British Journal of Nutrition (2021), 125, 1427–1436 doi:10.1017/S0007114520003712

British Journal of Nutrition

Ultra-processed food consumption, appetitive traits and BMI in children: a prospective study

Gabriela Milhassi Vedovato[1]*, Sofia Vilela[2], Milton Severo[2,3], Sara Rodrigues[2,4], Carla Lopes[2,3] and Andreia Oliveira[2,3]

[1]*Institute of Health and Society, Federal University of São Paulo, Santos, São Paulo 11015-020, Brazil*
[2]*EPIUnit – Instituto de Saúde Pública, Universidade do Porto (Institute of Public Health, University of Porto), Porto 4050-600, Portugal*
[3]*Department of Public Health and Forensic Sciences and Medical Education, Faculty of Medicine, University of Porto, Porto 4200-319, Portugal*
[4]*Faculty of Nutrition and Food Sciences, University of Porto, Porto 4200-465, Portugal*

(Submitted 15 April 2020 – Final revision received 4 September 2020 – Accepted 15 September 2020 – First published online 23 September 2020)

Abstract

This study aimed to investigate the association of ultra-processed food consumption at 4 and 7 years of age with appetitive traits at 7 years and BMI at 10 years of age. Participants were 1175 children of the population-based birth cohort Generation XXI, who provided food diaries and complete data on socio-demographic variables, anthropometric measures and the Portuguese Children's Eating Behaviour Questionnaire (P-CEBQ). Foods were grouped according to NOVA classification into: 'unprocessed, minimally or moderately processed, and culinary preparations'; 'processed' and 'ultra-processed'. To assess tracking of groups' consumption, Pearson's correlation coefficient (r) and the intraclass correlation coefficient (ICC) were calculated. Generalised linear models were fitted to test main associations, mediators and interactions among the variables. Ultra-processed consumption exhibited a fair level of stability between ages 4 and 7 years (r 0·34; ICC = 0·32; 95 % CI 0·25, 0·39), corresponding, respectively, to 27·3 % (1881·9 (SD 908·8) kJ/d) and 29·3 % (2204·5 (SD 961·1) kJ/d) of total energy intake. After adjusting for maternal and child characteristics, higher ultra-processed consumption at 4 years was associated directly with 'Food Responsiveness' (β = 0·019; 95 % CI 0·007, 0·037) and indirectly through energy intake with avoidant traits: 'Food Fussiness' (β = –0·007; 95 % CI 0·002, 0·012) and 'Satiety Responsiveness' (β = –0·007; 95 % CI 0·003, 0·012). Ultra-processed consumption at 4 years old was associated with BMI at 10 years old, but appetitive behaviours were not powerful mediators of this association. The results suggest a path by which ultra-processed products may impact on later appetitive traits and higher BMI in children.

Key words: Cohort studies: Children: Feeding behaviours: Appetitive behaviour: Food processing: BMI

Changes in dietary patterns, such as higher consumption of ultra-processed foods and drinks, and lower consumption of traditional foods, which by nature are less processed, are important determinants of obesity and related chronic diseases[1–4]. Ultra-processed products have been dominating the current food systems[3], influencing family purchase decisions[5] and home food availability[1]. Food advertising and aggressive marketing strategies of these products targeting parents and children, such as attractive packaging, health claims and the use of cartoon characters, have been observed[3]. Furthermore, as they are designed to be consumed anytime in any place, usually as snacks, drinks and ready-to-eat dishes, they may contribute to disarrange meals and displace cooking preparations at home[3,6].

Considering that ultra-processed foods are industrial formulations made mostly from a combination of various ingredients and substances, such as sugar, fat, salt and chemical additives to enhance their sensory qualities, they are commonly nutritionally unbalanced and hyper-palatable[3–5]. Highly processed foods are in general energy-dense, high-fat and sweet tasting, which appear to be particularly related to addictive-like eating behaviour[7]. They have been associated with a higher glycaemic response and with appetite triggering, leading to a low responsiveness to internal food cues and a higher responsiveness to external food cues[7]. It has been suggested that ultra-processed foods may affect gastric and brain structures which regulate satiety, appetite and energy balance, prompting overeating and

Abbreviations: ICC, intraclass correlation coefficient; P-CEBQ, Portuguese Children's Eating Behaviour Questionnaire.

* **Corresponding author:** Gabriela Milhassi Vedovato, email gabriela.vedovato@unifesp.br

weight gain[7,8]. Thus, their effects might be through their energy and/or from their additives. There is, however, little evidence to establish a rationale supporting energy intake as a mediator between ultra-processed foods and appetitive traits[7–9].

Appetitive behaviours in children, mainly food-approaching traits (i.e. eating behaviours that imply movements towards food), are established as mediators to a later weight gain[10–13]. Although cross-sectional studies have shown positive associations of consumption of ultra-processed foods with BMI[14] and other adiposity indicators[2,15], there is still a need for longitudinal designs to better understand the relationships between ultra-processed food consumption and obesity among children and adolescents[16,17]. However, to the best of our knowledge, no studies have investigated the associations between ultra-processed consumption and appetitive traits in children.

In the present study, we hypothesised that ultra-processed food consumption influences appetitive behaviours in children, leading to increased later BMI. Our aim is to identify the diet contribution from food processing at 4 and 7 years of age and to assess the association of ultra-processed food consumption with appetitive behaviours at 7 years of age. We also seek to investigate whether appetitive behaviours at 7 years old are mediators to an increased BMI at 10 years old.

Methods

Study design and participants

The present study was conducted within Generation XXI, a prospective population-based birth cohort described elsewhere[18]. A total of 8647 children and respective mothers were recruited between April 2005 and August 2006 at all the public maternity units in the Porto Metropolitan Area (Northern Portugal). These maternity units were responsible, at enrolment, for 91·6 % of the deliveries in the whole catchment population. Mothers were invited to participate 24–72 h after delivery, and 91 % of the invited mothers accepted to participate.

The three follow-ups of the entire cohort occurred between April 2009 and July 2011, April 2012 and April 2014, and July 2015 and July 2017, when the children were 4, 7 and 10 years of age (86, 81 and 76 % of the children were re-evaluated, respectively). The evaluations were performed by face-to-face interviews or by telephone with a shorter version of the questionnaire for those families not able to participate in-person (20, 15 and 16 % at 4, 7 and 10 years, respectively).

