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Patterns of ultra-processed foods consumption throughout childhood and trajectories of growth and adiposity

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SUMMARY

Background & aims: Ultra-processed foods (UPF) consumption has been associated with unhealthy outcomes. However, the literature lacks robust longitudinal studies considering its cumulative effect, particularly in young populations. This study aimed to evaluate the relationship between UPF consumption patterns throughout childhood with growth and adiposity trajectories.
Methods: Generation XXI population-based birth cohort (Porto, Portugal) participants were included. Food frequency questionnaire items at 4, 7 and 10 years were classified according to the processing degree using NOVA. UPF consumption patterns based on total quantity were identified using a probabilistic Gaussian mixture model using participants with complete data and predicting for the total sample (n = 8647). To assess whether the outcome trajectories from 4 to 13 years [body weight (kg), height (cm), body mass index (BMI) z-score, waist circumference (WC) (cm) and fat mass (FM) (%)] depend on UPF patterns, a mixed-effects model with linear and quadratic terms for age adjusted for confounders was used. Participants with at least 2 measurements at 4, 7, 10 or 13 years were included in this study (n range: 5885–6272).
Results: Four UPF consumption patterns were identified: *constantly lower consumption* (15.4%), *constantly intermediate consumption* (56.4%), *transition from low to high consumption* (11.2%), and *constantly higher consumption* (17.1%). Compared to the *constantly lower UPF consumption*, the *constantly higher consumption* pattern was associated with greater acceleration in body weight (β: 0.119; 95%CI: 0.027; 0.212), BMI z-score (β: 0.014; 95%CI: 0.004; 0.023), WC (β: 0.232; 95%CI: 0.144; 0.319) and FM% (β: 0.200; 95%CI: 0.092; 0.308) and with lower acceleration in height (β: −0.063; 95%CI: −0.111;-0.015). The *constantly intermediate UPF consumption* pattern was associated with greater acceleration in body weight (β: 0.123; 95%CI: 0.043; 0.203), WC (β: 0.120; 95%CI: 0.045; 0.195) and FM% (β: 0.146; 95%CI: 0.054; 0.238).
Conclusion: Constantly higher and *constantly intermediate UPF consumption* throughout childhood were associated with worse growth and adiposity trajectories until adolescence.

1. Introduction

Ultra-processed foods (UPF) are novel formulations combining substances extracted from foods, often chemically transformed, with food additives [1]. UPF are consumed globally, with higher levels of consumption reported in the US and UK, and in children and adolescents [2]. In Portugal, national data on the consumption of UPF showed the highest values in children (414 g/d,

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corresponding to 22.3% of the total quantity and 36.8% of the total energy intake) and adolescents (490 g/d, corresponding to 21.6% of the total quantity and 34.8% of the total energy intake) [3].

UPF consumption has been associated with overweight and other cardiometabolic risk-related outcomes in adults [4,5] but also at early ages [6]. The mechanisms that link UPF consumption with obesity include their nutritional and non-nutritional composition, their addictive capabilities and their ability to interfere with appetite regulation, and alteration of the intestinal microbiota, among others [7]. Current evidence is still weak for children and adolescents compared to adults, and it remains to be understood the stage of life in which the negative effects of UPF consumption start to appear. Childhood is a period of great physiological transformations with high nutrition requirements for growth. During this period, unhealthy eating habits acquired can be very harmful to future health [8] namely high UPF consumption. Data from a recent systematic review in children and adolescents [9] suggested that a consistent intake of UPF over time is needed to impact the nutritional status and body composition of children and adolescents, pointing to the need for further well-designed prospective studies worldwide. The cumulative effect considering the quantity and evolution of UPF consumption on growth and adiposity has been sparsely researched [10]. Heterogenous age trajectories and time trends of height and body mass index (BMI) in late childhood and adolescence between countries were reported, hypothesizing different food consumption and food policies [11]. As such, it is important to identify UPF consumption patterns in different populations with different cultures and food production technologies in order to relate them to their respective growth and adiposity trajectories. The aim of the present study was to evaluate longitudinally the relationship between UPF consumption patterns throughout childhood with growth and adiposity trajectories from childhood to adolescence in a Portuguese birth cohort.

2. Methodology

2.1. Survey design and participants

Data from the population-based birth cohort Generation XXI (G21) were used, which details were published previously [12,13]. Briefly, between April 2005 and August 2006 mothers and their newborns were recruited from five level III maternity hospitals in the metropolitan area of Porto, Portugal. At that time, these maternity hospitals contributed 91.6% of deliveries to the eligible population. Mothers were invited to participate 24–72 h after delivery, of which 91% accepted, with the participation of 8495 mothers and 8647 children. Follow-up of the entire cohort was performed at 4y (participation: 86%), 7y (participation: 80%), 10y (participation: 75%) and 13y (participation: 54% - follow-up interrupted in March 2020 due to issues related to COVID-19 pandemic). The present analysis includes participants who provided complete information on dietary intake at the 4-, 7-, or 10-year follow-up assessment and at least 2 measurements of each outcome of interest from the 4-, 7-, 10-, or 13-year follow-up assessments.

G21 was approved by the University of Porto Medical School/S. João Hospital Centre Ethics Committee and the National Data Protection Authority. Following the Declaration of Helsinki, a written informed consent was obtained from all participants, signed by the legal representatives and by adolescents at the 13-year follow-up.

2.2. Data collection

At the baseline and at each follow-up evaluation, trained interviewers collected data using structured questionnaires that covered information on sociodemographic, clinical, and behavioral characteristics, in addition to objective anthropometric measurements and biochemical blood analysis.

