar-sweetened beverages: −38.9; 95% CI: −64.9 to −12.9 g/day) (Table 2). In contrast, individuals in trajectory 4 showed the opposite trend, significantly increasing their consumption of foods like cheese (6.1; 95% CI: 0.1 to 12.1 g/day), margarine and vegetable oils (7.8; 95% CI: 5.2 to 10.3 g/day), and biscuits and cakes (6.4; 95% CI: 1.2 to 11.6 g/day) and significantly reducing their consumption of healthier choices such as vegetables (−39.6; 95% CI: −60.7 to −18.6 g/day), legumes (−12.9; 95% CI: −20.6 to −5.2 g/day), and fresh fruits (−82.5; 95% CI: −140.9 to −24.0 g/day) (Table 2). DQI-A significantly improved in trajectory 1 from baseline to 4-year FU (5.5; 95% CI: 2.8 to 8.2 points), whereas it significantly decreased in trajectory 4 (−2.2; 95% CI: −4.3 to −0.0 points) (Table 2). Similar trends were observed for changes between baseline and 2-year FU and between 2-year and 4-year FU (Supplemental Table 5).

Longitudinal associations with adiposity markers

The highest adherence to the obesogenic DP at all three time points (trajectory 4) was associated with the least healthy adiposity profile at final FU, especially for WC z-score (difference = 0.26 vs. trajectory 1, 95% CI: 0.00 to 0.51, *p*-value = 0.048), and increasing adiposity profile correlated directly with increasing adherence to the obesogenic DP (*p*-value for linear trend = 0.041) (Table 3). No significant associations were found with BMI, WHtR and FMI z-scores.

Table 3 Adjusted associations between trajectory of adherence to the obesogenic pattern during adolescence and adiposity markers at 4-year (final) follow-up

	Adiposity markers			
	BMI z-score	**WC z-score**	**WHtR z-score**	**FMI z-score**
Number of participants, n	555	556	556	546
Trajectory 1 (lowest adherence)	0 [Reference]	0 [Reference]	0 [Reference]	0 [Reference]
Trajectory 2	−0.00 (−0.19 to 0.18)	0.07 (−0.11 to 0.25)	0.02 (−0.17 to 0.21)	−0.08 (−0.30 to 0.13)
Trajectory 3	−0.03 (−0.24 to 0.17)	0.14 (−0.06 to 0.34)	0.06 (−0.15 to 0.27)	−0.06 (−0.29 to 0.18)
Trajectory 4 (highest adherence)	0.03 (−0.23 to 0.29)	0.26 (0.00 to 0.51)	0.15 (−0.12 to 0.42)	−0.08 (−0.39 to 0.22)
P-value for linear trend	0.884	0.041	0.252	0.647

Adjusted multilevel linear mixed models were used to determine the adjusted BMI, WC, WHtR, and FMI z-score ß coefficients and 95% confidence interval values. In these cases, fixed effects were the trajectory group, randomization group, parental educational level, migrant background, moderate-to-vigorous physical activity, sleep time, smoking and sexual maturity status, adherence to the obesogenic pattern, and the value of the adiposity marker at baseline. Region (Madrid or Barcelona) and schools within each region were handled as random effects. BMI, body mass index; FMI, fat mass index; WC, waist circumference; WHtR, waist-to-height ratio

Trajectories are ordered from lowest (1) to highest (4) adherence to the obesogenic dietary pattern over the course of the study

Discussion

This longitudinal study of a large adolescent cohort in Spain aged ~12 years at cohort entry used RRR to derive an energy-dense, high-fat and, low-fiber DP and identified four stable trajectory groups based on the adherence to this obesogenic DP characterized by higher intakes of margarine and vegetable oils, cheese, nuts and seeds, biscuits and cakes, processed meat, and mixed meat dishes, and lower intakes of fresh fruit, vegetables, and legumes. Diet quality in the study cohort was moderate overall but varied according to the trajectories of adherence to this DP, with better DQI-A scores in low adherence trajectories. Although the trajectories identified were stable, over the study period individuals in the group with the lowest adherence to the obesogenic DP (trajectory 1) significantly improved their overall diet quality, significantly increased their consumption of healthy choices, and significantly decreased their consumption of unhealthy foods; in contrast, individuals in the group with the highest adherence to the obesogenic DP (trajectory 4) showed the opposite trend. The trajectory 4 group had the least healthy central adiposity profile when aged ~16 years. To our knowledge, this is one of the first studies to scrutinize trajectories of obesogenic DPs in adolescence and to explore longitudinal changes in diet quality and food consumption and their relationship to adiposity markers at this stage of life.

DPs and food group consumption during adolescence

The study of DPs is increasingly used to assess the effects of dietary choices on health. This approach considers the complexities of food intake, such as synergic effects of certain food groups or substitution effects, whereby increased intake of one food group is linked to decreased intake of other groups. Foods are eaten in combination, and DPs offer an appropriately global perspective on dietary habits, capturing the cumulative and interactive effects of the most frequently consumed foods and nutrients. In addition, the study of DPs has the potential to yield results that can be easily translated into recommendations. The energy-dense, high-fat, and low-fiber DP identified in our study is similar to DPs described in previous studies [18, 19, 38], indicating that the use of RRR to derive DPs provides robust results that can be replicated in independent cohorts of adolescents from similar environments. This is especially advantageous when using variables related to food composition as the intermediate variables because the results are less dependent on the specific sample than is the case with other approaches such as principal component or cluster analysis.

The evidence for stability versus change in DPs during adolescence is inconsistent, with some studies indicating transient fluctuations in DP [39, 40] and others finding that DPs tracked over time during adolescence [9, 41–44], especially for healthy dietary choices [45]. Even if the consumption of specific food groups changes over time, the underlying nutritional variables taken into consideration in deriving DPs (in our case DED, FD, and the percentage of energy from fat) usually show a more stable association with health outcomes [40]. However, although DPs often track over time, changes within population subgroups can become increasingly extreme [43]. In our study, we found that individuals with the lowest adherence to the obesogenic DP (trajectory 1) significantly increased their consumption of healthy choices and significantly decreased the consumption of unhealthy foods, whereas those with the highest adherence (trajectory 4) showed the opposite trend. Thus, although the ranking of individuals according to their eating habits during adolescence was stable, between-trajectory differences in dietary intake increased over time, leading to greater divergence in dietary profiles.

Diet quality has been shown to be suboptimal throughout adolescence [46]. Previous studies of our cohort showed that less than 1% of adolescents ate a healthy diet when 12 years old and that diet did not improve substantially between the ages of 12 and 16 years [14, 36, 47]. In the present study, overall DQI-A was moderate, with the quality component scoring the lowest. Adolescence is a critical stage of life characterized by intense body changes, greater susceptibility to environmental influences, and increases in personal autonomy [48, 49]. Furthermore, the transition from adolescence to young adulthood implies important life changes such as leaving the parental home, starting university or work, and cohabitation, moving from a situation of family dependence to financial independence. Adolescents and young adults are among the most frequent consumers of away-from-home meals, often skip breakfast, and frequently replace dinner with snacks and foods characteristic of an unhealthy diet due to taste preference or limited cooking experience [41, 50]. The adolescence and early adult years are formative periods during which long-term eating habits are adopted and maintained [51, 52]. Engaging adolescents in food preparation activities, e.g. implementing policies or interventions in the school's food environment, has the potential to increase the likelihood that they will continue with these activities during the transition from the family home to an independent lifestyle [53]. Schools are important settings to promote healthy diets and instill lifelong lifestyle habits, since students may consume up to 50% of their daily calories at school [54]. For these reasons, it is important to establish healthy dietary choices early in adolescence so that when these important changes occur, dietary habits remain as

