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Food cognition: The crossroads of psychology, neuroscience and nutrition

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Food cognition: The crossroads of psychology, neuroscience and nutrition

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Editorial: Food cognition: the crossroads of psychology, neuroscience and nutrition

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Editorial on the Research Topic
Food cognition: the crossroads of psychology, neuroscience and nutrition

Every day we make several food choices, some of which are better than others with regards to our physical and brain health (1). These decisions are based on various factors such as our primary needs to restore homeostasis in the body, reward mechanisms related to pleasure and higher-level goals, such as healthy or ethical diets (i.e., *vegetarianism, veganism, sustainable diets*). Food characteristics that influence our dietary choices have been categorized into (i) *basic* attributes, such as taste, and (ii) *abstract* attributes such as healthiness (2). The brain assigns value to these attributes while reaching the decision to ingest a certain food or not. Additionally, the nutritional composition of the foods that we ingest influences both our physical and brain health (3).

For a given food, such value can also vary depending on the individual's current metabolic and psycho-physiological states (i.e., *hunger*), memories, or environment in which the food occurs (4). Therefore, it is essential to approach the question of how food choices are made from a multidisciplinary perspective, including sensory science, nutrition, psychology, medicine, and neuroscience. The purpose of this Research Topic was to collate findings from these different disciplines to shed new light on the underlying brain mechanisms, how nutrition affects cognition and wellbeing across our lifespan in healthy and clinical populations.

Two reviews are presented as overviews to the topics covered. First, the opinion manuscript by Devoto et al., presents the external (environmental and food-specific) and internal (biological and psychological) factors guiding neural responses to food-cues. The presented model, expanded from a model originally proposed in the domain of drug addictions, may serve as a theoretical framework for experimental studies as well as the development of diagnostic tools and targeted clinical treatments for eating behaviors. Second, the review from Pearce et al. describes the mechanisms that underlie reinforcement learning and value-based decision making in the context of food choices. The authors argue that incorporating neurocognitive frameworks, such as *sign-* vs. *goal-tracking* phenotypes and *model-free* vs. *model-based* learning, can enhance our comprehension of eating behaviors like cravings, habits, and food addictions. Understanding the brain's responses to environmental food cues is essential, especially in Western societies, where obesogenic environments prevail.

Then the collection moves on to address how diet and nutrition impact our cognition. For example, Muth et al. present how a healthy diet and lifestyle act as a protective factor in contrasting negative mental health outcomes, reporting data from the crucial stressful times of COVID-19 pandemic. Food intake was tracked *via* the smartphone *FoodApp*, and the authors found that higher intakes of fruit and vegetable and physical activity during COVID-19 pandemic lockdowns were associated with higher mood levels and wellbeing in a German sample. In another study, Terenzi et al. show the role of social factors (i.e., *loneliness*) and dietary intake (measured *via* the *FoodApp*) during COVID-19 pandemic lockdowns in the development of conspiracy theories and psychotic-like experiences. Such subclinical symptoms were associated with lower fruit, carbohydrate, and iron intakes, as well as with higher fat intake.

The impact of eating behaviors on cognition has been studied in specific clinical populations, such as individuals with eating disorders, and during critical periods of life such as pregnancy or childhood, when individuals are learning about new foods.

For instance, an individual's weight status has a fundamental impact on their food intake, food preferences, and overall cognition and brain structures. Lakritz et al. have shown that individuals with Anorexia Nervosa and Orthorexia hold implicit associations between food variables that cue energy density (i.e., *processed foods*) and moral attributes differently than the general population. The moralization of food appears to be pervasive in such individuals, and such results present an important experimental and diagnostic tool less vulnerable to self-presentation and social desirability bias as explicit association measures. Foinant et al. show that children's food neophobia, namely the fear for new foods, influences how they represent different types of foods. Neophobic children, who tend to eat less fruit and vegetables, miscategorized foods as foods in a food/non-food categorization task compared to the neophilic counterparts. In the review manuscript by Waclawek and Park, it is shown that pregnancy represents a critical period in which changes in the endocrine, cognitive, and reward systems have been shown to take place. During pregnancy, alterations in metabolic modulations, dietary intake (maternal high-fat diets), and brain functioning (such as reduced gray matter, executive functions, and worse memory) represent an important model for understanding eating behaviors.

Additionally, the collection presents experimental findings that demonstrate the impact of environmental and social factors on food choices. For instance, Masento et al. found that vegetable intake of preschool children significantly changed across Italian, Polish and British samples, with the Polish sample having the highest number of portions of vegetables per day. The results suggest that healthy eating interventions for children must take into account the specific needs of the countries where they are implemented.

Moreover, DeJesus investigated parent judgments about foods for infants and found that parents rated foods they were familiar with as more appropriate for their infants. Additionally, the adults' own pickiness was related to what they would eat but not to what they would offer to infants, namely the adults would choose foods for the infants that they themselves would not consume. Such findings are important for social modeling behaviors such as adults demonstrating eating and actual liking of the offered foods to infants. Li et al. have shown that in China a higher nutritional literacy, which involves obtaining, understanding, and using accurate nutrition information to make healthy food choices, was linked to a lower prevalence of obesity among adolescents.