2.2.1. Dietary variables

A food frequency questionnaire (FFQ) was developed to assess usual dietary intake and applied by an interviewer. Parents or less frequently another caregiver were asked how many times on average the child had consumed each food item in the previous 6 months. The nine frequency response options, ranged from "never" to "4 times or more per day" and were transformed into daily frequency. FFQs comprised 35, 38 and 41 food items at 4, 7 and 10 years, respectively and, were validated and calibrated using 3-day food diaries at 4 and 7 years, applying the formula: z-score = [(frequency from FFQ per item - mean of frequency from FFQ per item)/(standard deviation of grams from FFQ per item)-*(Standard deviation of grams from 3-day food diaries per item) + (mean of grams from 3-day food diaries per item)], as previously described in detail [14]. At the age of 10, the median absolute deviation was used instead of the standard deviation to avoid the influence of outliers with the exception of some items that showed a lack of variance because they were usually frequently consumed daily or almost every day by the majority of individuals as previously reported [15].

All reported items were classified according to the processing degree and its purpose using the NOVA classification [1,16]. NOVA is a food classification system based on the degree and purpose of food processing developed by researchers at the University of São Paulo, Brazil, which classifies all foods into four groups: 1) Unprocessed and minimally processed foods such as fresh fruit and vegetables, fresh meat and fish; 2) Processed culinary ingredients such as olive oil, butter, sugar; 3) Processed foods such as bread and cheese; and 4) UPF such as soft drinks, fast food, chocolates. Coding according to the degree and purpose of food processing was conducted independently by two researchers. Subsequently, both lists were verified by a third researcher who identified discrepant items, later discussed among all team, and classified by consensus. In case of doubtful classification, the experts opted for the most conservative classification, that is, the one with the lowest degree of processing within the options. As each FFQ item may include foods from different NOVA groups, classification was assumed based on the most consumed subtype in Portugal according to national data [17] [e.g. yogurts were classified in group 4 but the FFQ item also includes natural ones without sugar (group 1) and those with natural sweeteners (group 3)]. In the case of composite items, prepared at home, the main ingredient was assumed for classification (e.g. vegetable soup: despite salt and olive oil being used, the main foods are fresh vegetables, which is why it was placed in the NOVA group 1).

2.2.2. Growth and adiposity outcomes

Anthropometric measurements were performed with subjects in light clothing and barefoot, after 12 h of fasting, and under standard procedures. Body weight was measured to the nearest 0.1 kg using a digital scale (SECA, Columbia, USA), and height to the nearest centimetre using a wall stadiometer (SECA, Hamburg, Germany). Children and adolescents' BMI was classified according to age- and sex-specific BMI standard z-scores developed by WHO [18]. Waist circumference (WC) was ascertained as the midway between the lower limit of the rib cage and the iliac crest, to the nearest centimetre. Tetrapolar bioelectric impedance analysis was performed (Akern BIA 101 Anniversary, Florence, Italy). Fat-free mass (FFM) was determined by using the Schaefer et al. equation, and fat mass (FM) was derived accordingly [19].

2.2.3. Covariates

In the current study, sociodemographic variables included participant sex and age as well as maternal age and years of education at the 4-year follow-up assessment. The exact age of the participant at each evaluation was calculated by the difference between the evaluation date and the date of birth. The mother's pre-pregnancy BMI and birthweight were asked and collected respectively, at baseline. Children's physical activity was also collected at the 4-year follow-up assessment using a dichotomous question about the practice of scheduled and regular physical activity.

2.3. Statistical analysis

UPF consumption patterns were defined using model-based clustering based on the finite Gaussian mixture model [20], entering with the consumption of UPF (in grams) at 4, 7 and 10 years old. The model was applied to the 4203 participants with three assessments. To define the appropriate number of groups, the Bayesian Information Criterion (BIC) was used. As 79% of the total sample had information on at least one wave ($n_{1\ wave} = 1084$, $n_{2\ waves} = 1531$, $n_{3\ waves} = 4203$), UPF patterns were predicted for the remaining sample using naïve bayes model ($n = 8647$). Missing data were treated as at random.

Quartiles of UPF consumption found at 4 years of age (P25: 150 g, P50: 260 g, P75: 357 g) were applied to the other ages (7 and 10) as the agreement between the different combinations of clusters throughout the follow-ups was low, ranging between 23 and 30 % (supporting the use of patterns throughout as main exposure). For the outcomes [body weight, height, BMI z-score, WC and FM%], participants with at least 2 measurements at 4, 7, 10 or 13 years were included. Marginal means were used to generate the graphs of the trajectories.

To understand the effect of the different UPF consumption patterns on growth and adiposity trajectories, a mixed-effects model with linear and quadratic terms for age was applied. Interaction between age terms and consumption patterns were tested to assess if trajectories were different according to the UPF consumption patterns. Adjustments for confounders (defined a priori) were made in a stepwise manner: the first model was adjusted for sex, the second was also adjusted for birth weight, mother's pre-pregnancy BMI and mother's education; and the third model was further adjusted for the consumption of the remaining food groups according to processing level (un/minimally processed foods, processed culinary ingredients, processed foods). Since breastfeeding and physical activity did not change the results, we decided not to include them in the model to keep it as simple as possible.

A significance level of 0.05 was considered. Statistical analyses were carried out using R software [21] version 4.2.1 for *Windows*.

3. Results

The application of the model-based clustering based on the finite Gaussian mixture model to define patterns of UPF consumption resulted in six clusters. Nevertheless, considering that the solution with four, five and six clusters had similar BIC and the four clusters showed logic interpretation, this was considered as the final solution. The four UPF consumption patterns identified were *constantly lower UPF consumption* (15.4% of the sample) characterized by lower consumption in the three evaluations; *constantly intermediate UPF consumption* (56.4% of the sample) characterized by intermediate consumption in the three evaluations; *transition from low to high UPF consumption* (11.2% of the sample); and *constantly higher UPF consumption* (17.1% of the sample) characterized by higher consumption in the three evaluations (Fig. 1). The description of the consumption of all food groups of the NOVA