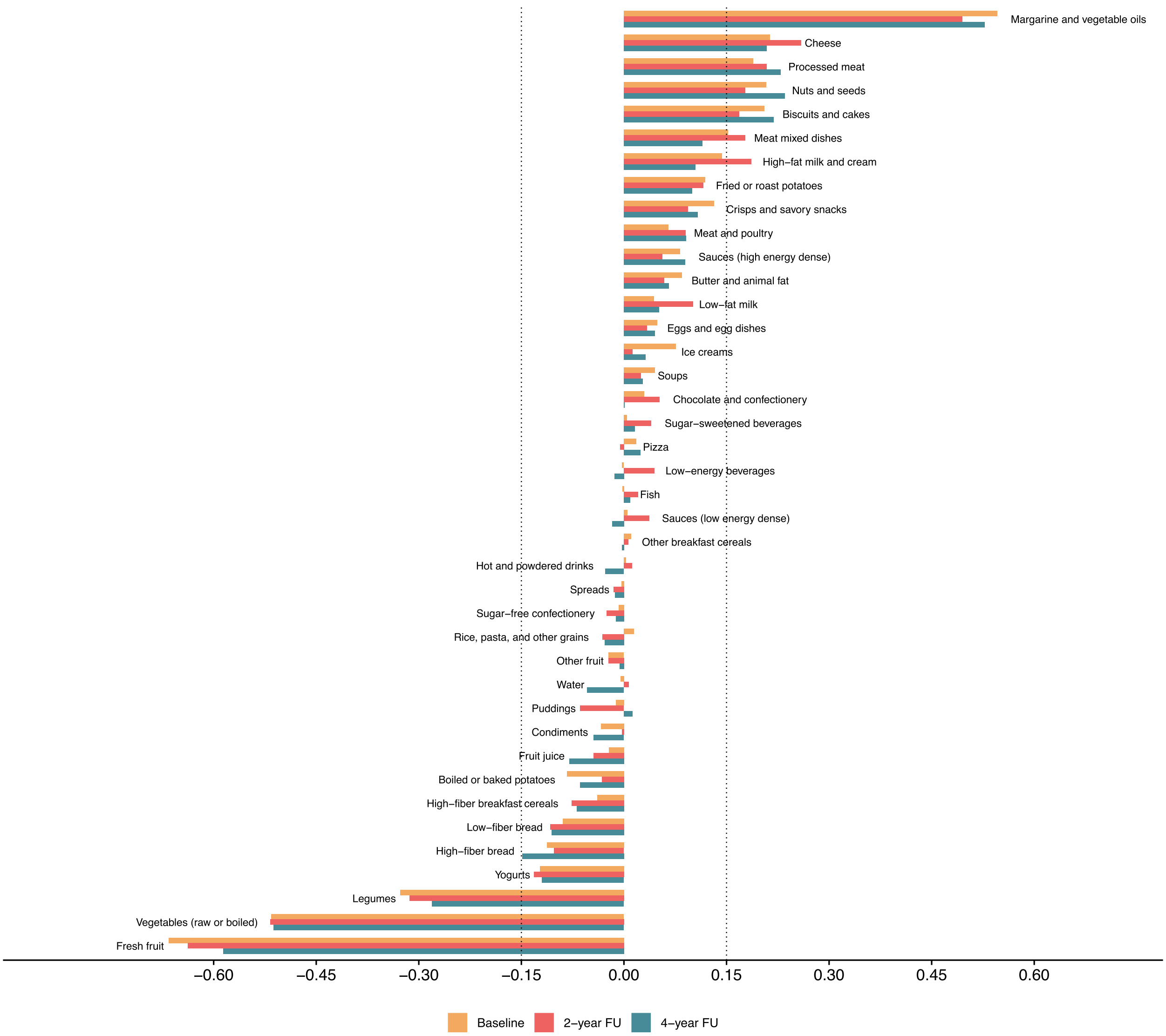

Fig. 1 Reduced rank regression (RRR) factor loadings for the obesogenic dietary pattern derived from the dietary intake assessments at each of the three time points. At each assessment three dietary patterns were derived by RRR. The figure shows the factor loadings for the obesogenic dietary pattern at baseline, 2-year follow-up (FU), and 4-year (final) FU. Positive factor loadings indicate higher frequencies of consumption, whereas negative values indicate lower frequencies of consumption. Factor loadings ≤ −0.15 and ≥ 0.15 were considered important contributors to the obesogenic dietary pattern

healthy as possible. Furthermore, many factors contribute to shaping dietary trajectories, with socioeconomic background being a key determinant. High-energy-dense foods, which are often more accessible to low-income populations [55], are often not only less satiating but also more palatable, contributing to increased food consumption [56]. Conversely, a low-energy-dense diet, generally more expensive than a high-energy-dense, contributes to weight-loss maintenance [57]. Moreover, psychological factors such as self-esteem and body image play a significant role in food choices [47, 58–62], heightening the risk of emotional eating characterized by excessive consumption of foods, particularly those rich in sugars and fat [63, 64]. Other lifestyle factors influence the way dietary trajectories shape. For instance, sleep deprivation disrupts daily fluctuations in appetite hormones resulting in higher levels of the appetite-stimulating ghrelin and low levels of the appetite-suppressing leptin [65, 66]. Moreover, the hedonic food pathway could be activated, resulting in choosing high-energy dense, low fiber, and high-fat foods [67, 68]. Higher levels of physical activity have been associated with higher diet quality during childhood

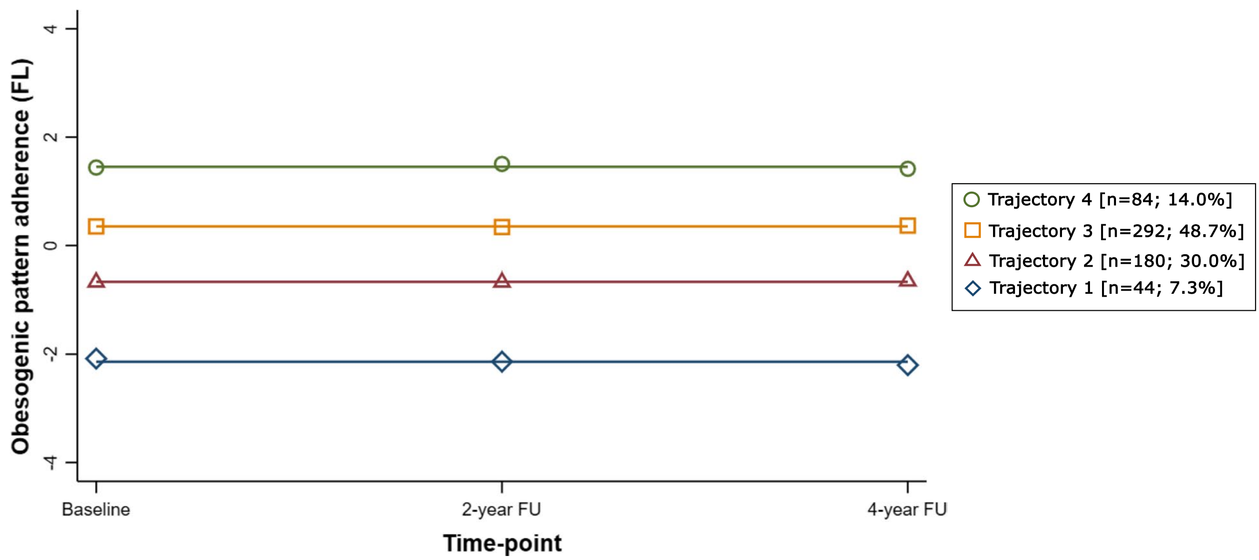

Fig. 2 Trajectories of adherence to the obesogenic dietary pattern in adolescence. The trajectories are ordered according to their mean factor loading (FL) score at baseline. A higher factor loading indicates a higher adherence to the obesogenic pattern. Trajectories were shaped using latent class growth modeling (LCGM) analysis, a longitudinal approach used to identify distinct subgroups (or "latent classes") within a population that follow similar patterns over time

[69], and sedentary behaviour has been associated with increased consumption of energy-dense and unhealthy meals, and a decrease in the daily servings of fruits and vegetables [70]. This can be also due to the fact that children and adolescents who spend more time in sedentary behaviour pay less attention to what they eat during this period [71] and are more exposed to advertisements promoting unhealthy products [72].