Finally, the collection concludes with a study emphasizing the significance of the evaluation context in which such food choices and behaviors are assessed. In Plaza et al. study, participants rated bread and pizza items of varying culinary preparation levels (e.g., homemade, ready-made, and a combination of the two) in a university cafeteria setting. The study employed both simple questions (*synthetic*) and questions with intensity attributes (*analytical*) to measure liking scores. The authors found that homemade pizza received lower liking scores (hedonic judgment) in the analytical task. The authors stress the fact that these findings highlight the importance of considering the evaluation task as part of the assessment context when designing ecologically valid consumer tests.

Taken together the work presented in our Research Topic shows that a multidisciplinary understanding of eating behaviors can lead to advancement in theoretical frameworks on food-related behaviors and can help in designing interventions promoting healthy and sustainable eating.

Author contributions

CC and CR conceived the original idea of the Research Topic and wrote the Editorial. CC, CR, and LT reviewed and finalized the Editorial. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Association Between Nutrition Literacy and Overweight/Obesity of Adolescents: A Cross–Sectional Study in Chongqing, China

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Objective: The burden of overweight and obesity in adolescents is increasing rapidly. This study aimed to assess the association between nutrition literacy and overweight/obesity among adolescents in China.

Methods: This cross–sectional online study involving adolescents aged 10–18 years was conducted in September 2020 in 239 schools in Chongqing China. Overweight and obese adolescents were determined based on the International Obesity Task Force's recommended age–sex specific body mass index cutoff points. Nutrition literacy was measured using the "Nutrition literacy scale for middle school students in Chongqing (CM–NLS)." The CM–NLS included three subdomains (functional nutritional literacy, interactive nutrition literacy, and critical nutrition literacy). Multinomial logistic regression model was used to examine the association.

Results: A total of 18,176 adolescents (49.8% girls) were included. The prevalence of overweight and obesity was 9.6% and 17.0%, respectively. Compared with those having a low nutrition literacy score (below median), those with a high score were less likely to be overweight and obese. The odds ratio (95% CI) for overweight was 0.87 (0.79–0.97) (nutrition literacy) and 0.81 (0.73–0.90) (functional nutritional literacy). The corresponding figures for obesity were 0.84 (0.77–0.91) and 0.73 (0.67–0.80), respectively. Significant interaction existed between grade and nutrition literacy. The inverse association between nutrition literacy and overweight/obesity was significant among those in senior school but not among those in junior high school.

Conclusion: Nutrition literacy was inversely associated with overweight/obesity among adolescents, especially those attending senior high schools.

Keywords: nutrition literacy, overweight, obesity, body mass index, adolescents, Chongqing

INTRODUCTION

Overweight and obesity are some of the most serious public health problems today. The World Health Organization declared that over 340 million children and adolescents were overweight or obese worldwide in 2016. The number of obese children and adolescents (aged 5–19 years) had risen ten–fold over the past four decades (1), and the rising trends is accelerating in parts of Asia (2). According to the Report on Nutrition and Chronic Diseases in China (2020), the prevalence of overweight/obesity among children and adolescents was nearly 20% (3). Being overweight or obese during childhood and adolescence is associated with adverse health consequences, such as being more likely to be obese in adulthood (4), and is a major risk factor for chronic diseases (5), including diabetes, cardiovascular disease, and some cancers (6, 7).

Overweight and obesity can be prevented by choosing healthier foods and regular physical activity. Adolescence is a crucial stage for developing dietary habits, influenced by nutrition knowledge and other factors (8). Nutrition literacy (NL) is associated with overall food habits (9, 10). It is defined as obtaining, understanding, and using correct nutrition information and nutrition knowledge to make healthy food choices (11). Krause et al. (12) classified NL into three subdomains, namely, functional NL (FNL), the ability to obtain and process nutrition information to improve decisions about nutrition; interactive NL (INL), the ability to utilize different forms of communication to obtain and apply relevant nutrition information; and critical NL (CNL), the ability to critically assess and reflect on nutrition information.

Nutrition literacy is a new field of study, and its concept originates from health literacy (13). Existing studies have shown the correlation of children's health literacy with overweight and obesity. A recent review based on 32 studies conducted in children ($n = 4$) and adults ($n = 28$) found that health literacy is a determinant in obesity control (14). A study of 162,209 sixth–grade (11–12 years old) students in Taiwan showed that students with higher health literacy are less likely to be obese (15). A study from Australia suggested that interventions on adolescent obesity should improve their NL and skills (16).