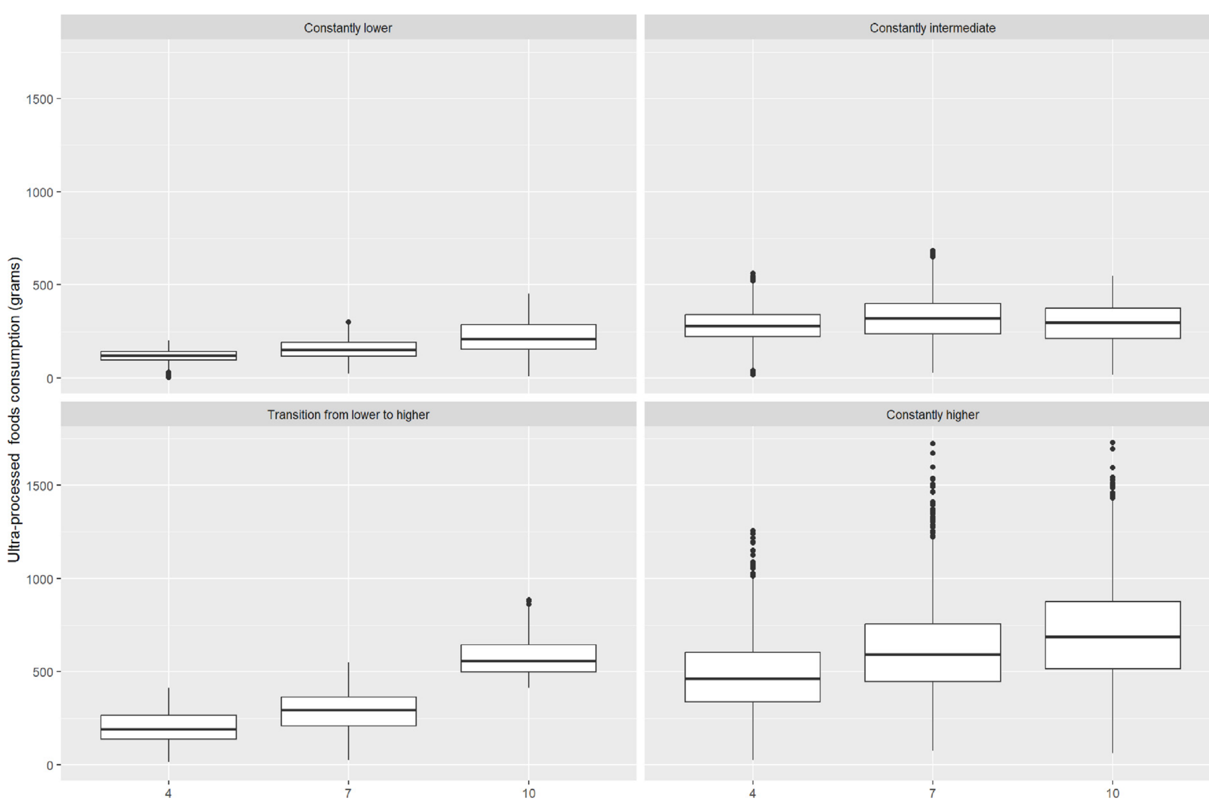

Fig. 1. Patterns of ultra-processed foods consumption through childhood among participants of the Generation XXI birth cohort.

classification by UPF consumption pattern can be found in Supplementary Table 1. Noteworthy is the mean contribution of UPF to the total weight of food consumed of 16.9% at 4 years old, 19.4% at 7 years old and 25.6% at 10 years old, in comparison with 26.1%, 30.3% and 38.1% respectively at the constant higher consumption pattern.

As shown in Table 1, the *constantly higher UPF consumption pattern* includes more girls (57%) and individuals whose mothers had fewer years of education (mean: 8.8). At the 4- and 7-year follow-up assessment, individuals belonging to this pattern had the highest mean body weight and height, but there were no statistically significant differences in BMI or WC, which became significant at 10 and 13 years. The percentage of fat mass was only statistically higher in this group at 13 years of age, along with the result observed in the *transition from low to high UPF consumption pattern*.

The association between UPF consumption patterns with growth and adiposity trajectories was studied. The first model included the adjustment for sex, represented graphically in Fig. 2 and presented in detail in Supplementary Table 2. The final results were interpreted according to the model 2 (Table 2), taking into account that the further adjustment for the consumption of the remaining groups of the NOVA classification (model 3) did not significantly change the results of model 2, in addition to the fact those variables may be exposure-related (Supplementary Table 3). Thus, interpreting the results of model 2 (Table 2), at the age of 4, body weight, BMI z-score and WC growth followed the same path regardless of the UPF consumption pattern, except in the case of FM %, in which individuals in the *constantly higher UPF consumption pattern* gained less 0.875% per year compared to the *constantly low UPF consumption pattern* (β: −0.875; 95%CI: −1.628;-0.121). These individuals also increased their height (cm/year) at a greater velocity, although no statistical significance was observed (β: 0.341; 95%CI: −0.010; 0.693). Over time, the reference UPF consumption pattern - the *constantly lower UPF consumption pattern* - had a positive acceleration in all indicators analysed. A superior acceleration in body weight gain (kg/year), from 4 to 13 years, was observed in the *constantly higher UPF consumption* pattern (β: 0.119; 95%CI: 0.027; 0.212) and in the *constantly intermediate UPF consumption pattern* (β: 0.123; 95%CI: 0.043; 0.203) when compared to the *constantly lower UPF consumption pattern*. A decrease in height acceleration (cm/year) was observed in the *constantly higher UPF consumption pattern* (β: −0.063; 95%CI: −0.111;-0.015), not observed for the other patterns. A positive association was found between the *constantly higher UPF consumption pattern* and the acceleration in the trajectory of BMI z-score (β: 0.014; 95%CI: 0.004; 0.023). Regarding the WC, individuals belonging to the *constantly higher UPF consumption pattern* and *constantly intermediate UPF consumption pattern*, increased faster (cm/year) than the reference (β: 0.232; 95%CI 0.144; 0.319 and β: 0.120; 95%CI: 0.045; 0.195, respectively). Also, for the percentage of FM, an additional increase in the acceleration was observed both in the *constantly higher UPF consumption pattern* (β: 0.200; 95%CI: 0.092; 0.308) and in a smaller magnitude in the *UPF constantly intermediate UPF consumption pattern* (β: 0.146; 95%CI: 0.054; 0.238) in relation to the reference. No significant differences were found in the acceleration of any indicator of growth and adiposity when comparing the pattern of *transition from low to high UPF consumption* with that of *constantly lower UPF consumption pattern.*

4. Discussion

The present study, using data from the G21 Portuguese birth cohort, was able to find an association between a persistent higher UPF consumption pattern throughout childhood and worse growth and adiposity trajectories. The *constantly intermediate UPF consumption* also presented negative results of similar or lesser magnitude for some indicators. This effect was possible to observe even in a population with lower UPF availability than the observed in other countries [22]. Interestingly, no pattern of decreasing consumption of UPF over time was found, which shows that these foods have a strong market position, probably due to their convenience and high palatability.