Sociodemographic correlates

Women tend to have a healthier diet than men, with higher intakes of fruit and vegetables, whole grains, and fish [73], and our results show similar differences in an adolescent population. A potential explanation for these differences is health beliefs in relation to food choices, since women tend to rate the factor "health" as a more important concern than men do [74]. Moreover, women and girls are often more strongly motivated to consume healthy foods in an attempt to align with gender stereotypes with girls idealizing thinner bodies and boys a more muscular figure [75]. DPs have also been linked to socioeconomic indicators, like education and income [44, 76, 77]. Low parental education level is often associated with higher intakes of sugar-rich and fatty foods among children; however, we found no significant association between parental education and adherence to the obesogenic DP during adolescence. This apparent discrepancy may be related to cultural differences in the influence of socioeconomic factors. In the HELENA study, an analysis of a cohort of adolescents from eight European countries showed that, although parental education was associated with adolescents' diet quality, the association was more pronounced in northern Europe than in countries in southern Europe, like Spain [78]. Our results indicate that individuals with a migrant background tended to have lower adherence to the obesogenic DP during adolescence, probably reflecting retention of traditional diets in the migrant population, irrespective of socioeconomic position [79]. A more precise definition of these associations will require further studies of DPs that consider multiple sociodemographic variables.

Association of DP trajectories with adiposity markers in adolescence

The evidence for an association between obesogenic DPs and adiposity markers in adolescence is conflicting. Several cross-sectional studies have reported an inverse association between obesogenic DP adherence and adiposity markers in adolescence [18, 80, 81]. Possible explanations for this counterintuitive finding include individuals with excess adiposity already attempting to lose weight or avoid further weight gain and thus selecting healthier dietary choices than their counterparts. It is also important to consider that body image satisfaction and perception become more important in adolescence and are often linked to changes in lifestyle. Adolescents who underestimate their body weight report less healthy diets than body-weight overestimators, whereas individuals dissatisfied with their body image and with a drive for thinness frequently adopt dietary habits linked to weight

Table 1 Baseline characteristics of participants stratified by trajectory of adherence to the obesogenic DP

		Trajectory*				
	Overall	1	2	3	4	*P*-value
	(*n* = 600)	(*n* = 44)	(*n* = 180)	(*n* = 292)	(*n* = 84)	
Age in years, mean (SD)	12.5 (0.4)	12.6 (0.4)	12.4 (0.3)	12.5 (0.4)	12.5 (0.3)	0.071
Female, n (%)	293 (48.8)	28 (63.6)	100 (55.6)	130 (44.5)	35 (41.7)	0.002
Parental education, n (%)						
Low	91 (15.2)	10 (22.8)	21 (11.7)	43 (14.7)	17 (20.3)	0.145
Medium	237 (39.5)	17 (38.6)	64 (35.5)	118 (40.4)	38 (45.2)	
High	272 (45.3)	17 (38.6)	95 (52.8)	131 (44.9)	29 (34.5)	
Migrant background, n (%)	150 (25.0)	21 (47.7)	64 (35.6)	59 (20.2)	6 (7.1)	< 0.001
MVPA in min/day, mean (SD)	73.3 (23.2)	70.1 (24.0)	71.9 (22.0)	73.5 (23.7)	77.3 (23.5)	0.277
Sleep time in h/day, mean (SD)	7.7 (0.9)	7.8 (0.7)	7.7 (0.9)	7.8 (1.0)	7.8 (0.9)	0.606
Smoking status, n (%)						
Never tried tobacco products	567 (94.7)	41 (93.2)	175 (97.2)	272 (93.5)	79 (94.1)	0.385
DQI-A, mean (SD)	66.1 (9.7)	70.8 (9.8)	68.6 (8.7)	65.6 (9.2)	60.2 (10.4)	< 0.001
Diet quality	55.5 (16.2)	65.4 (13.7)	60.0 (13.3)	54.0 (15.7)	45.9 (18.5)	< 0.001
Dietary diversity	88.0 (12.5)	91.7 (12.8)	89.6 (12.0)	87.9 (12.1)	83.1 (13.3)	< 0.001
Dietary equilibrium	54.8 (8.5)	55.3 (8.8)	56.1 (9.3)	54.9 (8.1)	51.7 (7.1)	0.001
Adiposity markers, mean (SD)						
BMI z-score	0.4 (1.0)	0.7 (0.9)	0.5 (1.0)	0.4 (0.9)	0.1 (1.0)	0.003
WC z-score	0.3 (0.8)	0.5 (0.8)	0.4 (0.8)	0.3 (0.8)	0.1 (0.9)	0.054
WHtR z-score	0.1 (0.9)	0.2 (0.9)	0.1 (1.0)	0.1 (0.9)	−0.1 (1.0)	0.190
FMI z-score	0.0 (1.0)	0.3 (1.0)	0.1 (1.1)	−0.0 (0.9)	−0.3 (0.9)	0.002

P-values are derived from one-way ANOVA test for continuous variables and by Cochran-Mantel–Haenszel test for ordered categorical variables

BMI, body mass index; DP, dietary patterns, DQI-A, Diet Quality Index for Adolescents; FMI, fat mass index; MVPA, moderate-to-vigorous physical activity; WC, waist circumference; WHtR, waist-to-height ratio

[*] Trajectories are ordered from lowest (1) to highest (4) adherence to the obesogenic dietary pattern over the course of the study

loss [59]. The reported inverse association between obesogenic DP and adiposity might also in part reflect differential social desirability bias according to nutritional status. Moreover, dietary choices considered unhealthy are more frequently under-reported than healthier foods, especially by individuals with excess weight, whereas lean, physically active children are less likely to under-report unhealthy items [82–84]. The few studies that have examined the association between adiposity markers and DPs longitudinally have produced mixed results [12, 13]. In our longitudinal design, the obesogenic DP was associated with higher WC z-score, but no significant associations were found with BMI, WHtR, or FMI z-score. A lack of association between an obesogenic diet and BMI in longitudinal studies has been reported previously [38, 44] and may reflect the limited value of using BMI to assess body composition or fat distribution; this can result in misclassification, especially during adolescence, when body composition changes rapidly. Other adiposity markers such as WC, WHtR, or FMI might be more appropriate at this stage of life, and abdominal fat accumulation in particular appears have a stronger independent impact on cardiometabolic profile during adolescence and could be included in routine clinical practice [85]. Surprisingly, however, we did not detect a specific association between FMI z-scores and the obesogenic DP, contrary to a prospective study that found a positive association between DP scores in 10-year-old children and subsequent FMI z-scores obtained when the children were 11, 13, and 15 years old [86]. Our less conclusive findings may reflect differences in methodological design, such as the use of DP trajectories over the course of adolescence or the slightly older age of our sample, in line with reports that childhood diet is more strongly associated with later adiposity than diet during adolescence [44, 86]. This suggests that diet might not be the primary driver of excess adiposity in adolescence, and that other lifestyle components, such as physical activity and sleep, should be considered. Moreover, although the trajectory 1 group, with the lowest adherence to the obesogenic DP, was considered the reference group, this does not imply that individuals in this group followed an optimal diet.