Existing studies on the association between NL and overweight/obesity were primarily conducted in adults (17). One study has revealed no association between NL with BMI (18). However, another research has shown that lower NL is more problematic for weight loss (19). Few studies have explored the relationship between NL and overweight/obesity. An enhanced understanding of the effect of adolescents' NL on overweight/obesity may play a positive role in obesity prevention and control. One of our previous studies assessed the determinants of NL and found that ethnicity, grade, residence, whether receiving school meal support from the government, primary caregiver, parents' education level, and BMI are related NL among adolescents [20]. The current study aimed to explore the relationship between NL and overweight/obesity among adolescents in Chongqing China. And we hypothesized that the low levels of NL and three subdomains were all associated with a high prevalence of overweight/obesity among adolescents.

MATERIALS AND METHODS

Study Design and Sample

This cross–sectional online study was conducted in September 2020. We selected 29 of 38 administrative areas and 239 schools in Chongqing as the survey sites. The convenience sampling method was utilized with the online survey platform "Questionnaire Star," which is a professional online survey platform in China. Then, the questionnaire link or QR code was sent to each regional school health workgroup through the Chongqing Municipal Education Commission. The school health worker forwarded the questionnaire to the class teacher of grades 7, 8, 10, and 11, and the teacher guided the students to complete the questionnaire. Students completed the questionnaire anonymously and independently in 10–15 min.

A total of 21,084 students (grades 7, 8, 10, and 11) participated in the survey. We excluded participants with extreme values of NL score (NL score < 5% centile, or NL score > 95% centile, $n = 917$), extreme BMI values (BMI < 1% centile, or > 99% centile, $n = 484$), and those reported "don't know" of their parents' education ($n = 1,507$). Finally, 18,176 participants aged 10–18 years were included in the study. The study was approved by the Ethics Committee of Chongqing Medical University (approval number: 2021041). All participants were informed about the study, and consents were obtained before the survey.

Outcome Variable: Overweight and Obesity

Height and weight were self–reported by the students. According to the regulations in China (20), schools need to organize physical examinations for students at the start of the school year in the spring and autumn. Thus, students' self–reported height and weight are more likely to be valid unless intentional over– or under–reporting of weight. Body mass index (BMI) was calculated and classified as underweight, normal, overweight, and obese based on the International Obesity Task Force cutoffs (21).

Exposure Variable: NL Score

Nutrition literacy was measured based on the "Nutrition literacy scale for middle school students in Chongqing (CM–NLS)." The development of the scale is described elsewhere (22). It includes three subdomains (FNL, INL, and CNL). The scale had been tested for its validity (KMO = 0.916) and reliability (Cronbach's α of the total scale and three subdomains = 0.849, 0.826, 0.942, 0.938, respectively) among 462 middle school students (23). The validity (KMO = 0.945) and reliability (Cronbach's α of the total scale and three subdomains = 0.899, 0.792, 0.925, 0.927, respectively) test of the 18,176 adolescents was also conducted.

The CM–NLS comprises 52 items (the specific items of FNL/INL/CNL are shown in the **Supplementary Material**). FNL includes 35 items with three skills, namely, obtain skill, understand skill, and apply skill. INL includes 5 items with interact skill. CNL comprises 12 items with media literacy and critical skill. To make the score comparable, we converted it into a centesimal for a sum score (0 to 100 points) of the total and three subdomains, with a higher score indicating a better NL level. The scores of NL, FNL, INL, and CNL were divided into

TABLE 1 | Distribution by levels of nutrition literacy across demographic characteristics.