An important discussion of our results is that the *constantly intermediate UPF consumption pattern* appears to be more worrying than the *transition from low to high UPF consumption pattern*. This may be related to the duration of a high exposure as suggested by dose-response studies performed in adult populations [23]. To our knowledge, this is the first study evaluating the cumulative effect of UPF consumption using assessment data at different age points during childhood. Cross-sectional data from more than 3000 adolescents belonging to the NHANES study showed that the consumption of UPF increased the chances of total, abdominal and visceral overweight/obesity by 45%, 52% and 63% respectively. In addition, an increase of just 10% in the consumption of UPF is capable of increasing the risk of abdominal and visceral overweight/obesity in 7% [24]. Also, a study carried out in the ALSPAC birth cohort in the UK [10] showed greater increases in adiposity (BMI, FM index, weight, WC) from infancy to early adulthood in those who consumed more UPF. However, as described below, other studies have failed to show these relationships due to probable methodological constraints. A study of Brazilian adolescents aged approximately 16 years [25] found no relationship between UPF consumption and weight changes over 3 years. It should be noted that at the baseline there was an inverse relationship between the frequency of consumption of UPF and BMI, which the authors justify by excluding obese children, as they could be avoiding energy-rich foods to reduce weight, or the use of an FFQ that made it difficult to identify UPF. A systematic review based on cohort studies that has analyzed the effect of UPF intake showed mixed results in body fat in children and adolescents [6]. The aforementioned work also alerted to the importance of considering variables such as physical activity, which can be associated with lower body fat. The higher acceleration in FM% found among those in the *constantly higher UPF consumption pattern* may be related to the high energy density and free sugar content of these foods [26] and not to the lower practice of regular leisure physical activity in individuals belonging to this pattern, once physical activity was not found as confounder in our sample.

Our results that a high consumption of UPF throughout childhood accelerates weight gain, BMI, WC and fat mass, but also decreases height are worthy of discussion. The higher UPF consumption pattern throughout childhood was highlighted for its high consumption of soft drinks and lower consumption of yogurt and consequently a lower contribution of protein (data not presented). High-protein diets may completely impact children's height by boosting growth hormone levels, allowing children to grow taller and stay leaner [27]. Lower protein content in UPF when compared with both processed foods and unprocessed or minimally processed foods combined with processed culinary ingredients might be an explanation; and also their dietary contribution was associated with reduced relative protein content in the diet in the US [28]. The protein leverage hypothesis − in which protein leverage interacts with a reduction in dietary protein density to drive energy overconsumption and obesity - may explain the associations found in our study. In addition, a previous study showed an interaction between protein and glycemic index in the waist-to-height ratio, particularly in boys [29]. The high glycemic response caused by UPF [30] can also justify these negative relationships between UPF and health. However, this is a topic that

Table 1
Characterization of the Generation XXI birth cohort sample in general and by ultra-processed foods consumption patterns.

		n	Total sample	Constantly lower UPF consumption pattern (15.4%)	Constantly intermediate UPF consumption pattern (56.4%)	Transition from low to high UPF consumption pattern (11.2%)	Constantly higher UPF consumption pattern (17.1%)	p-value
Sex, n (%)	Male	4237	NA	736 (55.3)	2401 (49.3)	465 (48.1)	635 (43.0)	<0.001
	Female	4410	NA	594 (44.7)	2473 (50.7)	502 (51.9)	841 (57.0)	
Education (years), mean (sd)		8591	10.5 (4.3)	12.9 (4.3)	10.2 (4.2)	10.8 (4.1)	8.8 (3.5)	<0.001
Birth weight (g), mean (sd)		8646	3149 (538)	3124 (534)	3151 (547)	3142 (553)	3169 (501)	0.170
Mothers' pre-pregnancy BMI (kg/m2), mean (sd)		8348	23.9 (4.3)	23.7 (4.3)	23.9 (4.3)	23.9 (4.1)	24.0 (4.3)	0.260
Regular leisure physical activity, n (%)	No		2244 (30.4)	313 (24.2)	1092 (29.5)	280 (29.7)	559 (38.8)	<0.001
	Yes		5139 (69.6)	981 (75.8)	2613 (70.5)	662 (70.3)	883 (61.2)	
Body weight (kg), mean (sd)	4y FU	5943	18.2 (3.0)	17.9 (2.9)	18.2 (3.1)	18.0 (2.9)	18.4 (3.2)	<0.001
	7y FU	6626	26.7 (5.6)	26.1 (5.1)	27.2 (5.9)	26.1 (5.1)	26.5 (5.6)	<0.001
	10y FU	5371	37.7 (8.9)	36.9 (8.1)	38.0 (9.0)	37.4 (8.8)	38.1 (9.3)	0.002
	13y FU	4637	53.2 (11.6)	52.3 (10.8)	53.6 (11.8)	52.4 (10.6)	53.8 (12.7)	0.003
Height (cm), mean (sd)	4y FU	5934	105.3 (5.1)	104.7 (4.9)	105.4 (5.1)	105.2 (5.0)	105.9 (5.2)	<0.001
	7y FU	6472	124.2 (6.1)	123.6 (5.6)	124.8 (6.6)	123.8 (5.4)	123.9 (5.6)	<0.001
	10y FU	5367	141.1 (6.7)	140.8 (6.5)	141.2 (6.8)	141.2 (6.7)	141.1 (6.5)	0.340
	13y FU	4637	159.8 (7.6)	159.4 (7.4)	160.0 (7.7)	160.1 (7.5)	159.7 (8.0)	0.200
BMI (z-score), mean (sd)	4y FU	5934	0.61 (1.10)	0.58 (1.06)	0.64 (1.11)	0.57 (1.05)	0.62 (1.16)	0.230
	7y FU	5833	0.72 (1.20)	0.69 (1.16)	0.75 (1.21)	0.65 (1.15)	0.71 (1.24)	0.110
	10y FU	5368	0.70 (1.24)	0.61 (1.17)	0.74 (1.24)	0.66 (1.22)	0.75 (1.31)	0.010
	13y FU	4637	0.45 (1.19)	0.40 (1.12)	0.48 (1.21)	0.38 (1.11)	0.52 (1.25)	0.040
Waist circumference (cm), mean (sd)	4y FU	6009	53.5 (7.3)	53.4 (7.3)	53.6 (7.2)	53.1 (6.6)	53.7 (7.8)	0.340
	7y FU	5825	59.1 (6.9)	59.4 (7.1)	58.7 (6.6)	59.2 (7.1)	58.9 (6.7)	0.050
	10y FU	5372	67.5 (10.4)	66.5 (9.6)	67.7 (10.8)	67.2 (10.1)	68.3 (10.4)	<0.001
	13y FU	4627	74.3 (10.3)	73.5 (10.0)	74.4 (10.3)	73.6 (9.4)	75.2 (11.1)	<0.001
Fat mass (%), mean (sd)	4y FU	4960	16.6 (8.0)	17.0 (7.7)	16.7 (8.1)	16.2 (7.6)	16.4 (8.2)	0.150
	7y FU	5731	15.9 (8.5)	16.0 (8.4)	16.2 (8.5)	15.4 (8.0)	15.6 (8.6)	0.070
	10y FU	5335	21.0 (11.9)	20.3 (11.2)	21.3 (12.0)	20.8 (11.4)	21.4 (12.5)	0.110
	13y FU	4608	24.9 (11.9)	24.5 (11.7)	25.4 (11.9)	23.6 (11.7)	25.2 (12.2)	0.003