The present study involved a subsample of children evaluated at face-to-face follow-up evaluations at 4, 7 and 10 years old. We included data from 1407 children who provided at least 2-d food diaries at 4 and 7 years of age (even though 3-d food diaries correspond to the majority of the sample 96·5 and 96 % of the children, respectively by age) and information on the Portuguese version of the Children's Eating Behaviour Questionnaire (P-CEBQ) at 7 and 10 years of age. We excluded twins, children with congenital anomalies or diseases that might influence dietary intake (coeliac disease, food allergy, food intolerance and phenylketonuria) and children who lacked data on variables of interest, achieving a final sample of 1175 children. Fig. 1 presents the flow chart of the study. Comparing the children included in the analysis with the remaining cohort, no statistical differences were found regarding children's sex and BMI at 10 years of age. Mothers of children included in the study at baseline were slightly older (mean 30·5 (SD 4·74) *v.* 28·4 (SD 6·27) years, $P < 0·001$) and more educated (mean 11·9 (SD 4·26) *v.* 9·8 (SD 4·11) years of complete schooling, $P < 0·001$), even though the Cohen's effect size was moderate (i.e. values of 0·36 for maternal age and 0·49 for maternal education level).

The study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all the procedures

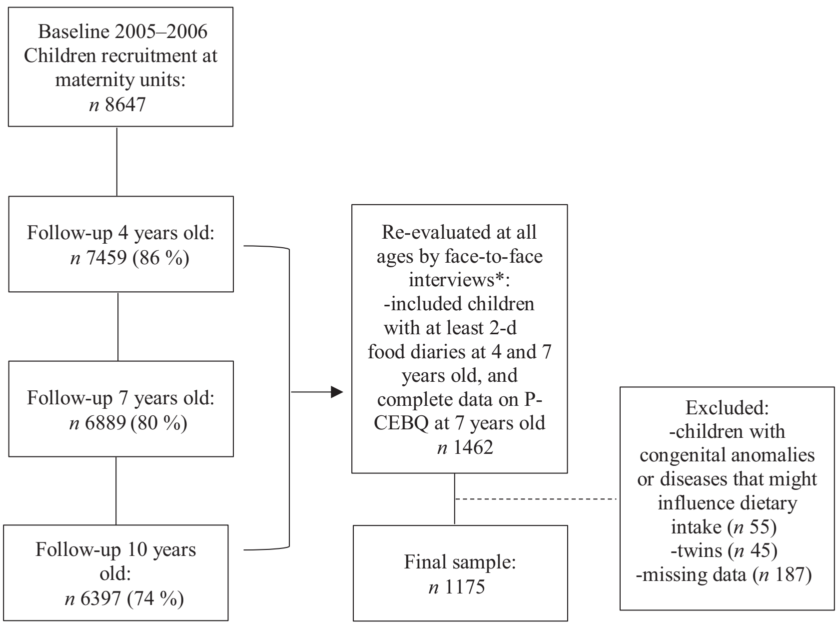

Fig. 1. Flow chart of the participants, Generation XXI birth cohort, Portugal. P-CEBQ, Portuguese version of the Children's Eating Behaviour Questionnaire. * 70 % of all children at 4 years old, 68 % at 7 years old and 62 % at 10 years old.

British Journal of Nutrition

involving human subjects were approved by the Ethics Committee of São João Hospital/University of Porto Medical School and by the Portuguese Authority of Data Protection. Parents or legal tutors of each participant received an explanation on the purposes and design of the study and gave written informed consent at baseline and follow-up evaluations.

Data collection

Data were collected by trained interviewers using structured questionnaires or by self-reported questionnaires filled out by the child's main caregiver. They gathered information on socio-demographic, clinical and behavioural characteristics at 4, 7 and 10 years old.

Ultra-processed food consumption. Dietary intake of children at 4 and 7 years of age was measured by 2-d or 3-d food diaries (1 or 2 weekdays and 1 weekend day) filled by the mother and/or another adult caregiver, as previously described[19]. Oral and written instructions were given for the correct completion of food diaries and for the quantification of food portions. Main caregivers were asked to report all foods and beverages consumed by the child and to provide detailed descriptions of each item, including the amount (in g, units or household measures), brand name, recipes (ingredients and methods of preparation) and location, whenever possible.

The codification process of food diaries was conducted by a team of trained nutritionists, using an age-specific food coding manual previously developed by the research team[19,20]. Energy and nutrient intake was estimated using the software Food Processor SQL (2004–2005 ESHA Research), based on an adapted version of the Food Composition Table of the US Department of Agriculture[21]. For typical Portuguese foods or culinary dishes, new codes were created with national nutritional information, as previously described[20].

Food and beverage items were further classified into groups according to the nature, extent and purpose of industrial processing, based on the NOVA food classification system[3] (Table 1). Groups 1 and 2 were grouped and consisted of unprocessed (i.e. natural foods having not undergone any kind of industrial processing), minimally processed (i.e. processed in ways that did not add substances or subtract edible parts), moderately processed foods (i.e. those that had an edible part subtracted, but no substance added, such as salt, sugar, oils or fats) and culinary preparations (i.e. handmade dishes made from these foods and basic culinary ingredients such as salt, sugar, honey, vegetable oils, butter and animal lards). Group 3 comprised processed foods (i.e. manufactured by adding salt, sugar, oil or fats to unprocessed, minimally or moderately processed foods), most foods having two or three ingredients and the industrial purpose to increase durability or to enhance sensory quality. Group 4 was composed of ultra-processed foods (i.e. industrial formulations typically with many ingredients and additives, most of them derived from foods or obtained with the further processing of foods constituents through chemical synthesis). Examples of the food items included in each group are presented in Table 1.

For each group, we calculated the total amount (in g or ml) consumed from each food or beverage items and expressed the consumption as a percentage of the total daily energy intake (for descriptive purposes) and in kcal (included in the statistical models, per 100 kcal, to enable readability of the estimates).