Factor	Total *N* = 18,176	Nutrition Literacy (NL)		p^a	Functional Nutrition Literacy (FNL)		p^a	Interactive Nutritional Literacy (INL)		p^a	Critical Nutrition Literacy (CNL)		p^a
		Low N = 9,434	High *n* = 8,742		Low *n* = 9,753	High *n* = 8,423		Low *n* = 9,134	High *n* = 9,042		Low *n* = 8,603	High *n* = 9,573	
Gender													
Boy	9118 (50.2)	4802 (50.9)	4316 (49.4)	0.040	5047 (51.7)	4071 (48.3)	<0.001	4623 (50.6)	4495 (49.7)	0.220	4300 (50.0)	4818 (50.3)	0.640
Girl	9058 (49.8)	4632 (49.1)	4426 (50.6)		4706 (48.3)	4352 (51.7)		4511 (49.4)	4547 (50.3)		4303 (50.0)	4755 (49.7)	
Grade													
Junior high school	7858 (43.2)	4456 (47.2)	5862 (67.1)	<0.001	4378 (44.9)	5940 (70.5)	<0.001	4424 (48.4)	5894 (65.2)	<0.001	4818 (56.0)	5500 (57.5)	0.049
Senior high school	10318 (56.8)	4978 (52.8)	2880 (32.9)		5375 (55.1)	2483 (29.5)		4710 (51.6)	3148 (34.8)		3785 (44.0)	4073 (42.5)	
Ethnicity													
Han	16137 (88.8)	8044 (85.3)	8093 (92.6)	<0.001	8263 (84.7)	7874 (93.5)	<0.001	7876 (86.2)	8261 (91.4)	<0.001	7570 (88.0)	8567 (89.5)	0.001
Minority	2039 (11.2)	1390 (14.7)	649 (7.4)		1490 (15.3)	549 (6.5)		1258 (13.8)	781 (8.6)		1033 (12.0)	1006 (10.5)	
Boarding school													
No	6251 (34.4)	2696 (28.6)	3555 (40.7)	<0.001	2615 (26.8)	3636 (43.2)	<0.001	2823 (30.9)	3428 (37.9)	<0.001	2909 (33.8)	3342 (34.9)	0.12
Yes	11925 (65.6)	6738 (71.4)	5187 (59.3)		7138 (73.2)	4787 (56.8)		6311 (69.1)	5614 (62.1)		5694 (66.2)	6231 (65.1)	
Residence													
Urban	8839 (48.6)	4111 (43.6)	4728 (54.1)	<0.001	4156 (42.6)	4683 (55.6)	<0.001	4362 (47.8)	4477 (49.5)	0.018	4000 (46.5)	4839 (50.5)	<0.001
Rural	9337 (51.4)	5323 (56.4)	4014 (45.9)		5597 (57.4)	3740 (44.4)		4772 (52.2)	4565 (50.5)		4603 (53.5)	4734 (49.5)	
Primary caregiver													
Parents	12961 (71.3)	6579 (69.7)	6382 (73.0)	<0.001	6846 (70.2)	6115 (72.6)	<0.001	6456 (70.7)	6505 (71.9)	0.060	6072 (70.6)	6889 (72.0)	0.040
Others[b]	5215 (28.7)	2855 (30.3)	2360 (27.0)		2907 (29.8)	2308 (27.4)		2678 (29.3)	2537 (28.1)		2531 (29.4)	2684 (28.0)	
Father's education													
Low[c]	4055 (22.3)	2446 (25.9)	1609 (18.4)	<0.001	2571 (26.4)	1484 (17.6)	<0.001	2232 (24.4)	1823 (20.2)	<0.001	2042 (23.7)	2013 (21.0)	<0.001
Medium[d]	9284 (51.1)	4837 (51.3)	4447 (50.9)		5036 (51.6)	4248 (50.4)		4493 (49.2)	4791 (53.0)		4389 (51.0)	4895 (51.1)	
High[e]	4837 (26.6)	2151 (22.8)	2686 (30.7)		2146 (22.0)	2691 (31.9)		2409 (26.4)	2428 (26.9)		2172 (25.2)	2665 (27.8)	
Mother's education													
Low[c]	5711 (31.4)	3475 (36.8)	2236 (25.6)	<0.001	3655 (37.5)	2056 (24.4)	<0.001	3134 (34.3)	2577 (28.5)	<0.001	2862 (33.3)	2849 (29.8)	<0.001
Medium[d]	8313 (45.7)	4172 (44.2)	4141 (47.4)		4350 (44.6)	3963 (47.0)		3989 (43.7)	4324 (47.8)		3888 (45.2)	4425 (46.2)	
High[e]	4152 (22.8)	1787 (18.9)	2365 (27.1)		1748 (17.9)	2404 (28.5)		2011 (22.0)	2141 (23.7)		1853 (21.5)	2299 (24.0)	

[a] *Chi–square test showing distribution by levels of NL across demographic characteristics.*
[b] *Grandparents and relatives.*
[c] *Elementary school and below.*
[d] *Junior high school.*
[e] *High/technical/vocational/college/undergraduate and above.*