UPF: ultra-processed foods. BMI: body mass index. FU: follow-up. NA: Non-applicable. sd: standard deviation.

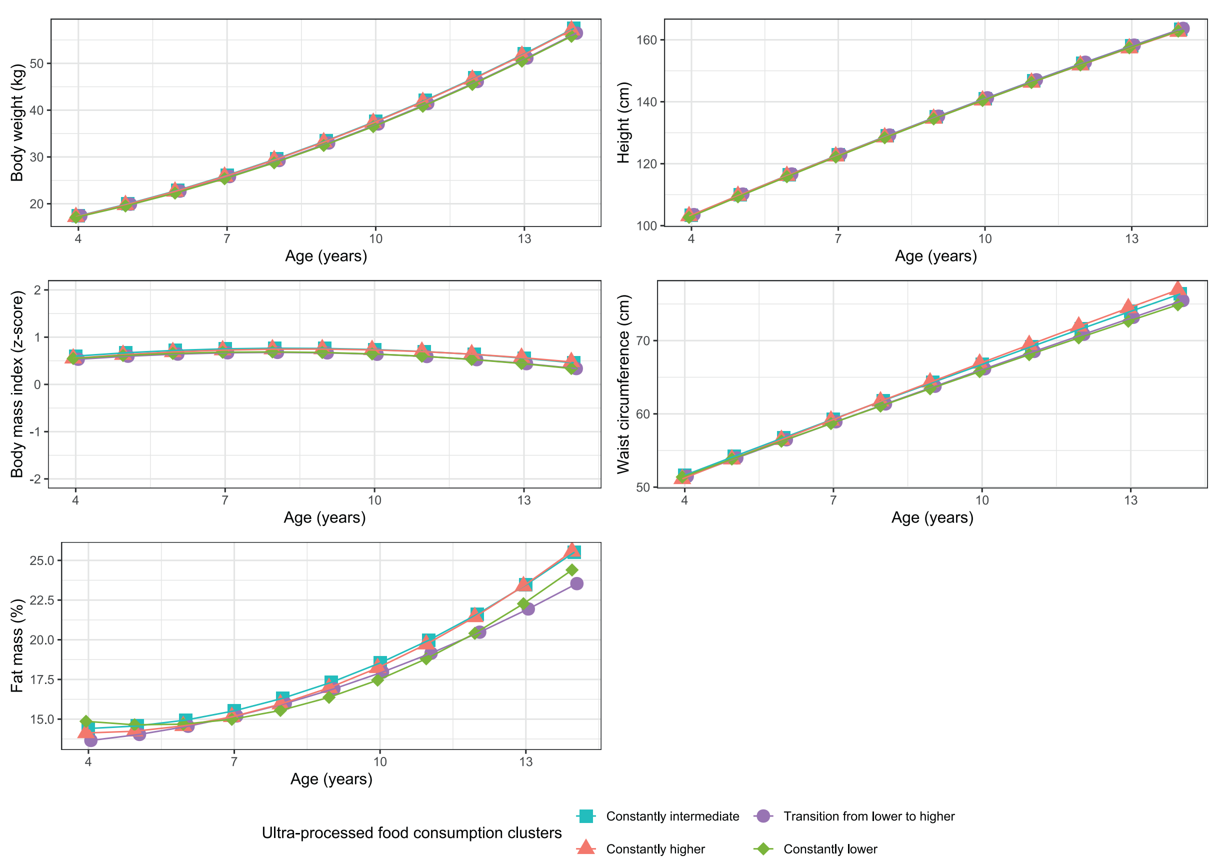

Fig. 2. Adiposity trajectories according to ultra-processed foods consumption patterns during childhood among participants of the Generation XXI birth cohort. Mixed-effects model with linear and quadratic terms for age adjusted for sex (model 1). Graphs generated using marginal means - results presented are for males.