Appetitive behaviours. Children's eating behaviours were assessed using the P-CEBQ, previously tested within the Generation XXI cohort[10]. Parents at the 7- and 10-year-old evaluations completed the questionnaire, being 96 and 91 % answered by mothers, respectively. The original CEBQ[12] and the P-CEBQ[10] measure appetitive traits in children and are composed of thirty-five items grouped into eight subdomains, four assessing food approach behaviours: 'Enjoyment of Food' (representing a general interest in food), 'Food Responsiveness' (measuring eating in response to external food cues), 'Emotional Overeating' (characterised by increased eating in response to negative emotions, such as anger and anxiety) and 'Desire to Drink' (evaluating the increased desire to have drinks); and four food avoidant behaviours: 'Satiety Responsiveness' (reflecting the ability to regulate the amount

Table 1. Groups identified according to the nature, extent and purpose of industrial processing based on the NOVA food classification system[3]

Food groups	Examples
Groups 1 + 2: unprocessed, minimally and moderately processed foods, and culinary preparations	Fresh, chilled, frozen, dried, vacuum-packed fruits, vegetables, fungi, tubers, roots, grains and legumes; unsalted nuts and seeds; fresh, dried, chilled, frozen meats, poultry and fish; eggs; fresh and pasteurised milk, plain yoghurt with no added sugar or artificial sweeteners added; 100 % unsweetened fruit juices; coffee; tea; water; butter, oils, sugar and salt
Group 3: Processed foods	Canned or bottled vegetables, fruits and legumes; salted or sugared nuts and seeds; salted, cured or smoked meats (e.g. bacon and typical Portuguese sausages); canned fish; fruits in syrup; cheeses and unpackaged freshly made bread; plain yoghurt with no added sugar
Group 4: Ultra-processed products	Soft drinks; sweet or savoury packaged snacks; ice cream, chocolate, candies; mass-produced packaged breads and buns; margarines and spreads; cookies, pastries and cake mixes; breakfast cereals and cereal/energy bars; milk, cocoa and fruit drinks; meat and chicken extracts and instant sauces; infant formulas, follow-on milks and other baby products; ready-to-heat/eat products and dishes (pies, pasta, pizza, desserts); processed meats and sausages; packaged soups and noodles; flavoured and/or artificial sweetened yoghurt

British Journal of Nutrition

of food eaten, based on perceived fullness), 'Slowness in Eating' (measuring the speed of eating during the course of a meal and reflecting a gradually reduced interest in a meal), 'Food Fussiness' (measuring a lack of interest in food and unwillingness to try new foods) and 'Emotional Undereating' (characterised by decreased eating in response to negative emotions). The items were answered on a five-point Likert scale ('never', 'seldom', 'sometimes', 'often' and 'always'), scored from 1 to 5. In accordance with the original scale, five of the items were reverse-scored due to opposite phrasing.

The CEBQ has demonstrated stability over time and good psychometric properties in diverse populations[12,13,22] including the current sample of children[10]. At 7 years old, the Cronbach's alpha for the different subdomains of the P-CEBQ ranged from 0·74 to 0·85, attesting its good internal consistency, and the reliability assessed by the mean intraclass correlation was 0·73, attesting its good reliability[10]. At 10 years old, the Cronbach's alpha of the P-CEBQ ranged from 0·76 to 0·84.

In participants with missing data in <50 % of the items, missing data (about 3 % at both 7 and 10 years old) were handled by imputation, replacing the average of the remaining questions within each subdomain[23].

Additionally, at 4 and 7 years of age, problematic eating behaviours in children were assessed through single questions by a caregiver report. Caregivers were asked about specific perceived eating problems observed during the previous year and their level of concern ('very concerned', 'somewhat concerned', 'not concerned'). The following questions were included in the analyses: 'my child does not eat enough', 'my child eats very slowly' and 'my child eats too much'. As described previously[24], these parental concerns were used as proxies of the subdomains of the CEBQ at 4 years of age, as at this age the P-CEBQ was not applied.

BMI. Participant's anthropometric measurements were performed at the ages of 4, 7 and 10 years by a team of experienced examiners, according to standard procedures[25]. Children were weighed and measured barefoot and in light clothing. Weight was measured to the nearest 0·1 kg using a digital scale (Tanita®, Arlington Heights), and height was measured to the nearest 0·1 cm using a fixed wall stadiometer (SECA®). BMI was obtained by calculating weight/height^2 (kg/m^2). Age- and sex-specific BMI standard deviation scores (BMI *z*-scores) were computed according to the WHO criteria[26].

Potential confounders. Characteristics that may confound the association between ultra-processed food consumption, appetitive traits and BMI were considered. The following potential confounders were selected on the basis of previous literature and exploratory data analyses: maternal age, maternal education (number of completed schooling years) and BMI before pregnancy were recorded at baseline; exclusive breast-feeding for the first 6 months was recorded at 4 years old as 'yes' or 'no'; parental concerns regarding child's eating behaviour at 4 years of age ('yes, 'very/somewhat concerned/not concerned' *v.* 'no, 'never happened'); the practice of regular physical exercise was collected at 4 years of age as a dichotomous response ('non-practitioners' *v.* 'practitioners'); daily screen time (time spent in front of television/videos, computer or game devices) during both weekdays and weekends was also collected at 4 years of age and was categorised into <2 and ≥2 h/d.

Statistical analysis

Descriptive statistics were performed for maternal and child characteristics.

After checking normal distribution of food consumption data, Pearson's correlation coefficient (r) and the intraclass correlation coefficient between the consumption of each of the NOVA food groups at 4 and 7 years of age were computed to assess tracking of dietary patterns. Intraclass correlation coefficient values between 0·81 and 1·00 were considered to represent almost perfect agreement, 0·61 and 0·80 substantial agreement, 0·41 and 0·60 moderate agreement, 0·21 and 0·40 fair agreement and values <0·21 slight agreement[27].

Associations between ultra-processed food consumption (group 4) at 4 years of age (exposure) and appetitive behaviours measured by the P-CEBQ subdomains (outcomes) at 7 years of age were evaluated through linear regression models (regression coefficients and respective 95 % CI). The following regression models were estimated: model 0 – crude (unadjusted); model 1 – adjusted for maternal characteristics (age, years of education and BMI before pregnancy) and model 2 – adjusted for maternal and child characteristics (exclusive breast-feeding for the first 6 months, parental concerning on eating behaviours, practice of physical exercise and daily screen time at 4 years of age).

The interaction of the child's sex in these associations was investigated by including an interaction term into the fully adjusted models, but no modification by child's sex was found in the linear regressions. Child BMI *z*-score was treated as a collider variable because it is believed to be 'caused' by both ultra-processed consumption and appetitive behaviours, and for that reason, it was not included as a confounder of the associations.

Another set of models was performed through the Haye's PROCESS approach using 5000 bootstrap simulations to examine two potential mediators of the associations between the ultra-processed food consumption at 4 years and P-CEBQ subdomains at 7 years of age: energy intake from groups 1 + 2 and 3 (not ultra-processed foods) at 7 years of age (kcal/d), and ultra-processed food consumption at 7 years of age (kcal/d).