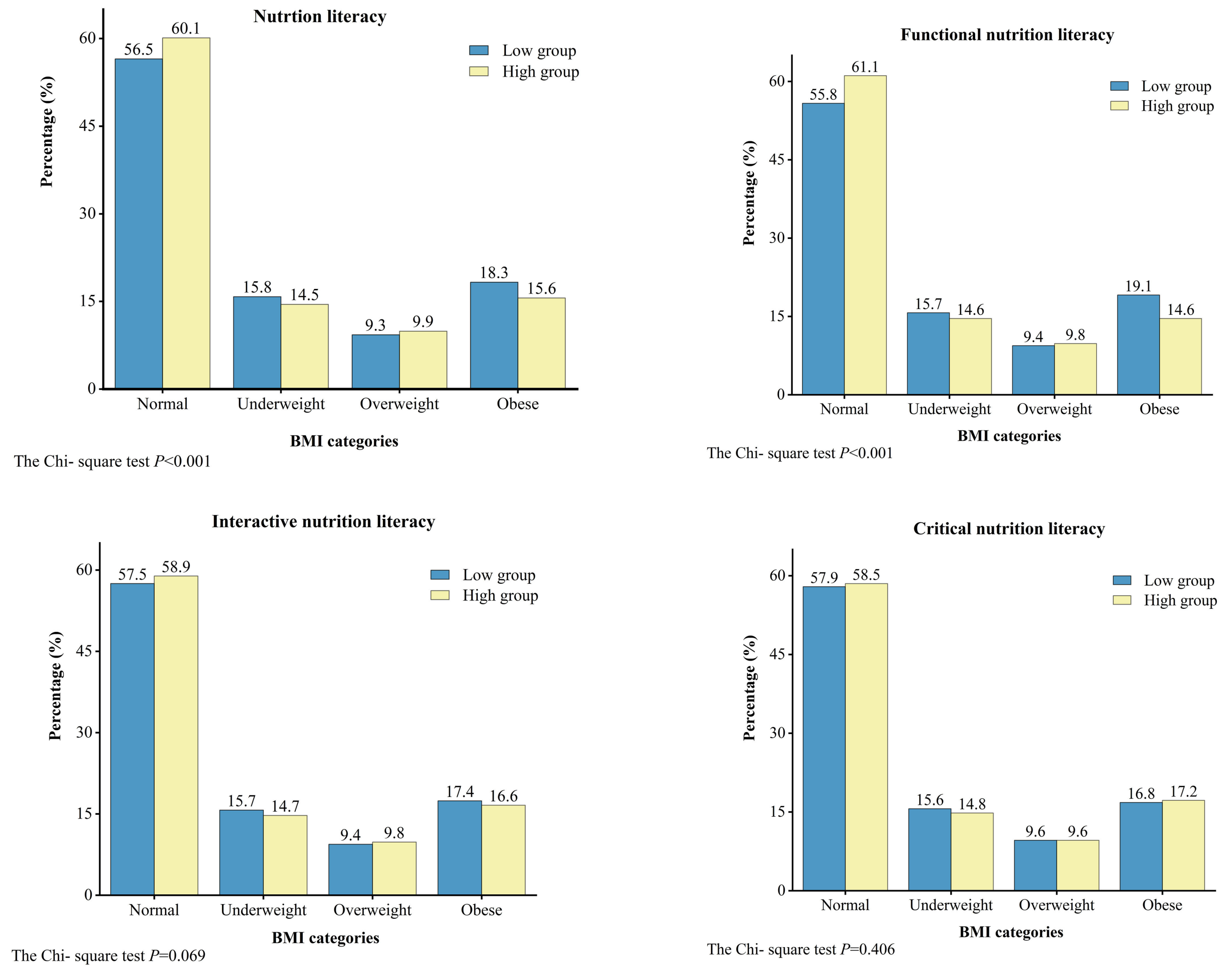

FIGURE 1 | Distribution of underweight, overweight, and obese in different nutrition literacy levels .

low and high levels based on their median scores (61.9, 68.7, 70.0, and 45.8, respectively).

Covariates

The following variables were treated as covariates: gender, grade (junior high school included grade 7 and 8, whereas senior high school included grade 10 and 11), ethnicity (Han and minority), residence (urban and rural), primary caregiver (parents and others), and parent's education (low, elementary school, and below; medium, junior high school; and high, high school, or above). As a high proportion of students lived in school (boarding school), we treated it as a covariate.

Statistical Analysis

Descriptive statistics included frequencies and percentages of research variables. The Chi–square test was used to analyze the associations between the category of BMI and NL, as well as other covariates. Multinomial logistic regression model was used to analyze the association between NL and BMI categories. Two models were established as follows: model 1 was not adjusted; and model 2 was adjusted for gender, grade, ethnicity, boarding school, residence, primary caregiver, and parent's education. We tested multiplicative interaction between NL and demographic characteristics (gender, grade, ethnicity, boarding in school, residence, and primary caregiver) by adding the product of the variables in a multivariable model.

All analyses were performed using STATA version 16.0 (STATA Corporation, College Station, TX, USA). Statistical significance was considered when $p < 0.05$ (two–sided).

RESULTS

Sample Description

Table 1 summarizes the demographic characteristics of 18,176 middle school students. The median age of students was 14 years (range 10–18 years). In the sample, 50.2% of the participants were boys, 43.2% were junior high school students, 88.8%

TABLE 2 | Multinomial logistic regression model of the association between BMI categories and nutrition literacy.

Factor	Model 1[a]		Model 2[b]	
	Odds Ratio (95% CI)	*p*–value	Odds Ratio (95% CI)	*p*–value
Nutrition Literacy (NL)				
Normal (Ref)				
Underweight	0.86 (0.79–0.93)	<0.001	0.91 (0.83–0.99)	0.029
Overweight	1.00 (0.90–1.10)	0.954	0.87 (0.79–0.97)	0.012
Obese	0.80 (0.74–0.86)	<0.001	0.84 (0.77–0.91)	<0.001
Functional Nutrition Literacy (FNL)				
Normal (Ref) Underweight	0.85 (0.78–0.93)	<0.001	0.92 (0.84–1.00)	0.060
Overweight	0.96 (0.86–1.06)	0.400	0.81 (0.73–0.90)	<0.001
Obese	0.70 (0.64–0.76)	<0.001	0.73 (0.67–0.80)	<0.001
Interactive Nutritional Literacy (INL)				
Normal (Ref) Underweight	0.91 (0.84–0.99)	0.035	0.95 (0.87–1.04)	0.252
Overweight	1.01 (0.91–1.12)	0.831	0.95 (0.86–1.06)	0.365
Obese	0.93 (0.86–1.00)	0.065	0.94 (0.87–1.02)	0.148
Critical Nutrition Literacy (CNL)				
Normal (Ref) Underweight	0.93 (0.86–1.01)	0.107	0.94 (0.87–1.03)	0.171
Overweight	0.99 (0.89–1.09)	0.764	0.96 (0.86–1.06)	0.410
Obese	1.01 (0.93–1.09)	0.855	1.02 (0.95–1.12)	0.495