Table 2
Association between ultra-processed foods consumption patterns and adiposity trajectories. Mixed-effects model with linear and quadratic terms for age adjusted for sex, birth weight, mother's pre-pregnancy BMI and mother's education (final model: model 2).

Predictors	Body weight (kg)			Height (cm)			BMI z-score			Waist circumference (cm)			Fat mass (%)		
	β	95% CI	p	β	CI	p	β	95% CI	p	β	95% CI	p	β	95% CI	p
(Intercept)	12.228	11.567; 12.889	<0.001	94.521	93.567; 95.474	<0.001	−1.890	−2.128;-1.651	<0.001	42.201	41.065; 43.337	<0.001	2.287	0.362; 4.212	0.020
Age (years)	2.292	2.218; 2.366	<0.001	6.695	6.649; 6.740	<0.001	0.071	0.062; 0.081	<0.001	2.466	2.382; 2.549	<0.001	−0.109	−0.231; 0.013	0.080
Constantly lower UPF consumption pattern	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Constantly intermediate UPF consumption pattern	0.126	−0.076; 0.328	0.221	0.267	−0.026; 0.560	0.074	−0.003	−0.081; 0.074	0.931	0.015	−0.330; 0.359	0.934	−0.342	−0.974; 0.291	0.290
Transition from low to high UPF consumption pattern	0.092	−0.160; 0.344	0.475	0.177	−0.188; 0.543	0.341	−0.057	−0.153; 0.038	0.239	−0.193	−0.619; 0.233	0.375	−0.482	−1.268; 0.304	0.230
Constantly higher UPF consumption pattern	0.029	−0.215; 0.272	0.817	0.341	−0.010; 0.693	0.057	−0.072	−0.164; 0.020	0.125	−0.374	−0.788; 0.039	0.076	**−0.875**	**−1.628;-0.121**	**0.023**
Age^2 (years^2)	0.159	0.155; 0.162	<0.001	−0.069	−0.072;-0.065	<0.001	−0.009	−0.010;-0.009	<0.001	−0.012	−0.018;-0.006	<0.001	0.107	0.097; 0.116	<0.001
Age [a] Constantly lower UPF consumption pattern	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Age [a] Constantly intermediate UPF consumption pattern	**0.123**	**0.043;0.203**	**0.003**	−0.008	−0.050; 0.033	0.689	0.008	−0.001; 0.016	0.067	**0.120**	**0.045;0.195**	**0.002**	**0.146**	**0.054;0.238**	**0.002**
Age [a] Transition from low to high UPF consumption pattern	0.008	−0.091; 0.108	0.868	0.013	−0.039; 0.064	0.631	0.003	−0.007; 0.013	0.522	0.052	−0.041; 0.144	0.276	0.027	−0.088; 0.142	0.645
Age [a] Constantly higher UPF consumption pattern	**0.119**	**0.027;0.212**	**0.012**	**−0.063**	**−0.111;-0.015**	**0.011**	**0.014**	**0.004;0.023**	**0.005**	**0.232**	**0.144;0.319**	**<0.001**	**0.200**	**0.092;0.308**	**<0.001**
Male sex	0.100	−0.048; 0.247	0.185	0.336	0.123; 0.549	0.002	−0.044	−0.097; 0.009	0.106	−0.532	−0.785;-0.280	<0.001	−3.959	−4.385;-3.533	<0.001
Education (years)	−0.011	−0.029; 0.007	0.236	−0.004	−0.030; 0.023	0.782	−0.008	−0.015;-0.002	0.012	−0.003	−0.035; 0.029	0.858	−0.031	−0.084; 0.022	0.252
Birth weight/1000	1.255	1.115; 1.395	<0.001	2.279	2.077; 2.481	<0.001	0.296	0.246; 0.346	<0.001	1.646	1.406; 1.887	<0.001	2.142	1.736; 2.548	<0.001
Mothers' pre-pregnancy BMI	0.043	0.025; 0.061	<0.001	0.040	0.015; 0.066	0.002	0.070	0.064; 0.076	<0.001	0.195	0.164; 0.225	<0.001	0.411	0.359; 0.462	<0.001

UPF: ultra-processed foods. BMI: body mass index. CI: confidence interval.
Bold denotes statistical significance (p<0.05).
[a] Age centered at 4 years.

still needs to be explored because a recent study showed that UPF has a lower glycemic index and load compared to minimally processed foods [31]. Furthermore, the presence of non-nutrient substances in UPF such as certain food additives [32,33] and contaminants, whether from packaging [34] or processing [35] can also justify negative relationships with health.

Regarding the clinical relevance of the findings, it was also possible to observe that the effect measure was greater for the BMI z-score than the other studied variables (body weight, heigh, waist circumference, fat mass), when comparing the crude model with the model that includes exposure of interest (R-squared, data not shown). In other words, in the case of a *constantly higher UPF consumption pattern*, we can attribute greater relevance to the increase of 0.014 kg/m2 per year in the BMI z-score (than, for example, to the increase of 0.119 kg per year in weight or to the smaller growth of 0.063 cm/year in the case of height). However, despite the statistical significance, the effect size found was moderate, perhaps because the BMI z-score presented a relatively low mean in this sample, with a stronger relationship being expected for higher values.