Additionally, we evaluated the mediating role of eating behaviours related to appetite in the associations between ultra-processed food consumption at 4 and 7 years of age and BMI *z*-score at 10 years of age: crude associations; model 1 (total effect) was adjusted based on theoretical considerations for variables associated with obesity (maternal education, BMI before pregnancy, exclusive breast-feeding, daily screen time and physical exercise), and direct and indirect effects of the subdomains of the P-CEBQ that showed associations with ultra-processed food consumption (parallel mediation); model 2 included the child BMI *z*-score at 4 years to isolate its effect. The indirect effect estimates for which the 95 % CI did not include zero were considered statistically significant, and thus evidence of potential mediations.

Sensitivity analyses were further performed to assess whether results would be substantively different using the exposure variable consumption of ultra-processed products (group 4) in percentage of total energy intake.

All the analyses were conducted using the statistical software package IBM SPSS® Statistics version 25 (SPSS Inc.), including the PROCESS macro version 3.5 for mediation analyses. Significance was defined as a P value of <0·05.

Results

Children and their mothers' characteristics are described in Table 2. The study sample had 52 % of boys (data not shown). About 14 % were exclusively breastfed during the first 6 months of age. Over 91 % of children lived with parents, and 50 % had no siblings at 4 years of age. The majority of the children spent <2 h/d in front of a screen (67·2 %) and practiced regular physical activity (71·8 %) at 4 years of age. At the evaluations of 4, 7 and 10 years of age, 9·4, 13·7 and 17·2 % of children had obesity, respectively (data not shown).

The children's average reported energy intake from food diaries at 4 and 7 years of age was 6786 (SD 1214·2) and 7414 (SD 1242·2) kJ/d, respectively. Table 3 presents the tracking coefficients of food consumption from 4 to 7 years of age for the groups based on the NOVA food classification system. Ultra-processed food products (group 4) consumption corresponded to 27·3 % (1881·9 (SD 908·8) kJ/d) at 4 years old and 29·3 % (2204·5 (SD 961·1) kJ/d) at 7 years old. Group 4 exhibited stability coefficients slightly higher than groups 1 + 2 and 3, overall showing a fair level of agreement between measures at the two age frames.

The upper quartile of the ultra-processed food consumption (group 4) had the highest mean energy content (7744·6 (SD 1223·4) kJ/d) and a higher percentage of children following an 'Energy-dense food' (32·0 %) and 'Snacking' (31·8 %) dietary patterns (data not shown). These patterns were previously described in the literature as less healthy dietary patterns[28].

Significant positive associations between ultra-processed consumption at 4 years old and three subdomains of the P-CEBQ at age 7 were found in univariate analysis (Table 4, model 0): 'Satiety Responsiveness' ($\beta = 0{\cdot}022$; 95 % CI 0·004, 0·039); 'Food Fussiness' ($\beta = 0{\cdot}034$; 95 % CI 0·015, 0·054) and 'Desire to Drink' ($\beta = 0{\cdot}026$; 95 % CI 0·005, 0·047). These significant associations persisted after adjustment for maternal confounders (Table 4, model 1), except for 'Desire to Drink'. In the final adjusted models (further adjusted for child characteristics, Table 4, model 2), higher ultra-processed food consumption at 4 years old was significantly associated with later higher scores of 'Food Fussiness' ($\beta = 0{\cdot}026$; 95 % CI 0·007, 0·045) at 7 years old.

The consumption of ultra-processed foods at 4 years old had a significant direct effect on later increased 'Food Responsiveness' ($\beta = 0{\cdot}019$; 95 % CI 0·007, 0·037), but no indirect effect (mediated by energy intake) was found ($\beta = -0{\cdot}002$; 95 % CI 0·007, 0·002) (Table 4, model 2).

Energy intake was a mediator between ultra-processed consumption at 4 years old and both appetitive traits domains (Table 4, Model 2, indirect effect): 'Satiety Responsiveness' ($\beta = -0{\cdot}007$; 95 % CI 0·003, 0·012) and 'Food Fussiness' ($\beta = -0{\cdot}007$; 95 % CI 0·002, 0·012). Ultra-processed food consumption at 7 years old was not a mediator on the relationship between early ultra-processed consumption and appetitive behaviours at 7 years old (data not shown).

Ultra-processed food consumption at 4 years old was significantly associated with BMI z-score at age 10, after adjustment for maternal and child confounders (Table 5, model 2) ($\beta = 0{\cdot}028$; 95 % CI 0·006, 0·051); and appetitive behaviours at 7 years old associated with early ultra-processed consumption (Food Responsiveness, Satiety Responsiveness and Food Fussiness) were not powerful mediators (Table 5, model 1 – indirect effect) ($\beta = -0{\cdot}002$; 95 % CI –0·014, 0·011). Ultra-processed food consumption at 7 years old did not show an association with later BMI.

Table 2. Participants' characteristics (n 1175), Generation XXI birth cohort, Portugal
(Mean values and standard deviations; numbers and percentages)

	n	%
Maternal characteristics		
Age at 4 years		
Mean	30·50	
SD	4·74	
Education at 4 years		
Mean	11·86	
SD	4·26	
BMI before pregnancy (kg/m^2)		
Mean	23·87	
SD	4·15	
Child lives with both parents at 4 years	1076	91·60
Number of siblings at 4 years		
0	589	50·10
1	505	43·00
≥2	81	6·90
Exclusive breast-feeding for the first 6 months	169	14·40
Parental concerns regarding child's eating behaviours at 4 years		
'My child does not eat enough'	507	43·10
'My child eats very slowly'	601	51·10
'My child eats too much'	134	11·40
<2 h of daily screen time at 4 years	790	67·20
Regular practice of physical exercise at 4 years	844	71·80
BMI z-score at 4 years		
Mean	0·58	
SD	1·05	
BMI z-score at 7 years		
Mean	0·69	
SD	1·17	
BMI z-score at 10 years		
Mean	0·70	
SD	1·25	

Discussion

This study, to our knowledge, is the first to prospectively investigate, within a large population-based sample, the relationship between ultra-processed food consumption, appetitive behaviours and BMI in children. Higher ultra-processed consumption at 4 years of age was positively associated with food responsiveness (directly) and food fussiness and satiety responsiveness at 7 years of age (indirectly). For these two, energy intake mediated the relationship between early ultra-processed food consumption and food avoidant traits 3 years later. Furthermore,

Table 3. Tracking of food consumption groups based on food processing (the NOVA classification) from 4 to 7 years of age, Generation XXI birth cohort, Portugal
(Mean values and standard deviations; correlation coefficients and 95 % confidence intervals)