[a] *Model 1 unadjusted.*
[b] *Model 2 adjusted for gender, grade, ethnicity, primary caregiver, parent's education, boarding school, and residence.*

were of Han ethnicity, 65.6% were in boarding school, 48.6% lived in urban area, and 71.3% of the participant's primary caregivers were parents. The prevalence of overweight and obesity was 9.6% and 17.0%, respectively. Across the levels of NL, the participants of Han nationality who were living in an urban area had a higher rate of of NL, FNL, INL, and CNL. Girls and participants whose primary caregivers were parents also had a higher rate of elevated levels of NL and FNL. Compared with senior high school students, junior high school students had a higher level of all domains of NL. Students who were in boarding school had higher NL levels than their counterparts. And the results showed that the levels of NL varied between different levels of parents' education ($p < 0.001$).

Association Between NL and BMI Categories

The results of Chi–square test for two–by–two comparisons showed that participants with high levels of NL and FNL had a lower prevalence of obesity than those with low levels (**Figure 1**). The prevalence of obesity was higher in low NL (18.3%) and low FNL (19.1%) groups than in high NL (15.6%) and high FNL (14.6%) groups, respectively ($p < 0.001$). However, no difference existed in the prevalence of obesity by levels of INL and CNL.

In the fully adjusted model, compared with those having lower NL, those with higher NL were less likely to be underweight or overweight/obese (**Table 2**). The odds ratios (95% CI) for underweight, overweight, and obese were 0.91 (95% CI = 0.83–0.99), 0.87 (95% CI = 0.79–0.97), and 0.84 (95% CI = 0.77–0.91). Higher FNL was inversely associated with overweight (0.81; 95% CI 0.73–0.90) and obesity (0.73; 95% CI = 0.67–0.80). However, INL and CNL were not associated with underweight or overweight/obesity.

Subgroup Analyses of the Association Between NL and BMI Categories

No interactions of NL, FNL, INL, and CNL with gender, ethnicity, boarding in school, residence, and primary caregiver in relation to overweight/obesity were observed (**Table 3**). A significant NL ($p = 0.009$), FNL ($p = 0.003$), and grade interaction was observed. In participants from senior high school, NL and FNL were inversely associated with overweight/obesity. However, no such association was found in junior high school students.

An association between NL and overweight/obesity was found across genders, residence (urban and rural), and participants from the Han nationality, not boarding in school, and primary caregiver was parents. For the three subdomains, the association between FNL and overweight/obese was similar across genders, grade, ethnicity, boarding school, residence, and primary caregiver. An association between INL and overweight/obesity was found among senior high school students, Han ethnicity, in boarding school, and the primary caregiver was parents. However, no significant association between CNL and overweight/obesity existed across genders, grade, ethnicity, boarding in school, residence, and primary caregiver.

DISCUSSION

Given the importance of promoting NL among adolescents and in light of surging obesity levels, this cross–sectional study in a large population–based sample examined the relative contributions of NL to overweight/obesity among middle school students in Chongqing. Our results showed that the prevalence

TABLE 3 | Subgroup analyses of the association between BMI categories and nutrition literacy.

Factor	NL	p^a	FNL	p^a	INL	p^a	CNL	p^a
	High vs. Low		**High vs. Low**		**High vs. Low**		**High vs. Low**	
Gender								
Boy	0.85 (0.78–0.92)**	0.333	0.82 (0.75–0.90) **	0.857	0.94 (0.87–1.03)	0.639	0.95 (0.87–1.03)	0.332
Girl	0.90 (0.83–0.98)*		0.81 (0.74–0.88) **		0.95 (0.88–1.04)		1.02 (0.93–1.11)	
Grade								
Junior high school	0.93 (0.86–1.01)	0.009	0.83 (0.76–0.90) **	0.379	1.02 (0.94–1.10)	0.003	1.02 (0.94–1.10)	0.163
Senior high school	0.78 (0.71–0.86)**		0.77 (0.70–0.85) **		0.85 (0.77–0.93) **		0.93 (0.85–1.02)	
Ethnicity								
Han	0.87 (0.82–0.93)**	0.937	0.80 (0.75–0.85) **	0.436	0.93 (0.87–0.99) *	0.198	0.98 (0.92–1.04)	0.652
Minority	0.87 (0.71–1.05)		0.88 (0.71–1.08)		1.05 (0.88–1.27)		1.02 (0.85–1.21)	
Boarding school								
No	0.87 (0.79–0.97) *	0.958	0.80 (0.72–0.88) **	0.660	1.03 (0.93–1.14)	0.061	0.95 (0.86–1.05)	0.393
Yes	0.87 (0.81–0.94)		0.81 (0.75–0.88) **		0.90 (0.84–0.97) **		1.00 (0.93–1.08)	
Residence								
Urban	0.87 (0.80–0.95) *	0.989	0.82 (0.75–0.90) **	0.706	0.95 (0.87–1.04)	0.945	0.97 (0.89–1.06)	0.801
Rural	0.87 (0.79–0.94) **		0.79 (0.73–0.87) **		0.94 (0.86–1.02)		0.99 (0.91–1.07)	
Primary caregiver								
Parents	0.85 (0.79–0.91) **	0.349	0.79 (0.74–0.85) **	0.663	0.91 (0.85–0.98) **	0.098	1.01 (0.90–1.04)	0.486
Others	0.92 (0.82–1.02)		0.83 (0.74–0.93) *		1.04 (0.93–1.16)		0.97 (0.90–1.13)	