There were several strengths and limitations in the present study that deserve to be discussed. Due to the exhaustive and systematic data collection in the G21 birth cohort, it was possible to study a range of anthropometric parameters and adiposity markers suspected of being influenced by UPF consumption patterns and also to adjust for several confounding factors. The methods described as those with the best performance in estimating UPF consumption are food records and 24-h recalls [36]. However, for foods not eaten daily, as in the case of some UPF, food records could bring problems of underestimation. So, using information from FFQ can be helpful because it captures less frequently consumed foods and considers better the estimation of non-healthy food that seems to be more consumed on weekend days [37]. In this work, a validated and calibrated FFQ data using 3-day food diaries in approximately 50% of the sample were used [14], allowing to improve the accuracy of the estimates, to have larger sample size and higher statistical power. A specific validation of these FFQ for UPF was also carried out using the subsample that provided 3-day food diaries, having found reasonable results and increasing with age – 4-year follow-up: ICC = 0.226, 95%CI = 0.112–0.326, 7-year follow-up: ICC = 0.321, 95%CI = 0.151–0.453, 10-year follow-up: ICC = 0.391, 95%CI = 0.322–0.453 - data not shown). The use of NOVA classification, widely assumed as a proper classification system based on food processing also values this work. However, FFQ is based on a fixed and comprehensive list of food groups whereby the classification decided for each FFQ item cannot be applied equally to all individuals, as each item may include foods from different NOVA groups. An attempt was made to minimize classification errors consulting, whenever necessary, the results of the last national food survey [17]. For example, there was a greater consumption of yogurts from NOVA group 4 compared to groups 1 and 3, which reinforced the decision to classify the yogurt item in group 4. Based on national data, a sensitivity analysis was carried out using the consumption proportions of the different NOVA groups for each item, but this did not change the results - data not shown. The greatest strength of the present study is the evaluation of the cumulative effect of UPF consumption throughout childhood on growth and adiposity trajectories. Given that the majority of the sample had dietary information at least in one assessment, it was possible to complete missing data predicting the UPF consumption pattern for the entire sample, gaining statistical power. Misreport cannot be excluded, however UPF consumption was studied in the form of quartiles, grouping consumption according to distribution and minimizing this possible problem. Regarding outcomes, approximately 70% of the sample provided at least 2 measurements in the 4 assessments, allowing us to obtain a good sample size.

In general, the studies on UPF consumption and its associated factors currently available use its energy proportion as the outcome [2]. Instead, in this study, as explained previously [3], the absolute quantity was used whereby comparability with other studies may be affected. However, in order to minimize this limitation, descriptive results on UPF consumption were presented as the relative contribution of UPF to the total quantity of food. The use of the absolute quantity gives strength to the results since it gives relevance to low or no calorie foods while avoiding the residual confounding effect of dividing by energy. The adjustment for the other NOVA groups was intended to be a substitute for the adjustment for energy that did not include exposure. Also, the definition and mechanisms by which the negative effect of UPF on health has been alleged involve other points, in addition to their energy and nutritional value, such as changes in the matrix that condition normal metabolism, the existence of contaminants from processing and packaging. Given the sample size and study design, it was possible to study the cumulative effect of exposure across UPF consumption patterns, longitudinally relating them to outcomes that were carefully measured using standard procedures. In Portugal, even with relatively low UPF consumption compared to other countries [2,3], a negative effect on growth and adiposity trajectories was found.

5. Conclusion

As conclusion, compared to a constantly lower UPF consumption during childhood, a constantly higher consumption, and to a lesser extent a constantly intermediate consumption, were associated with worse growth and adiposity trajectories, namely body weight, height, BMI z-score, waist circumference and FM%, until adolescence. Therefore, early interventions that limit the UPF consumption are necessary and essential for adequate growth.

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Author contributions

VM had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

VM participated in the design of the study, interpreted the data analysis, and wrote the first draft of the manuscript.

MS performed the main data analysis and gave additional inputs to the study design.

SV was involved in the methodological procedures of dietary data and the interpretation of the data analysis.

CL and DT had an important role on study design, collection data procedures, and interpretation of the data analysis.

All authors revised each draft for important intellectual content and discussed the results, contributing to the final document.

Data availability statement

The data from Generation XXI are not publicly available due to privacy or ethical restrictions. The data can be made available for research proposals on request to the Generation XXI Executive Committee (generationxxi@ispup.up.pt). Further information about Generation XXI can be obtained via the Generation XXI website [www.geracao21.com] or by emailing generationxxi@ispup.up.pt.

Conflict of Interest statement

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnu.2024.08.032.