Table 2 Energy-adjusted* daily intake and DQI-A differences between 4-year follow-up and baseline

Food Group (g/day)	Trajectory†			
	1	2	3	4
High-fat milk and cream	−37.0 (−68.3 to −5.8)	−32.8 (−48.3 to −17.3)	−3.0 (−14.9 to 8.9)	−23.7 (−46.4 to −1.1)
Low-fat milk	−1.9 (−40.5 to 36.6)	8.2 (−11.0 to 27.4)	6.1 (−8.6 to 20.9)	−1.1 (−29.1 to 26.9)
Yogurts	−26.0 (−47.6 to −4.3)	−4.8 (−15.4 to 5.9)	−8.9 (−17.1 to −0.7)	−26.1 (−41.6 to −10.6)
Cheese	−0.7 (−9.0 to 7.6)	1.4 (−2.8 to 5.5)	2.0 (−1.1 to 5.2)	6.1 (0.1 to 12.1)
Butter and animal fat	−0.3 (−0.9 to 0.2)	−0.2 (−0.5 to 0.0)	−0.2 (−0.4 to −0.0)	0.3 (−0.1 to 0.7)
Margarine and vegetable oils	−1.1 (−4.5 to 2.3)	−0.2 (−2.0 to 1.6)	2.7 (1.2 to 4.1)	7.8 (5.2 to 10.3)
Eggs and egg dishes	3.1 (−0.6 to 6.8)	2.7 (0.8 to 4.6)	1.5 (−0.0 to 2.9)	−1.4 (−4.1 to 1.3)
Low-fiber bread	−17.3 (−30.9 to −3.8)	−0.5 (−7.6 to 6.5)	−1.2 (−6.8 to 4.4)	−2.1 (−12.1 to 8.0)
High-fiber bread	14.5 (7.9 to 21.0)	4.5 (1.2 to 7.8)	1.7 (−0.9 to 4.3)	−1.2 (−5.9 to 3.5)
High-fiber breakfast cereals	2.7 (0.9 to 4.4)	0.7 (−0.2 to 1.5)	0.1 (−0.6 to 0.7)	0.4 (−0.8 to 1.7)
Other breakfast cereals	−2.9 (−5.8 to −0.0)	−1.5 (−3.0 to −0.1)	−1.3 (−2.4 to −0.1)	−4.3 (−6.4 to −2.3)
Rice, pasta, and other grains	−2.1 (−9.5 to 5.3)	2.6 (−2.5 to 7.7)	−0.3 (−5.1 to 4.4)	−1.9 (−8.0 to 4.2)
Pizza	0.8 (−4.2 to 5.8)	−0.3 (−2.8 to 2.1)	2.2 (0.3 to 4.1)	0.7 (−2.9 to 4.3)
Biscuits and cakes	−12.6 (−19.7 to −5.5)	−5.9 (−9.5 to −2.4)	0.2 (−2.5 to 2.9)	6.4 (1.2 to 11.6)
Puddings	−5.7 (−9.9 to −1.6)	−4.9 (−7.1 to −2.8)	−4.1 (−5.8 to −2.4)	−3.3 (−6.3 to −0.2)
Ice creams	−2.4 (−5.5 to 0.7)	−4.4 (−5.9 to −2.8)	−3.0 (−4.2 to −1.8)	−4.5 (−6.7 to −2.2)
Chocolate and confectionery	1.5 (−0.9 to 4.0)	−1.4 (−2.6 to −0.1)	0.4 (−0.5 to 1.4)	−1.1 (−2.9 to 0.7)
Sugar-free confectionery	0.0 (−0.0 to 0.1)	−0.0 (−0.0 to 0.0)	0.0 (−0.0 to 0.0)	−0.0 (−0.1 to 0.0)
Spreads	0.2 (−0.7 to 1.0)	0.0 (−0.4 to 0.4)	−0.3 (−0.6 to 0.0)	−0.4 (−1.1 to 0.2)
Meat and poultry	−12.0 (−29.6 to 5.7)	−7.2 (−16.6 to 2.1)	−4.9 (−12.4 to 2.6)	0.4 (−12.6 to 13.4)
Meat mixed dishes	−4.0 (−8.1 to 0.1)	−3.3 (−5.8 to −0.8)	−0.7 (−2.8 to 1.5)	0.7 (−2.5 to 3.9)
Processed meat	−10.6 (−16.6 to −4.6)	−6.4 (−9.4 to −3.4)	−2.1 (−4.3 to 0.2)	−2.0 (−6.4 to 2.3)
Fish	5.0 (−6.8 to 16.9)	5.9 (0.0 to 11.9)	−3.4 (−7.9 to 1.1)	−8.4 (−17.1 to 0.3)
Fried or roast potatoes	−6.2 (−12.1 to −0.2)	−3.4 (−6.3 to −0.4)	2.6 (0.4 to 4.9)	3.4 (−1.0 to 7.9)
Boiled or baked potatoes	−2.5 (−8.1 to 3.0)	−0.6 (−4.2 to 3.0)	−3.0 (−6.2 to 0.2)	−6.3 (−10.7 to −1.8)
Vegetables (raw or boiled)	120.5 (91.3 to 149.7)	47.7 (33.3 to 62.0)	−9.8 (−20.6 to 1.1)	−39.6 (−60.7 to −18.6)
Legumes	29.2 (18.9 to 39.5)	15.0 (9.3 to 20.7)	−0.2 (−5.0 to 4.6)	−12.9 (−20.6 to −5.2)
Fresh fruits	309.1 (242.0 to 376.2)	87.0 (34.9 to 139.1)	−14.7 (−64.3 to 34.9)	−82.5 (−140.9 to −24.0)
Other fruit	−2.5 (−6.1 to 1.2)	1.3 (−0.6 to 3.1)	−1.6 (−3.0 to −0.2)	−1.2 (−3.8 to 1.5)
Nuts and seeds	5.4 (1.2 to 9.7)	4.1 (1.9 to 6.3)	1.2 (−0.5 to 3.0)	1.9 (−1.2 to 5.0)
Crisps and savory snacks	−2.0 (−4.3 to 0.2)	−1.5 (−2.6 to −0.4)	−0.2 (−1.1 to 0.6)	1.6 (0.0 to 3.2)
Soups	4.5 (−0.4 to 9.4)	1.7 (−1.7 to 5.1)	1.7 (−1.5 to 4.8)	−0.8 (−4.9 to 3.2)
Sauces (low energy dense)	−0.6 (−1.7 to 0.6)	−0.2 (−0.8 to 0.4)	0.5 (0.0 to 0.9)	0.1 (−0.7 to 1.0)
Sauces (high energy dense)	−0.1 (−1.2 to 1.0)	0.2 (−0.3 to 0.8)	0.2 (−0.2 to 0.7)	0.6 (−0.2 to 1.3)
Condiments	1.1 (0.2 to 2.1)	0.8 (0.3 to 1.3)	0.7 (0.3 to 1.1)	0.6 (−0.1 to 1.3)
Sugar-sweetened beverages	−38.9 (−64.9 to −12.9)	−32.1 (−45.9 to −18.4)	−6.8 (−17.8 to 4.2)	14.8 (−4.3 to 33.9)
Low-energy beverages	−3.9 (−14.7 to 6.8)	5.5 (−0.3 to 11.2)	3.7 (−1.0 to 8.5)	−3.8 (−11.9 to 4.2)
Fruit juice	38.6 (19.6 to 57.5)	0.4 (−9.2 to 10.0)	−8.2 (−15.7 to −0.7)	−15.4 (−29.3 to −1.6)
Hot and powdered drinks	68.6 (34.8 to 102.5)	27.7 (6.1 to 49.4)	11.2 (−8.2 to 30.5)	−1.1 (−28.1 to 25.9)
Water	201.9 (75.9 to 328.0)	93.9 (31.2 to 156.6)	44.3 (−3.8 to 92.5)	58.1 (−33.6 to 149.8)
DQI-A	5.5 (2.8 to 8.2)	3.9 (2.3 to 5.5)	0.4 (−0.9 to 1.8)	−2.2 (−4.3 to −0.0)

Multilevel linear mixed models were used to determine the adjusted marginal means and 95% confidence interval values. Fixed effects were the trajectory group, age, gender, randomization group, parental educational level, migrant background, moderate-to-vigorous physical activity, sleep time, smoking and sexual maturity status, and each food group consumption/DQI-A at baseline. Region (Madrid or Barcelona) and schools within each region were handled as random effects. *Scaled to a 2000-kcal/day diet. †Trajectories are ordered from lowest (1) to highest (4) adherence to the obesogenic dietary pattern over the course of the study. DQI-A, Diet Quality Index for Adolescents

Study limitations and strengths

There are some limitations that warrant consideration. Given the observational nature of the study, the possibility of residual confounding including reverse causality cannot be excluded. Further research applying more robust designs, such as randomized controlled trials, are needed to fully support causality. The schools and their participants were selected with a non-probabilistic sampling method; although the findings of this article are similar to published studies, it should be taken into account that the population analyzed might not be representative of the whole adolescent population in Spain, and even less so of countries with different DPs. Therefore, the results presented cannot be extrapolated directly to adolescents from other regions with different food environments.