	Food consumption								Energy intake difference between the ages (kJ/d)				
	4 years				7 years								
	% of total energy		kJ/d		% of total energy		kJ/d						
NOVA food groups†	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*r*	ICC	95 % CI
Groups 1 + 2	62·9	10·6	4239·2	906·2	59·8	10·0	4404·1	892·4	164·8	1049·8	0·32**	0·31*	0·26, 0·37
Group 3	9·8	5·7	665·7	410·0	10·9	5·9	803·7	451·9	138·1	548·9	0·19**	0·18*	0·12, 0·24
Group 4	27·3	11·1	1881·9	908·8	29·3	10·4	2204·5	961·1	322·6	1073·6	0·34**	0·32*	0·25, 0·39

r, Pearson's correlation coefficient (two-tailed); ICC, intraclass correlation coefficient (computed for absolute agreement; two-way random model; single measures).
* $P < 0·05$, ** $P < 0·001$.
† Groups 1 + 2: Unprocessed, minimally and moderately processed foods, and culinary preparations. Group 3: Processed foods. Group 4: Ultra-processed food products.

ultra-processed food consumption at 4 years of age was a predictor of higher BMI at 10 years old, and appetitive traits at 7 years old were not mediators of this relationship.

In the current study, the energetic contribution of ultra-processed products to the diet of pre-school and school-age children in Portugal (approximately 28 and 30 % of total energy, respectively) was lower than those found for other populations[2,16,29]. Ultra-processed foods comprised about 42 % of total energetic intake at age 4, 48 % at age 8 in a Brazilian population sample[16] and 33 % in a Belgian population sample of children aged 3–9 years[29]. Formerly, Portuguese households had shown a low availability of ultra-processed foods (10·2 %) and a high consumption of unprocessed or minimally processed foods (43·4 %), compared with that of other European countries over the period of 1991 and 2008[1]. Despite this fact, dietary patterns high in energy-dense foods (such as sweets, soft drinks, salty pastry and processed meats) and low in foods typically consumed at main meals (such as vegetables, fish, meat, eggs, rice, pasta and potato) and intermediate in snacks were recently identified in Portuguese children at ages 4 and 7 years[28] and associated with a higher weight[22]. In the current sample, children with higher ultra-processed foods consumption (at the upper quartile) had followed more frequently these dietary patterns and had higher energetic intake.

Higher ultra-processed consumption at 4 years of age was positively directly associated with food responsiveness at 7 years old, which reflects the urge to eat when children see, smell or taste palatable food, such as ultra-processed foods. In a study with British and Australian pre-school children, food responsiveness was unrelated to liking fruits and vegetables, but was positively related to the preference for non-core foods (i.e. high in sugar and fat)[30]. Previous evidence suggests that highly palatable food-cues promote food-seeking behaviours even when in a state of satiety[7–9] what is a risk factor for obesity[31].

Since ultra-processed foods and beverages are typically energy-dense[3,32], we tested the hypothesis that the association between the consumption of such products and appetitive traits was mediated, in part, by the energy intake. The usual method for adjusting ultra-processed food consumption for total energy intake in epidemiology studies is using total energy intake as a denominator. This method has the potential disadvantage of leaving some residual confounding regarding total energy content and, since total energy intake is associated with appetitive traits, it can induce an association in the opposite direction. For this reason, we used in the models the variable consumption of ultra-processed food and beverages in kcal/d instead of the percentage of total energy intake, even though it is most commonly used in other studies adopting NOVA classification[2,14,16,29]. It is worth to mention that sensitivity models using group 4 in percentage of total of energy intake were essentially similar to the models with kcal/d (results not shown). In fact, in this study, the energy intake was found to be a mediator of the relationship between high ultra-processed consumption at 4 years and food avoidant behaviours at 7 years of age, attenuating the total effects of ultra-processed foods in appetitive behaviours.

Increased consumption of ultra-processed products early in life was, surprisingly, associated with a later food avoidant eating profile comprising high food fussiness and satiety responsiveness. Food avoidant behaviours, in general, are related to insufficient food intake and lower energy intake[33]. However, this does not mean that these children consume less energy-dense foods; preliminary data in this sample suggest that food fussiness, in particular, is negatively correlated with fruit and vegetables intake and positively correlated with ultra-processed food intake. The observed association may reflect food reward adaptations that result from increased consumption of ultra-processed products[9]. These products have higher amounts of sugar and fat, in combinations not encountered in natural foods, which seem to influence the fidelity of gut–brain signalling of food choices, that is, increased doses of those products increase food reinforcement[9]. In the current sample, mothers may have observed that children who eat more ultra-processed foods started to eat less of other foods, and thus reported higher food fussiness and satiety responsiveness among their children. Besides that, the early consumption of ultra-processed foods showed a direct effect (i.e. without mediating effect of energy content) on higher food responsiveness – a food approach behaviour – indicating that food properties other than energy density (e.g. combination of ingredients and other additives,

https://doi.org/10.1017/S0007114520003712 Published online by Cambridge University Press

Table 4. Associations between ultra-processed food consumption at 4 years of age‡ and appetitive behaviours at 7 years of age, Generation XXI birth cohort, Portugal§
(β Values and 95 % confidence intervals)

	Enjoyment of food		Food responsiveness		Emotional overeating		Emotional undereating		Satiety responsiveness		Slowness in eating		Food fussiness		Desire to drink	
	β	95 % CI	β	95 % CI	β	95 % CI	β	95 % CI	β	95 % CI	β	95 % CI	β	95 % CI	β	95 % CI
Model 0	−0·010	−0·031, 0·010	0·013	−0·06, 0·032	0·009	−0·07, 0·025	0·009	−0·011, 0·028	0·022*	0·004, 0·039	−0·004	−0·027, 0·019	0·034*	0·015, 0·054	0·026*	0·005, 0·047
Model 1	−0·012	−0·032, 0·009	0·011	−0·009, 0·030	0·009	−0·007, 0·025	0·011	−0·009, 0·030	0·021*	0·004, 0·039	−0·006	−0·029, 0·017	0·034*	0·014, 0·054	0·019	−0·001, 0·040
Model 2																
Total effect	−0·002	−0·021, 0·016	0·017	−0·001, 0·035	0·010	−0·006, 0·026	0·007	−0·012, 0·027	0·013	−0·004, 0·029	−0·015	−0·035, 0·006	0·026*	0·007, 0·045	0·018	−0·003, 0·039
Direct effect	0·001	−0·018, 0·020	0·019*	0·007, 0·037	0·010	−0·007, 0·027	0·006	−0·015, 0·026	0·006	−0·011, 0·023	−0·017	−0·037, 0·004	0·019	−0·000, 0·039	0·021	−0·001, 0·042
Indirect effect	−0·034	−0·008, 0·001	−0·002	−0·007, 0·002	0·000	−0·003, 0·040	0·002	−0·003, 0·007	0·007†	0·003, 0·012	0·002	−0·003, 0·007	0·007†	0·002, 0·012	−0·003	−0·008, 0·002