Model adjusted for gender, grade, ethnicity, primary caregiver, parent's education, boarding school, and residence.
[a] *p for interaction.*
$^*p < 0.05$, $^{**}p < 0.01$.

of overweight and obesity in low (27.6%) and high (25.5%) NL groups was higher than the national average (19.0%) based on the Report on Nutrition and Chronic Diseases in China (2020) (3). Moreover, consistent with our hypothesis, NL and FNL was inversely associated with the prevalence of overweight/obesity. But no difference was observed in the prevalence of underweight or overweight/obesity by levels of INL and CNL. These findings, along with several other interesting results, raise theoretical references for interventions of preventing and controlling obesity of adolescents.

To the best of our knowledge, few studies have examined the association between NL of adolescents and BMI or overweight/obesity. Our previous studies found that BMI is a determinant of NL among middle school students in Chongqing, China (24). Using multinomial logistic regression model and subgroup analyses, our findings suggested inverse relationships between NL, FNL, and overweight/obesity, different from some previous studies (11, 18). Several explanations were considered for these findings. Previous researchers have demonstrated that NL significantly affects healthy eating behavior (25, 26) and positively changes the food habits (9) and choices (27) of the adolescents. Overall diet quality was shown to decrease with age as adolescents (28), but it can be mitigated with the attainment of NL (29, 30). Additionally, NL is a significant element of dietary diversity and nutrient sufficiency in adolescents (31). Simultaneously, adolescents who have higher FNL are less likely to be overweight/obese compared with those having lower FNL. People with poor NL tend to consume more fried foods, sugared beverages, red meat, and processed foods, whereas those with good NL consume more vegetables, olive oil, and nuts (10). And a study has shown that increased FNL is associated with lower sugar intake, higher dairy intake, and better energy balance, which positively affect adolescent weight status (30). Prior research has shown that high INL is associated with increased energy score, and high CNL leads to increased consumption of fruits and vegetables (30). In another study (32), INL such as frequency of reading food labels was not a significant predictor of dietary intake. In the current study, INL and CNL were not associated with underweight or overweight/obesity. We proposed several possible reasons for this phenomenon. On the one hand, adolescents may not have enough opportunities to practice knowledge of INL and CNL, as their food habits are determined to a large extent by their schools and parents (33). On the other hand, having high INL/CNL does not mean that the students have the corresponding attitude and can apply knowledge well to critically evaluate nutrition information and handle nutrition problems (34). In this context, schools and teachers should play a leading role in addressing and preventing adolescents' overweight and obesity by providing nutrition education intervention. However, changing intention and behavior is more challenging than changing knowledge (35). Therefore, we should also attend to the influence of the community and families.

In the subgroup analyses, we found that the association between NL and overweight/obesity was consistent. It was suggested that the results were less likely to be confounded by these factors and intervention may work in all subgroups. The only significant interaction we found was between grade and NL with a strong association between NL and overweight/obesity only in senior high school. However, we observed that the NL of junior high school students was higher than that of senior high school students. We did not find a similar study yet, but several explanations were considered for these findings. First, senior high school students have to focus more on their academic subjects (36), and they do not have sufficient time to learn nutrition knowledge. Parents and school staff should realize that health–related behaviors of students directly affect their academic achievement (37). Second, senior high school students may have more self–efficacy and flexibility to translate nutrition knowledge into healthy behaviors (38). A study has revealed that dietary knowledge alone is insufficient to change individual dietary choices (26). Essential behavior capabilities, environmental support, collaborative action, and partnership at multiple levels of influence are all needed to achieve behavior change (39). Therefore, the lack of significant association between NL and overweight/obesity in junior high school students may be due to the failure of nutrition interventions to improve NL as an important mediator between knowledge and practice (26). In brief, strategies and measures need to be adopted to facilitate the ability of junior high school students to apply nutrition knowledge and skills to healthy eating habits. Furthermore, diets of junior high school students may be largely determined by their parents (40). A study has shown that school meals can help students learn about dietary knowledge and skills (41). Our research also showed that boarding school students had higher NL than non–boarding students. Therefore, schools and families may set up supportive environments for lower–grade adolescents to make healthier food choices and sustain behavior change to maintain a healthy weight (42).