No dietary assessment method can provide a completely accurate assessment of usual dietary intake; in this case, dietary intake was assessed with an FFQ completed by caregivers. Although FFQ can be more vulnerable to imprecisions and misreporting by participants than other methods such as the 24-h recall or dietary records, the FFQ is inexpensive and can be easily administrated [87]. Of note, the FFQ is one the most commonly used tools to rank participants according to their overall DPs in epidemiological studies, providing a better estimation of the long-term dietary exposures in relation to health outcomes [88, 89]. In this line, obesogenic DPs applying RRR derived from food records [90] showed similar results in adolescents to those reported here. Another limitation of the study is that alcohol consumption was not included to derive the obesogenic DP, despite its potential contribution to calorie intake. The main reason to do so is because the FFQ was proxy-reported by the caregivers and this information would have been highly biased. Given the proportion of missing data, another potential limitation is loss to FU bias, since adolescents with unhealthier DPs and adiposity markers more often drop out of prevention studies. However, there were no significant differences in adiposity markers among participants included vs excluded in this work (data not shown) and all statistical models were adjusted for relevant confounders including sociodemographic and lifestyle variables.

A major strength of the study is the longitudinal analysis of a large adolescent cohort at three assessment time points, tracking multiple food groups and adherence to an obesogenic DP during adolescence. Indeed, this is one of the first studies to track a DP by RRR and LCGM over the course of adolescence. Other strengths include the objective measurement of fat mass, weight, height, and WC at all time points by trained staff; identical data collection at all three time points; and the inclusion of a plethora of variables related to adolescents' socioeconomic status and health behaviors, such as physical activity and sleep duration measured by accelerometry.

Conclusions

Four distinct stable trajectory groups were identified in this cohort of adolescents based on adherence to an obesogenic DP. Over the study period, individuals in the group with the lowest adherence (trajectory 1) increased their overall diet quality and their consumption of healthy choices and decreased their consumption of unhealthy foods. In contrast, the group with the highest adherence to the obesogenic DP (trajectory 4) showed the opposite trend. Trajectory 4 was also associated with the least healthy central adiposity profile measured when the study participants were ~16 years old. Further research is needed to explore the determinants of adherence to obesogenic DPs in adolescence and to evaluate their effects on adiposity and health later in life. Additionally, continued research and monitoring of policies or educational interventions will contribute to the development of effective strategies that can positively impact in shifting unhealthy dietary trajectories.

Abbreviations

BMI	Body mass index
DED	Dietary energy density
DP	Dietary pattern
DQI-A	Diet Quality Index for Adolescents
FD	Fiber density
FMI	Fat mass index
FFQ	Food frequency questionnaire
FU	Follow-up
ISCED	International Standard Classification of Education
LCGM	Latent class growth modeling
MVPA	Moderate-to-vigorous physical activity
RRR	Reduced rank regression
SD	Standard deviation
SI!	*Salud Integral* (Comprehensive Health)
WC	Waist circumference
WtHR	Waist-to-height ratio

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12937-025-01102-y.

Supplementary Material 1. Table S1. The STrengthening the Reporting of OBservational studies in Epidemiology (STROBE)-nut: An extension of the STROBE statement for nutritional epidemiology. Table S2. Food groups and their contents used to derive the obesogenic dietary pattern. Table S3. Categorization of the food groups used to derive the Dietary Quality Index for Adolescents (DQI-A). Table S4a. Daily food intake at baseline stratified by trajectory of adherence to the obesogenic dietary pattern. Table S4b. Daily food intake at 2-year follow-up stratified by trajectory of adherence to the obesogenic dietary pattern. Table S4c. Daily food intake at 4-year follow-up stratified by trajectory of adherence to the obesogenic dietary pattern. Table S5a. Energy-adjusted* daily intake and DQI-A differences between 2-year follow-up and baseline. Table S5b. Energy-adjusted* daily intake and DQI-A differences between 4-year follow-up and 2-year follow-up.

Acknowledgements
The authors thank the SHE Foundation (intellectual owner of the SI! Program) and its partners, especially Isabel Carvajal, Vanesa Carral, Xavier Orrit, Carla Rodríguez, and Domènec Haro for their contribution to the study design and the coordination, development, and implementation of the educational program and all personnel who performed measurements in adolescents at participating schools. The authors are indebted to the adolescents, parents/caregivers and other family members, and school staff for their indispensable participation in the study. The authors also thank the teachers who delivered the educational intervention, the school and educational directors for coordinating this initiative, all volunteers who contributed to the study, and Simon Bartlett (CNIC) for English editing. Finally, J.M.-G. wishes to dedicate his third paper as first author to his Martens, for learning together of nutrition since adolescence.

Authors' contributions
R.F.-J drafted the overall SI! Program for Secondary Schools trial design. J.M.-G., P.B., G.S.-B., A.d.C.-G., J.M.F.-A., A.T.-R., A.M.R.-L., M.d.M., R.E., and R.M.L.-R. coordinated the recruitment of schools and participants, consent process, and/or data collection. M.d.M coordinated the development and implementation of the educational intervention program. J.M.-G., and P.B. conducted statistical analyses and drafted the first version of the manuscript. J.M.-G., P.B., and M.B.D. designed and provided tables and figure visualizations. J.M.-G., A.d.C.-G., and M.B.D. directly accessed and verified the underlying data reported in the manuscript. J.M.F.-A. and R.F.-J. provided scientific support over the course of the study. All authors revised the manuscript critically for intellectual content and approved the published version.

Funding
The SI! Program for Secondary School trial was funded by the *Fundació la Marató de TV3* (grant number 369/C/2016); 'la Caixa' Foundation (grant number LCF/PR/CE16/10700001); the *Ministerio de Ciencia e Innovación* (grant number AGL2016–75329-R); the *Generalitat de Catalunya* (2021-SGR-00334); and the SHE Foundation. J.M-G is a recipient of grant FPU21/04891 (*Ayudas para la formación de profesorado universitario*, FPU-2021) from the *Ministerio de Educación, Cultura y Deporte*. AT-R is a Serra Húnter fellow. RF-J is recipient of grant PI22/01560 funded by the *Instituto de Salud Carlos III (ISCIII)-Fondo de Investigación Sanitaria* and co-funded by the European Union. The CNIC is supported by the ISCIII, the *Ministerio de Ciencia, Innovación y Universidades,* and the Pro CNIC Foundation, and is a Severo Ochoa Center of Excellence (grant CEX2020-001041-S funded by MICIN/AEI/10.13039/501100011033). INSA-UB is a María de Maeztu Center of Excellence (grant CEX2021-001234-M funded by MICIN/AEI/FEDER, UE).