* $P<0·05$
† Significant if the 95 % CI does not include zero.
‡ In kcal per 100 kcal/d.
§ Model 0: crude. Model 1: adjusted for maternal age, maternal education and BMI before pregnancy. Model 2: total effect – adjusted for maternal age, maternal education and BMI before pregnancy, exclusive breast-feeding for the first 6 months, parental concerns 'my child does not eat enough'/'my child eats very slowly'/'my child eats too much', daily screen time, and practice of physical exercise at 4 years. Mediation of energy intake from food groups 1 + 2 and 3 (kcal/d) at 4 years old: direct and indirect effects.

orosensory properties), as well as the associated dietary patterns (e.g. snacking), may be implicated in satiety and food cue responsiveness in children and should be investigated further.

A high dietary share of ultra-processed products is associated with high content of added sugar, total and trans fatty acids, and low content of protein, fibre, vitamins and minerals[14,34,35]. These cohort findings showed that the intake of ultra-processed foods and beverages was somewhat stable from 4 to 7 years of age. Dietary pattern stability throughout childhood corroborates other studies that observed some level of tracking in the same age span[24,34,36]. Even though the Portuguese children's ultra-processed consumption is relatively low in comparison with other child populations and has shown stability over the period analysed, the slight increase in consumption should be considered alarming because it may limit the consumption of home-made meals from unprocessed, minimally or moderately processed foods. Examining whether there is a displacement of food patterns as a result of increased ultra-processed consumption and if it extends to late childhood and adolescence warrant further research.

The present results revealed that higher consumption of ultra-processed products at 4 years of age was positively associated with higher scores in food fussiness at 7 years of age, regardless of child and maternal characteristics. This finding confirms previous evidences that children exhibiting less healthy dietary patterns early in life may later have some problematic eating behaviours related to appetite[10,24,36,37]. Fussy eating has been described as a common problem among young children[10,24,36–39], with a peak incidence at approximately 2 years of age, and that tends to decrease as the child grows older and is exposed to a wide variety of foods[22,37,40]. Vilela *et al.*[24] observed in the same population-based cohort a general trend for a decrease in diet variety from 4 to 7 years of age. Considering that children are predisposed to prefer foods high in sugar and salt, and to reject bitter or sour tastes[38], in fussy children the intake of staple foods and fresh produce can be easily replaced by hyper-palatable processed foods[24,36,37], and it may be associated with destructured meals[41]. Additionally, it is common that parents of fussy children, who are usually thinner, adopt mealtime strategies, such as offering commercially prepared nutrition supplement drinks and preparing special meals with well-accepted foods[42]. Thus, children's food preferences and counter-productive parents' behaviours may increase the consumption of ultra-processed foods, limiting diet variety and intensifying food fussiness afterwards[33,39,43].

Increasing satiety responsiveness reflects a greater capacity of responsiveness to internal satiety cues; children feel fullness earlier[11]. In the current study, it was positively associated with prior higher consumption of ultra-processed foods. At short-term, ultra-processed products have been linked to lower satiety potential[7,8], and addictive-like eating behaviours, mainly as a result of the added fat through the activation of somatosensory brain regions, and of the refined carbohydrate content and high glycaemic load, which are involved in the activation of reward-related neural circuitry, craving and overeating[7]. There is evidence that satiety responsiveness may have a strong genetic component[13] and may be associated with breast-feeding duration, weaning style[44], child emotional temperament[41] and lower child age[13,22]. In Powell's study (2011), mothers who

Table 5. Associations between ultra-processed food consumption at 4 and 7 years of age and BMI at 10 years of age, and the mediating role of appetitive behaviours, Generation XXI birth cohort, Portugal‡
(β Values and 95 % confidence intervals)

	Child BMI z-score at 10 years								Model 2	
	Crude		Model 1							
	Crude		Total effect		Direct effect		Indirect effect			
Ultra-processed consumption (group 4) (kcal per 100 kcal/d)	β	95 % CI	β	95 % CI	β	95 % CI	β	95 % CI	β	95 % CI
At child's 4 years	0·016	−0·017, 0·049	0·017	−0·013, 0·048	0·019	−0·010, 0·048	−0·002	−0·014, 0·011	0·028*	0·006, 0·051†
At child's 7 years	−0·005	−0·036, 0·026	−0·001	−0·030, 0·028	0·004	−0·023, 0·031	−0·005	−0·017, 0·008	0·014	−0·007, 0·036

* $P < 0·05$.
† Significant if the 95 % CI does not include zero.
‡ Model 1: total effect – adjusted for maternal (age, education and BMI before pregnancy) and child (exclusive breast-feeding for the first 6 months, practice of physical exercise and daily screen time) characteristics. Mediation of appetitive behaviours at 7 years old associated with ultra-processed consumption (food responsiveness, satiety responsiveness and food fussiness): direct and indirect effects. Model 2: model 1 (total effect) + child BMI z-score at 4 years old.

reported higher satiety responsiveness of their children between 3 and 6 years old revealed the use of food as a reward, more pressure to eat, a less healthy food-related home environment and higher levels of dietary restraint themselves. Thus, behavioural factors within families[6,30,39] (e.g. poor food preparation skills by caregivers, infrequent habit of cooking, low preferences for vegetables and fruits) may also be linked to ultra-processed consumption, which appears to influence the child's satiety responsiveness and may explain our results.

In the current study, when adjusting the models to child's BMI at 4 years of age, we found ultra-processed food consumption at 4 years of age significantly associated with BMI at 10 years. Ultra-processed food consumption early in childhood has been linked to subsequent increases in the waist circumference[16], body fat[2] and blood lipid levels[17,34]. In cross-sectional studies with adolescents, ultra-processed products were positively associated with the occurrence of obesity[14] and the metabolic syndrome[45]. The relationship between ultra-processed products and increased risk of weight gain and health-related problems has been shown[1–3], but little is known about the mechanisms underpinning the association between such foods attributes and increased BMI in children, as well as the understanding of patterns of BMI changes across time. Recent studies have suggested that an increased contribution of ultra-processed foods in diets seems to cause a sustained increase in energy intake rate, and a subsequent longer-term overconsumption and weight gain in adults[32,46]. Besides being a result of the characteristics of ultra-processed foods (such as high energy density and lower satiety potential)[8,46], this increased energy intake rate can also reflect the individual's appetitive drive to eat, particularly hyper-palatable foods.