References

[1] Monteiro CA, Cannon G, Levy RB, Moubarac JC, Louzada ML, Rauber F, et al. Ultra-processed foods: what they are and how to identify them. Publ Health Nutr 2019;22(5):936–41.
[2] Marino M, Puppo F, Del Bo C, Vinelli V, Riso P, Porrini M, et al. A systematic review of worldwide consumption of ultra-processed foods: findings and criticisms. Nutrients 2021;13(8).
[3] Magalhaes V, Severo M, Correia D, Torres D, Costa de Miranda R, Rauber F, et al. Associated factors to the consumption of ultra-processed foods and its relation with dietary sources in Portugal. J Nutr Sci 2021;10:e89.
[4] Pagliai G, Dinu M, Madarena MP, Bonaccio M, Iacoviello L, Sofi F. Consumption of ultra-processed foods and health status: a systematic review and meta-analysis. Br J Nutr 2021;125(3):308–18.
[5] Santos FSD, Dias MDS, Mintem GC, Oliveira IO, Gigante DP. Food processing and cardiometabolic risk factors: a systematic review. Rev Saude Publica 2020;54:70.
[6] Frias JRG, Cadena LH, Villarreal AB, Pina BGB, Mejia MC, Cerros LAD, et al. Effect of ultra-processed food intake on metabolic syndrome components and body fat in children and adolescents: a systematic review based on cohort studies. Nutrition 2023;111:112038.
[7] Juul F, Vaidean G, Parekh N. Ultra-processed foods and cardiovascular diseases: potential mechanisms of action. Adv Nutr 2021;12(5):1673–80.
[8] Kaikkonen JE, Mikkila 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] De Amicis R, Mambrini SP, Pellizzari M, Foppiani A, Bertoli S, Battezzati A, et al. Ultra-processed foods and obesity and adiposity parameters among children and adolescents: a systematic review. Eur J Nutr 2022;61(5):2297–311.
[10] Chang K, Khandpur N, Neri D, Touvier M, Huybrechts I, Millett C, et al. Association between childhood consumption of ultraprocessed food and adiposity trajectories in the avon longitudinal study of parents and children birth cohort. JAMA Pediatr 2021;175(9):e211573.
[11] NCD Risk Factor Collaboration. Height and body-mass index trajectories of school-aged children and adolescents from 1985 to 2019 in 200 countries and territories: a pooled analysis of 2181 population-based studies with 65 million participants. Lancet 2020;396(10261):1511–24.
[12] Larsen PS, Kamper-Jorgensen M, Adamson A, Barros H, Bonde JP, Brescianini S, et al. Pregnancy and birth cohort resources in europe: a large opportunity for aetiological child health research. Paediatr Perinat Epidemiol 2013;27(4):393–414.
[13] Alves E, Correia S, Barros H, Azevedo A. Prevalence of self-reported cardiovascular risk factors in Portuguese women: a survey after delivery. Int J Publ Health 2012;57(5):837–47.
[14] Vilela S, Severo M, Moreira T, Ramos E, Lopes C. Evaluation of a short food frequency questionnaire for dietary intake assessment among children. Eur J Clin Nutr 2019;73(5):679–91.
[15] Marinho AR, Severo M, Vilela S, Torres D, Oliveira A, Lopes C. Association of dietary macronutrient intake with adiposity during childhood according to sex: findings from the generation XXI birth cohort. Pediatr Obes 2022;17(9):e12916.
[16] Monteiro CA, Cannon G, Moubarac JC, Levy RB, Louzada MLC, Jaime PC. The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. Publ Health Nutr 2018;21(1):5–17.
[17] Lopes C, Torres D, Oliveira A, Severo M, Guiomar S, Alarcao V, et al. National food, nutrition, and physical activity survey of the Portuguese general population (2015-2016): protocol for design and development. JMIR Res Protoc 2018;7(2):e42.
[18] WHO Multicentre Growth Reference Study Group. WHO Child Growth Standards: length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age. Methods and development. Geneva: WHO; 2006.
[19] Schaefer F, Georgi M, Wuhl E, Scharer K. Body mass index and percentage fat mass in healthy German schoolchildren and adolescents. Int J Obes Relat Metab Disord 1998;22(5):461–9.
[20] Scrucca L, Fop M, Murphy TB, Raftery AE. Mclust 5: clustering, classification and density estimation using Gaussian finite mixture models. The R Journal 2016;8(1):289–317.
[21] R Core Team. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2017.
[22] Monteiro CA, Moubarac JC, Levy RB, Canella DS, Louzada M, Cannon G. Household availability of ultra-processed foods and obesity in nineteen European countries. Publ Health Nutr 2018;21(1):18–26.
[23] Yuan L, Hu H, Li T, Zhang J, Feng Y, Yang X, et al. Dose-response meta-analysis of ultra-processed food with the risk of cardiovascular events and all-cause mortality: evidence from prospective cohort studies. Food Funct 2023;14(6):2586–96.
[24] Neri D, Martinez-Steele E, Khandpur N, Levy R. Associations between ultra-processed foods consumption and indicators of adiposity in US adolescents: cross-sectional analysis of the 2011-2016 national health and nutrition examination survey. J Acad Nutr Diet 2022;122(8):1474–14787 e2.
[25] Cunha DB, da Costa THM, da Veiga GV, Pereira RA, Sichieri R. Ultra-processed food consumption and adiposity trajectories in a Brazilian cohort of adolescents: ELANA study. Nutr Diabetes 2018;8(1):28.
[26] Neri D, Steele EM, Khandpur N, Cediel G, Zapata ME, Rauber F, et al. Ultra-processed food consumption and dietary nutrient profiles associated with obesity: a multicountry study of children and adolescents. Obes Rev 2022;23(Suppl 1):e13387.
[27] Braun KV, Erler NS, Kiefte-de Jong JC, Jaddoe VW, van den Hooven EH, Franco OH, et al. Dietary intake of protein in early childhood is associated with growth trajectories between 1 and 9 Years of age. J Nutr 2016;146(11):2361–7.
[28] Martinez Steele E, Raubenheimer D, Simpson SJ, Baraldi LG, Monteiro CA. Ultra-processed foods, protein leverage and energy intake in the USA. Publ Health Nutr 2018;21(1):114–24.
[29] Durao C, Oliveira A, Santos AC, Severo M, Guerra A, Barros H, et al. Protein intake and dietary glycemic load of 4-year-olds and association with adiposity and serum insulin at 7 years of age: sex-nutrient and nutrient-nutrient interactions. Int J Obes (Lond). 2017;41(4):533–41.
[30] Fardet A. Minimally processed foods are more satiating and less hyperglycemic than ultra-processed foods: a preliminary study with 98 ready-to-eat foods. Food Funct 2016;7(5):2338–46.
[31] Basile A, Ruiz-Tejada A, Mohr A, Morales A, Hjelm E, Atkinson F, et al. Ultra-processed foods have a lower glycemic index and load compared to minimally processed foods. Curr Dev Nutr 2022;6:504.
[32] Canella DS, Pereira Montera VdS, Oliveira N, Mais LA, Andrade GC, Martins APB. Food additives and PAHO's nutrient profile model as contributors' elements to the identification of ultra-processed food products. Sci Rep 2023;13(1):13698.
[33] Chazelas E, Deschasaux M, Srour B, Kesse-Guyot E, Julia C, Alles B, et al. Food additives: distribution and co-occurrence in 126,000 food products of the French market. Sci Rep 2020;10(1):3980.
[34] Buckley JP, Kim H, Wong E, Rebholz CM. Ultra-processed food consumption and exposure to phthalates and bisphenols in the US national health and nutrition examination survey, 2013-2014. Environ Int 2019;131:105057.
[35] Martinez Steele E, Buckley JP, Monteiro CA. Ultra-processed food consumption and exposure to acrylamide in a nationally representative sample of the US population aged 6 years and older. Prev Med 2023;174:107598.
[36] Food and Agriculture Organization of the United Nations. Guidelines on the collection of information on food processing through food consumption surveys. Rome: FAO; 2015.
[37] Czlapka-Matyasik M, Lonnie M, Wadolowska L, Frelich A. "Cutting down on sugar" by non-dieting young women: an impact on diet quality on weekdays and the weekend. Nutrients 2018;10(10).