Data availability
Data availability to external researchers is restricted to related project proposals upon request to the corresponding author. Based on these premises, deidentified participant data will be available with publication after approval of the proposal by the Steering committee and a signed data sharing agreement.

Declarations

Ethics approval and consent to participate
The study was approved by the Committee for Ethical Research (CEI) of the Instituto de Salud Carlos III in Madrid (CEI PI 35_2016) and by the CEI of the Fundació Unió Catalana d'Hospitals in Barcelona (CEI 16/41) and the University of Barcelona Bioethics Committee (IRB00003099). All participants gave informed consent prior to their inclusion in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Centro Nacional de Investigaciones Cardiovasculares (CNIC), 28029 Madrid, Spain. [2]Foundation for Science, Health, and Education (SHE), 08008 Barcelona, Spain. [3]Fisiopatología de La Obesidad y Nutrición (CIBERObn), Consorcio CIBER, Instituto de Salud Carlos III (ISCIII), 28029 Madrid, Spain. [4]Polyphenol Research Group, Department of Nutrition, Food Science and Gastronomy, School of Pharmacy and Food Sciences, 08028 Barcelona, Spain. [5]Department of Internal Medicine, Institut d'Investigacions Biomèdiques August Pi I Sunyer (IDIBAPS), Hospital Clínic, University of Barcelona, 08036 Barcelona, Spain. [6]University of Barcelona, 08921 Santa Coloma de Gramenet, Spain. [7]GENUD (Growth, Exercise, Nutrition, and Development) Research Group, Faculty of Health Sciences, Instituto Investigación Sanitaria de Aragón (IIS Aragón), Instituto Agroalimentario de Aragón (IA2), University of Zaragoza, 50009 Zaragoza, Spain. [8]Department of Cardiology, Hospital Universitario Clínico San Carlos - IdISSC, 28040 Madrid, Spain. [9]Centro de Investigación Biomédica En Red en Enfermedades CardioVasculares (CIBERCV), 28029 Madrid, Spain.

Received: 6 September 2024 Accepted: 21 February 2025
Published online: 07 March 2025

References
1. Collaborators GBDD. Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet. 2019;393(10184):1958–72.
2. Vassiliou VS, Tsampasian V, Abreu A, Kurpas D, Cavarretta E, O'Flaherty M, et al. Promotion of healthy nutrition in primary and secondary cardiovascular disease prevention: a clinical consensus statement from the European Association of Preventive Cardiology. Eur J Prev Cardiol. 2023;30(8):696–706.
3. Baker P, Machado P, Santos T, Sievert K, Backholer K, Hadjikakou M, et al. Ultra-processed foods and the nutrition transition: Global, regional and national trends, food systems transformations and political economy drivers. Obes Rev. 2020;21(12): e13126.
4. Popkin BM, Adair LS, Ng SW. Global nutrition transition and the pandemic of obesity in developing countries. Nutr Rev. 2012;70(1):3–21.
5. Collaboration NCDRF. Worldwide trends in underweight and obesity from 1990 to 2022: a pooled analysis of 3663 population-representative studies with 222 million children, adolescents, and adults. Lancet. 2024.
6. Kant AK. Dietary patterns and health outcomes. J Am Diet Assoc. 2004;104(4):615–35.
7. Dahm CC, Chomistek AK, Jakobsen MU, Mukamal KJ, Eliassen AH, Sesso HD, et al. Adolescent Diet Quality and Cardiovascular Disease Risk Factors and Incident Cardiovascular Disease in Middle-Aged Women. J Am Heart Assoc. 2016;5(12).
8. Kaikkonen JE, Mikkilä V, Magnussen CG, Juonala M, Viikari JS, Raitakari OT. Does childhood nutrition influence adult cardiovascular disease risk?–insights from the Young Finns Study. Ann Med. 2013;45(2):120–8.
9. Appannah G, Pot GK, Oddy WH, Jebb SA, Ambrosini GL. Determinants of a dietary pattern linked with greater metabolic risk and its tracking during adolescence. J Hum Nutr Diet. 2018;31(2):218–27.
10. Pinto A, Pauze E, Mutata R, Roy-Gagnon MH, Potvin Kent M. Food and Beverage Advertising to Children and Adolescents on Television: A Baseline Study. Int J Environ Res Public Health. 2020;17(6).
11. Signal LN, Stanley J, Smith M, Barr MB, Chambers TJ, Zhou J, et al. Children's everyday exposure to food marketing: an objective analysis using wearable cameras. Int J Behav Nutr Phys Act. 2017;14(1):137.
12. Neves MEA, Souza MR, Gorgulho BM, Cunha DB, Muraro AP, Rodrigues PRM. Association of dietary patterns with blood pressure and body adiposity in adolescents: a systematic review. Eur J Clin Nutr. 2021;75(10):1440–53.
13. Schneider BC, Dumith SC, Orlandi SP, Assuncao MCF. Diet and body fat in adolescence and early adulthood: a systematic review of longitudinal studies. Cien Saude Colet. 2017;22(5):1539–52.
14. Santos-Beneit G, Fernández-Alvira JM, Tesserra-Rimbau A, Bodega P, de Cos-Gandoy A, de Miguel M, et al. School-based cardiovascular health promotion in adolescents: a cluster randomized clinical trial. JAMA cardiology. 2023;8(9):816–24.