The strengths of our study are its prospective design and the use of the NOVA classification as a prominent approach to identifying and tracking children's dietary patterns based on the extent and purpose of food processing. Also, it adds to the literature by examining temporal relationships between ultra-processed consumption, appetitive traits and weight gain among children. There is a need for evidence exploring the determinants of appetitive characteristics in children[22]. The current study also has some limitations. First, we should consider that studies on children's eating habits that involve caregiver's report on child dietary intake and appetitive behaviours are particularly susceptible to misreporting and social desirability bias. Furthermore, children's eating behaviours were assessed subjectively through caregiver's report using the P-CEBQ, which can also be influenced by their emotional attitudes towards food. However, the CEBQ subdomains have shown good correlation with objective measures[13] and good psychometric properties in this population[10]. Moreover, the use of a self-administered questionnaire is likely to reduce social desirability bias. On the other hand, this could lead to low response rates. In the present analysis, we were able to recover missing data in cases with more than 50 % of the CEBQ items completed, which minimised the sample losses. In addition, the comparison between children included in the analysis and the remaining cohort suggests that participants have mothers with higher education, which may influence feeding practices and, consequently, children's appetitive traits, being a potential study limitation. However, the magnitude of differences was not high and is likely due to the large sample size and not to systematic differences between participants. Another limitation was that we did not collect CEBQ data at 4 years of age. Nonetheless, parental concerns for problematic eating behaviour of children at 4 years were used as proxies of antecedent eating behaviour and were added to the models.

In conclusion, early ultra-processed consumption influences on later appetitive traits and BMI in childhood. The findings indicate that a higher consumption of ultra-processed foods at pre-school age children may lead to higher food approach behaviours, such as food responsiveness (direct effect), and food avoidant behaviours at 7 years old (indirectly through the mediation of energy intake). In addition, a higher consumption of ultra-processed foods at age 4 was prospectively associated with later increased BMI at 10 years of age, but appetitive behaviours at 7 years old did not mediate this relationship. Further studies should investigate mechanisms underlying the associations of the characteristics of ultra-processed products with dietary, metabolic, behavioural and environmental factors which lead to an increased risk of obesity and associated diseases.

Acknowledgements

The authors gratefully acknowledge the families enrolled in Generation XXI for their kindness, all members of the research team for their enthusiasm and perseverance and the participating hospitals and their staff for their help and support. We also acknowledge the support from the Epidemiology Research Unit (EPI-Unit: UID-DTP/04750/2013; POCI-01-0145-FEDER-006862).

Generation XXI was funded by the Health Operational Programme – Saúde XXI, Community Support Framework III and the Regional Department of Ministry of Health. This study was supported through FEDER from the Operational Programme Factors of Competitiveness – COMPETE and through national funding from the Foundation for Science and Technology – FCT (Portuguese Ministry of Education and Science) under the projects 'Appetite regulation and obesity in childhood: a comprehensive approach towards understanding genetic and behavioural influences' (POCI-01-0145-FEDER-030334; PTDC/SAU-EPI/30334/2017); 'Appetite and adiposity – evidence for gene-environment interplay in children' (IF/01350/2015) and through Investigator Contract (IF/01350/2015 – Andreia Oliveira). It had also support from the Calouste Gulbenkian Foundation.

The authors' responsibilities were as follow: G. M. V. was involved in formulating the research questions, designing the study, analysing and interpreting the data, and writing the first draft of the paper; S. V. and M. S. were involved in analysing and interpreting the data and critically revising the paper; S. R. and C. L. were involved in interpreting the data and critically revising the paper; A. O. was involved in formulating the research questions, designing the study, analysing and interpreting the data, writing and critically revising the paper. All authors read and approved the final manuscript.

The authors declare that there are no conflicts of interest.