15. Fernandez-Jimenez R, Santos-Beneit G, Tresserra-Rimbau A, Bodega P, de Miguel M, de Cos-Gandoy A, et al. Rationale and design of the school-based SI! Program to face obesity and promote health among Spanish adolescents: A cluster-randomized controlled trial. Am Heart J. 2019;215:27–40.
16. Fernandez-Ballart JD, Pinol JL, Zazpe I, Corella D, Carrasco P, Toledo E, et al. Relative validity of a semi-quantitative food-frequency questionnaire in an elderly Mediterranean population of Spain. Br J Nutr. 2010;103(12):1808–16.
17. Willett W. Nutritional Epidemiology: Oxford University Press; 2012 24 Jan 2013.
18. Huybrechts I, Lioret S, Mouratidou T, Gunter MJ, Manios Y, Kersting M, et al. Using reduced rank regression methods to identify dietary patterns associated with obesity: a cross-country study among European and Australian adolescents. Br J Nutr. 2017;117(2):295–305.
19. Johnson L, Mander AP, Jones LR, Emmett PM, Jebb SA. Energy-dense, low-fiber, high-fat dietary pattern is associated with increased fatness in childhood. Am J Clin Nutr. 2008;87(4):846–54.
20. Vyncke K, Cruz Fernandez E, Fajo-Pascual M, Cuenca-Garcia M, De Keyzer W, Gonzalez-Gross M, et al. Validation of the Diet Quality Index for Adolescents by comparison with biomarkers, nutrient and food intakes: the HELENA study. Br J Nutr. 2013;109(11):2067–78.
21. Iglesia I, Intemann T, De Miguel-Etayo P, Pala V, Hebestreit A, Wolters M, et al. Dairy Consumption at Snack Meal Occasions and the Overall Quality of Diet during Childhood. Prospective and Cross-Sectional Analyses from the IDEFICS/I.Family Cohort. Nutrients. 2020;12(3).
22. Huybrechts I, Vereecken C, De Bacquer D, Vandevijvere S, Van Oyen H, Maes L, et al. Reproducibility and validity of a diet quality index for children assessed using a FFQ. Br J Nutr. 2010;104(1):135–44.
23. Hernández JM, Hurtado MC, Pons RG, Fandos EG, García EL, Vinuesa JM. Report of the Scientific Committee of the Spanish Agency for Food Safety and Nutrition (AESAN) on the review and update of Dietary Recommendations for the Spanish population. Report of the Scientific Committee of the Spanish Agency for Food Safety and Nutrition (AESAN) on the review and update of Dietary Recommendations for the Spanish population. 2020;32.
24. Kuczmarski RJ, Ogden CL, Guo SS, Grummer-Strawn LM, Flegal KM, Mei Z, et al. 2000 CDC Growth Charts for the United States: methods and development. Vital Health Stat 11. 2002(246):1–190.
25. Sharma AK, Metzger DL, Daymont C, Hadjiyannakis S, Rodd CJ. LMS tables for waist-circumference and waist-height ratio Z-scores in children aged 5–19 y in NHANES III: association with cardio-metabolic risks. Pediatr Res. 2015;78(6):723–9.
26. Martinez-Gomez J, Fernandez-Alvira JM, de Cos-Gandoy A, Bodega P, de Miguel M, Tresserra-Rimbau A, et al. Sleep duration and its association with adiposity markers in adolescence: a cross-sectional and longitudinal study. Eur J Prev Cardiol. 2023;30(12):1236–44.
27. Chandler JL, Brazendale K, Beets MW, Mealing BA. Classification of physical activity intensities using a wrist-worn accelerometer in 8–12-year-old children. Pediatr Obes. 2016;11(2):120–7.
28. Cole RJ, Kripke DF, Gruen W, Mullaney DJ, Gillin JC. Automatic sleep/wake identification from wrist activity. Sleep. 1992;15(5):461–9.
29. Kripke DF, Hahn EK, Grizas AP, Wadiak KH, Loving RT, Poceta JS, et al. Wrist actigraphic scoring for sleep laboratory patients: algorithm development. J Sleep Res. 2010;19(4):612–9.
30. Moreno C.R.P. RF, Jiménez-Iglesias A., García I. Health Behaviour in School Aged Children (HBSC-2010). In: Ministerio de Sanidad SSeI, (ed.). 2012.
31. Tanner JM, Whitehouse RH. Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. Arch Dis Child. 1976;51(3):170–9.
32. Statistics UIf. International standard classification of education: ISCED 2011. Int Stand Classif Educ(ISCED) 2011. 2012.
33. Zhao J, Li Z, Gao Q, Zhao H, Chen S, Huang L, et al. A review of statistical methods for dietary pattern analysis. Nutr J. 2021;20(1):37.
34. Nagin DS. Analyzing developmental trajectories: a semiparametric, group-based approach. Psychol Methods. 1999;4(2):139.
35. Jones BL, Nagin DS, Roeder K. A SAS procedure based on mixture models for estimating developmental trajectories. Sociological methods & research. 2001;29(3):374–93.
36. Martinez-Gomez J, de Cos-Gandoy A, Fernandez-Alvira JM, Bodega P, de Miguel M, Tresserra-Rimbau A, et al. Cardiovascular Health Trajectories in Adolescence and Their Association With Sociodemographic and Cardiometabolic Outcomes in Spain. J Adolesc Health. 2024.
37. Andruff H, Carraro N, Thompson A, Gaudreau P, Louvet B. Latent class growth modelling: a tutorial. Tutorials in quantitative methods for psychology. 2009;5(1):11–24.
38. Appannah G, Pot GK, Huang RC, Oddy WH, Beilin LJ, Mori TA, et al. Identification of a dietary pattern associated with greater cardiometabolic risk in adolescence. Nutr Metab Cardiovasc Dis. 2015;25(7):643–50.
39. Ritchie LD, Spector P, Stevens MJ, Schmidt MM, Schreiber GB, Striegel-Moore RH, et al. Dietary patterns in adolescence are related to adiposity in young adulthood in black and white females. J Nutr. 2007;137(2):399–406.
40. Ambrosini GL, Emmett PM, Northstone K, Jebb SA. Tracking a dietary pattern associated with increased adiposity in childhood and adolescence. Obesity (Silver Spring). 2014;22(2):458–65.
41. Cutler GJ, Flood A, Hannan P, Neumark-Sztainer D. Major patterns of dietary intake in adolescents and their stability over time. J Nutr. 2009;139(2):323–8.
42. Wang Y, Bentley ME, Zhai F, Popkin BM. Tracking of dietary intake patterns of Chinese from childhood to adolescence over a six-year follow-up period. J Nutr. 2002;132(3):430–8.
43. Christoph MJ, Larson NI, Winkler MR, Wall MM, Neumark-Sztainer D. Longitudinal trajectories and prevalence of meeting dietary guidelines during the transition from adolescence to young adulthood. Am J Clin Nutr. 2019;109(3):656–64.
44. Bull CJ, Northstone K. Childhood dietary patterns and cardiovascular risk factors in adolescence: results from the Avon Longitudinal Study of Parents and Children (ALSPAC) cohort. Public Health Nutr. 2016;19(18):3369–77.
45. Movassagh EZ, Baxter-Jones AD, Kontulainen S, Whiting SJ, Vatanparast H. Tracking dietary patterns over 20 years from childhood through adolescence into young adulthood: the Saskatchewan Pediatric Bone Mineral Accrual Study. Nutrients. 2017;9(9):990.
46. Tao Y, Wall M, Larson N, Neumark-Sztainer D, Winpenny EM. Changes in diet quality across life transitions from adolescence to early adulthood: a latent growth analysis. medRxiv. 2024.
47. Fernandez-Jimenez R, Santos-Beneit G, de Cos-Gandoy A, Fernandez-Alvira JM, Tresserra-Rimbau A, Storniolo C, et al. Prevalence and correlates of cardiovascular health among early adolescents enrolled in the SI! Program in Spain: a cross-sectional analysis. Eur J Prev Cardiol. 2020.
48. Grootens-Wiegers P, Hein IM, van den Broek JM, de Vries MC. Medical decision-making in children and adolescents: developmental and neuroscientific aspects. BMC Pediatr. 2017;17(1):120.
49. Organization WH. Global Accelerated Action for the Health of Adolescents (AA-HA!): guidance to support country implementation. 2017.
50. Machado SP, Bezerra IN, Silva MA, D'Oran MHL, Cunha DB, Moreno LA, et al. Evolution of adolescents' dietary patterns in Northeast Brazil from 2008 to 2018. Rev Saude Publica. 2024;58:05.
51. Nelson MC, Story M, Larson NI, Neumark-Sztainer D, Lytle LA. Emerging adulthood and college-aged youth: an overlooked age for weight-related behavior change. Obesity (Silver Spring). 2008;16(10):2205–11.
52. Hagan JF, Shaw J, Duncan P. Bright futures: American Academy of Pediatrics Itasca, IL; 2017.
53. Laska MN, Larson NI, Neumark-Sztainer D, Story M. Does involvement in food preparation track from adolescence to young adulthood and is it associated with better dietary quality? Findings from a 10-year longitudinal study. Public Health Nutr. 2012;15(7):1150–8.
54. Durão S, Wilkinson M, Davids EL, Gerritsen A, Kredo T. Effects of policies or interventions that influence the school food environment on children's health and nonhealth outcomes: a systematic review. Nutr Rev. 2024;82(3):332–60.
55. Rao M, Afshin A, Singh G, Mozaffarian D. Do healthier foods and diet patterns cost more than less healthy options? A systematic review and meta-analysis. BMJ Open. 2013;3(12): e004277.
56. Moosavian SP, Haghighatdoost F. Dietary energy density and appetite: A systematic review and meta-analysis of clinical trials. Nutrition. 2020;69: 110551.
57. Izadi V, Haghighatdoost F, Moosavian P, Azadbakht L. Effect of Low-Energy-Dense Diet Rich in Multiple Functional Foods on Weight-Loss Maintenance, Inflammation, and Cardiovascular Risk Factors: A Randomized Controlled Trial. J Am Coll Nutr. 2018;37(5):399–405.

58. Mercader-Yus E, Neipp-Lopez MC, Gomez-Mendez P, Vargas-Torcal F, Gelves-Ospina M, Puerta-Morales L, et al. Anxiety, Self-esteem and Body Image in Girls with Precocious Puberty. Rev Colomb Psiquiatr (Engl Ed). 2018;47(4):229–36.
59. Bodega P, de Cos-Gandoy A, Fernandez-Alvira JM, Fernandez-Jimenez R, Moreno LA, Santos-Beneit G. Body image and dietary habits in adolescents: a systematic review. Nutr Rev. 2023;82(1):104–27.
60. Finne E, Schlattmann M, Kolip P. Gender role orientation and body satisfaction during adolescence - Cross-sectional results of the 2017/18 HBSC study. J Health Monit. 2020;5(3):37–52.
61. Lloyd-Jones DM, Allen NB, Anderson CAM, Black T, Brewer LC, Foraker RE, et al. Life's Essential 8: Updating and Enhancing the American Heart Association's Construct of Cardiovascular Health: A Presidential Advisory From the American Heart Association. Circulation. 2022;146(5):e18–43.
62. Duarte LS, Palombo CNT, Solis-Cordero K, Kurihayashi AY, Steen M, Borges ALV, et al. The association between body weight dissatisfaction with unhealthy eating behaviors and lack of physical activity in adolescents: A systematic review. J Child Health Care. 2021;25(1):44–68.
63. Shriver LH, Dollar JM, Calkins SD, Keane SP, Shanahan L, Wideman L. Emotional Eating in Adolescence: Effects of Emotion Regulation, Weight Status and Negative Body Image. Nutrients. 2021;13(1):79.
64. He ZH, Li MD, Liu CJ, Ma XY. Relationship between body image, anxiety, food-specific inhibitory control, and emotional eating in young women with abdominal obesity: a comparative cross-sectional study. Arch Public Health. 2021;79(1):11.
65. Moosavi-Movahedi F, Yousefi R. Good Sleep as an Important Pillar for a Healthy Life. In: Moosavi-Movahedi AA, editor. Rationality and Scientific Lifestyle for Health. Cham: Springer International Publishing; 2021. p. 167–95.
66. Chaput JP, McHill AW, Cox RC, Broussard JL, Dutil C, da Costa BGG, et al. The role of insufficient sleep and circadian misalignment in obesity. Nat Rev Endocrinol. 2023;19(2):82–97.
67. Duraccio KM, Whitacre C, Krietsch KN, Zhang N, Summer S, Price M, et al. Losing sleep by staying up late leads adolescents to consume more carbohydrates and a higher glycemic load. Sleep. 2022;45(3).
68. Hart CN, Spaeth AM, Egleston BL, Carskadon MA, Raynor HA, Jelalian E, et al. Effect of changes in children's bedtime and sleep period on targeted eating behaviors and timing of caloric intake. Eat Behav. 2022;45: 101629.
69. Fisk CM, Crozier SR, Inskip HM, Godfrey KM, Cooper C, Robinson SM. Influences on the quality of young children's diets: the importance of maternal food choices. Br J Nutr. 2011;105(2):287–96.
70. da Costa MP, Severo M, Araújo J, Vilela S. Longitudinal tracking of diet quality from childhood to adolescence: The Interplay of individual and sociodemographic factors. Appetite. 2024;196: 107279.
71. Börnhorst C, Wijnhoven TMA, Kunešová M, Yngve A, Rito AI, Lissner L, et al. WHO European Childhood Obesity Surveillance Initiative: associations between sleep duration, screen time and food consumption frequencies. BMC Public Health. 2015;15(1):442.
72. Kelly B, Freeman B, King L, Chapman K, Baur LA, Gill T. Television advertising, not viewing, is associated with negative dietary patterns in children. Pediatr Obes. 2016;11(2):158–60.
73. Imamura F, Micha R, Khatibzadeh S, Fahimi S, Shi P, Powles J, et al. Dietary quality among men and women in 187 countries in 1990 and 2010: a systematic assessment. Lancet Glob Health. 2015;3(3):e132–42.
74. Egele VS, Stark R. Specific health beliefs mediate sex differences in food choice. Front Nutr. 2023;10:1159809.
75. Deslippe AL, Bergeron C, Cohen TR. Boys and girls differ in their rationale behind eating: a systematic review of intrinsic and extrinsic motivations in dietary habits across countries. Front Nutr. 2023;10:1256189.
76. Stea TH, Holvik K, Bryntesen CS, Myhre JB. Changes in food habits amongst Norwegian adolescents in 2016 and 2019 according to gender and socioeconomic status. Food & Nutrition Research. 2021;65.
77. Northstone K, Smith AD, Cribb VL, Emmett PM. Dietary patterns in UK adolescents obtained from a dual-source FFQ and their associations with socio-economic position, nutrient intake and modes of eating. Public Health Nutr. 2014;17(7):1476–85.
78. Beghin L, Dauchet L, De Vriendt T, Cuenca-Garcia M, Manios Y, Toti E, et al. Influence of parental socio-economic status on diet quality of European adolescents: results from the HELENA study. Br J Nutr. 2014;111(7):1303–12.
79. Yau A, Adams J, White M, Nicolaou M. Differences in diet quality and socioeconomic patterning of diet quality across ethnic groups: cross-sectional data from the HELIUS Dietary Patterns study. Eur J Clin Nutr. 2020;74(3):387–96.
80. Cutler GJ, Flood A, Hannan PJ, Slavin JL, Neumark-Sztainer D. Association between major patterns of dietary intake and weight status in adolescents. Br J Nutr. 2012;108(2):349–56.
81. Bodega P, Fernandez-Alvira JM, Santos-Beneit G, de Cos-Gandoy A, Fernandez-Jimenez R, Moreno LA, et al. Dietary Patterns and Cardiovascular Risk Factors in Spanish Adolescents: A Cross-Sectional Analysis of the SI! Program for Health Promotion in Secondary Schools. Nutrients. 2019;11(10).
82. Bel-Serrat S, Julián-Almárcegui C, González-Gross M, Mouratidou T, Börnhorst C, Grammatikaki E, et al. Correlates of dietary energy misreporting among European adolescents: the Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) study. Br J Nutr. 2016;115(8):1439–52.
83. Lioret S, Touvier M, Balin M, Huybrechts I, Dubuisson C, Dufour A, et al. Characteristics of energy under-reporting in children and adolescents. Br J Nutr. 2011;105(11):1671–80.
84. Oellingrath IM, Svendsen MV, Brantsaeter AL. Tracking of eating patterns and overweight - a follow-up study of Norwegian schoolchildren from middle childhood to early adolescence. Nutr J. 2011;10:106.
85. Schröder H, Ribas L, Koebnick C, Funtikova A, Gomez SF, Fito M, et al. Prevalence of abdominal obesity in Spanish children and adolescents. Do we need waist circumference measurements in pediatric practice? PloS one. 2014;9(1):e87549.
86. Ambrosini GL, Emmett PM, Northstone K, Howe LD, Tilling K, Jebb SA. Identification of a dietary pattern prospectively associated with increased adiposity during childhood and adolescence. Int J Obes (Lond). 2012;36(10):1299–305.
87. Livingstone MB, Robson PJ, Wallace JM. Issues in dietary intake assessment of children and adolescents. Br J Nutr. 2004;92(Suppl 2):S213–22.
88. Cui Q, Xia Y, Wu Q, Chang Q, Niu K, Zhao Y. A meta-analysis of the reproducibility of food frequency questionnaires in nutritional epidemiological studies. Int J Behav Nutr Phys Act. 2021;18(1):12.
89. Shim JS, Oh K, Kim HC. Dietary assessment methods in epidemiologic studies. Epidemiol Health. 2014;36: e2014009.
90. Appannah G, Pot GK, O'Sullivan TA, Oddy WH, Jebb SA, Ambrosini GL. The reliability of an adolescent dietary pattern identified using reduced-rank regression: comparison of a FFQ and 3 d food record. Br J Nutr. 2014;112(4):609–15.

Publisher's Note