References

1. Monteiro CA, Moubarac JC, Levy RB, *et al.* (2018) Household availability of ultra-processed foods and obesity in nineteen European countries. *Public Health Nutr* **21**, 18–26.
2. Costa CS, Del-Ponte B, Assunção MCF, *et al.* (2018) Consumption of ultra-processed foods and body fat during childhood and adolescence: a systematic review. *Public Health Nutr* **21**, 148–159.
3. Monteiro CA, Cannon G, Moubarac JC, *et al.* (2018) The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. *Public Health Nutr* **21**, 5–17.
4. Poti JM, Braga B & Qin B (2017) Ultra-processed food intake and obesity: what really matters for health-processing or nutrient content? *Curr Obes Rep* **6**, 420–431.
5. Poti JM, Mendez MA, Ng SW, *et al.* (2015) Is the degree of food processing and convenience linked with the nutritional quality of foods purchased by US households? *Am J Clin Nutr* **101**, 1251–1262.
6. Lam MCL & Adams J (2017) Association between home food preparation skills and behaviour, and consumption of ultra-processed foods: cross-sectional analysis of the UK National Diet and nutrition survey (2008–2009). *Int J Behav Nutr Phys Act* **14**, 68.
7. Schulte EM, Avena NM & Gearhardt AN (2015) Which foods may be addictive? The roles of processing, fat content, and glycemic load. *PLOS ONE* **10**, e0117959.
8. Fardet A (2016) Minimally processed foods are more satiating and less hyperglycemic than ultra-processed foods: a preliminary study with 98 ready-to-eat foods. *Food Funct* **7**, 2338–2346.
9. Small DM & DiFeliceantonio AG (2019) Processed foods and food reward. *Science* **363**, 346–347.
10. Albuquerque G, Severo M & Oliveira A (2017) Early life characteristics associated with appetite-related eating behaviors in 7-year-old children. *J Pediatr* **180**, 38–46.e32.
11. Wardle J (2007) Eating behaviour and obesity. *Obes Rev* **8**, Suppl. 1, 73–75.
12. Wardle J, Guthrie CA, Sanderson S, *et al.* (2001) Development of the children's eating behaviour questionnaire. *J Child Psychol Psychiatry* **42**, 963–970.
13. Carnell S & Wardle J (2007) Measuring behavioural susceptibility to obesity: validation of the child eating behaviour questionnaire. *Appetite* **48**, 104–113.
14. Louzada ML, Baraldi LG, Steele EM, *et al.* (2015) Consumption of ultra-processed foods and obesity in Brazilian adolescents and adults. *Prev Med* **81**, 9–15.
15. Costa S, Pinto A, Santos AC, *et al.* (2019) The association of problematic eating behaviours with food quality and body mass index at 7 years of age. *Eur J Clin Nutr* **73**, 549–557.
16. Costa C, Rauber F, Leffa P, *et al.* (2019) Ultra-processed food consumption and its effects on anthropometric and glucose profile: a longitudinal study during childhood. *Nutr Metab Cardiovasc Dis* **29**, 177–184.
17. Leffa PS, Hoffman DJ, Rauber F, *et al.* (2020) Longitudinal associations between ultra-processed foods and blood lipids in childhood. *Br J Nutr* **124**, 341–348.
18. Larsen PS, Kamper-Jørgensen M, Adamson A, *et al.* (2013) Pregnancy and birth cohort resources in Europe: a large opportunity for aetiological child health research. *Paediatr Perinat Epidemiol* **27**, 393–414.
19. Vilela S, Severo M, Moreira T, *et al.* (2019) Evaluation of a short food frequency questionnaire for dietary intake assessment among children. *Eur J Clin Nutr* **73**, 679–691.
20. Moreira T, Severo M, Oliveira A, *et al.* (2015) Eating out of home and dietary adequacy in preschool children. *Br J Nutr* **114**, 297–305.
21. U.S. Department of Agriculture, Agricultural Research Service (2003) *USDA National Nutrient Database for Standard Reference*. Beltsville, MD: USDA.
22. Ashcroft J, Semmler C, Carnell S, *et al.* (2008) Continuity and stability of eating behaviour traits in children. *Eur J Clin Nutr* **62**, 985–990.
23. Engels JM & Diehr P (2003) Imputation of missing longitudinal data: a comparison of methods. *J Clin Epidemiol* **56**, 968–976.
24. Vilela S, Hetherington MM, Oliveira A, *et al.* (2018) Tracking diet variety in childhood and its association with eating behaviours related to appetite: the Generation XXI birth cohort. *Appetite* **123**, 241–248.
25. Gibson RS (2005) *Principles of Nutritional Assessment*, 2nd ed. New York: Oxford University Press.
26. WHO Multicentre Growth Reference Study Group (2006) *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: World Health Organization.
27. Landis JR & Koch GG (1977) The measurement of observer agreement for categorical data. *Biometrics* **33**, 159–174.
28. Durão C, Severo M, Oliveira A, *et al.* (2017) Association between dietary patterns and adiposity from 4 to 7 years of age. *Public Health Nutr* **20**, 1973–1982.
29. Vandevijvere S, De Ridder K, Fiolet T, *et al.* (2019) Consumption of ultra-processed food products and diet quality among children, adolescents and adults in Belgium. *Eur J Nutr* **58**, 3267–3278.
30. Fildes A, Mallan KM, Cooke L, *et al.* (2015) The relationship between appetite and food preferences in British and Australian children. *Int J Behav Nutr Phys Act* **12**, 116.

British Journal of Nutrition

31. Belfort-DeAguiar R & Seo D (2018) Food cues and obesity: overpowering hormones and energy balance regulation. *Curr Obes Rep* **7**, 122–129.
32. Hall KD, Ayuketah A, Brychta R, *et al.* (2019) Ultra-processed diets cause excess calorie intake and weight gain: an inpatient randomized controlled trial of ad libitum food intake. *Cell Metab* **30**, 67–77.e63.
33. Brown CL, Vander Schaaf EB, Cohen GM, *et al.* (2016) Association of picky eating and food neophobia with weight: a systematic review. *Child Obes* **12**, 247–262.
34. Rauber F, Campagnolo PDB, Hoffman DJ, *et al.* (2015) Consumption of ultra-processed food products and its effects on children's lipid profiles: a longitudinal study. *Nutr Metab Cardiovasc Dis* **25**, 116–122.
35. Cornwell B, Villamor E, Mora-Plazas M, *et al.* (2018) Processed and ultra-processed foods are associated with lower-quality nutrient profiles in children from Colombia. *Public Health Nutr* **21**, 142–147.
36. Vilela S, Severo M, Moreira T, *et al.* (2019) Association between eating frequency and eating behaviours related to appetite from 4 to 7 years of age: findings from the population-based birth cohort Generation XXI. *Appetite* **132**, 82–90.
37. Cole NC, An RP, Lee SY, *et al.* (2017) Correlates of picky eating and food neophobia in young children: a systematic review and meta-analysis. *Nutr Rev* **75**, 516–532.
38. Taylor CM, Wernimont SM, Northstone K, *et al.* (2015) Picky/fussy eating in children: review of definitions, assessment, prevalence and dietary intakes. *Appetite* **95**, 349–359.
39. Tharner A, Jansen PW, Kiefte-de Jong JC, *et al.* (2014) Toward an operative diagnosis of fussy/picky eating: a latent profile approach in a population-based cohort. *Int J Behav Nutr Phys Act* **11**, 14.
40. Lafraire J, Rioux C, Giboreau A, *et al.* (2016) Food rejections in children: cognitive and social/environmental factors involved in food neophobia and picky/fussy eating behavior. *Appetite* **96**, 347–357.
41. Powell FC, Farrow CV & Meyer C (2011) Food avoidance in children. The influence of maternal feeding practices and behaviours. *Appetite* **57**, 683–692.
42. Hendy HM, Williams KE, Riegel K, *et al.* (2010) Parent mealtime actions that mediate associations between children's fussy-eating and their weight and diet. *Appetite* **54**, 191–195.
43. Russell CG, Worsley A & Campbell KJ (2015) Strategies used by parents to influence their children's food preferences. *Appetite* **90**, 123–130.
44. Brown A & Lee M (2015) Early influences on child satiety-responsiveness: the role of weaning style. *Pediatr Obes* **10**, 57–66.
45. Tavares LF, Fonseca SC, Rosa MLG, *et al.* (2012) Relationship between ultra-processed foods and metabolic syndrome in adolescents from a Brazilian Family Doctor Program. *Public Health Nutr* **15**, 82–87.
46. Forde CG, Mars M & De Graaf K (2020) Ultra-processing or oral processing? A role for energy density and eating rate in moderating energy intake from processed foods. *Curr Dev Nutr* **4**, nzaa019.

British Journal of Nutrition