This study had several policy implications. Obesity has brought a substantial burden to economic, social, and health. And the Chinese government has made many efforts to curb the incidence of obesity, including the implementation of national policies and programs to promote healthy lifestyles and prevent non-communicable diseases (43). However, the prevalence of overweight/obesity is increasing in China. As promoting NL may improve adolescents' weight status for enhancing their ability to make food choices, perceive food labels, implement food safety precautions, apply healthy cooking methods, and adopt appropriate dietary recommendations (44), it would be of great significance for policymakers, researchers, and other stakeholders in society to assess and develop the NL of adolescents. Meanwhile, our evidence stresses the encouragement to apply nutrition–related knowledge to practical use.

This study had certain limitations. First, this study used cross–sectional survey data and did not permit a reliable inference of causality. Longitudinal studies are necessary to examine the association between NL and overweight/obesity. Second, although quality control was strictly implemented in the process, the online and self–reported survey inevitably brought some information bias. Height and weight were self–reported by the students, which may also introduce biases caused by dishonesty and measurement flaws. Due to the use of online survey, we did not collect information on obesity–related diseases, and thus, students with obesity–related diseases may be included in the study. Third, although we adjusted for gender, grade, ethnicity, residence, primary caregiver, parent's education, and whether boarding in school in the multivariable analysis, residual confounding was still possible. It has been shown that obesity of parents probably may affect the risk of obesity in their offspring due to shared genetic or environmental factors within the family (45). The effect of parental BMI should also be considered in future studies.

In conclusion, this study with a large population–based sample was a representative examination of the association between NL and overweight/obesity among adolescents in Chongqing, applying a specifically developed instrument for the target group. We found that NL was inversely associated with overweight/obesity among adolescents, especially those attending senior high schools. Our results demonstrated that interventions on adolescent obesity may improve their NL and skills. Future study should assess mechanisms such as the effect on eating/physical activity.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of ChongQing Medical University (approval number: 2021041). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SL and YZ contributed to conception and design of this study. MZ organized the database. SL and ZS performed the statistical analysis. SL, YZ, and ZL wrote the first draft of the manuscript. HZ and ZS wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Sinful Foods: Measuring Implicit Associations Between Food Categories and Moral Attributes in Anorexic, Orthorexic, and Healthy Subjects

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Recently, neurocognitive studies have shown that food categorization is sensitive to both the properties of the food stimuli (e.g., calorie content) and the individual characteristics of subjects (e.g., BMI, eating disorders) asked to categorize these stimuli. Furthermore, groups of patients with eating disorders (ED) were described as relying more on moral criteria to form food categories than were control subjects. The present studies built on these seminal articles and aimed to determine whether certain food properties might trigger moral categories preferentially in subjects suffering from ED and in the general population. Using a Go/No-Go Association Task, Study 1 focused on the extent to which food categories are laden with moral attributes in ED patients compared to control subjects. Study 2 was a follow-up with a different design (an Implicit Association Test), another food variable (calorie content), and two non-clinical subgroups (orthorexic and healthy control subjects). Results revealed for the first time implicit associations between food variables cueing for energy density and moral attributes in the general population, the population suffering from anorexia nervosa, and subjects suffering from disordered eating such as orthorexia nervosa. These findings suggest that moralization of food is a pervasive phenomenon that can be measured with methods reputed to be less vulnerable to self-presentation or social desirability biases.

Keywords: food categorization, moral judgment, cognition, eating disorders, anorexia nervosa, orthorexia nervosa

INTRODUCTION

Categorization is a fundamental ability that we rely on to organize sensory information into entities or categories of entities we might refer to. From such categories, we then generalize information to novel instances and act accordingly. For example, if an object is categorized as a blackberry, you are entitled to ascribe the edibility property to that object and then decide to eat it (1). Recent studies that investigated the nature of food categorization revealed that food categorization is far from simple and that the term actually uncovers manifold processes: from early and automatic discrimination of food depending on the sensory properties (2) to the building of elaborate morally-laden conceptual representations about foods (3). A further complication comes from the fact that food categorization seems very sensitive to both the properties of the food stimuli and the individual characteristics of subjects asked to categorize these stimuli.

At a very early stage of cognitive processing, the mere sight of food triggers a wide range of physiological, emotional, and cognitive reactions (4). For instance, in an electroencephalogram (EEG) study using visual evoked potentials, Toepel et al. (2) obtained evidence of early discrimination of subclasses of food images by manipulating their reward value (e.g., low fat food versus high fat food). They identified two discrimination stages: an early stage of categorization at ∼165 milliseconds (ms) and a second at ∼300 ms post-stimulus. The calorie content and the degree to which the food has been processed are also rapidly discriminated by the cognitive system. Analyzing event-related potentials, Pergola et al. (5) evidenced different neuronal activity depending on the degree of food processing and calorie content: natural (e.g., an apple) versus processed (e.g., lasagna).

In addition to the properties of the food, an individual's characteristics influence food categorization as well. In the EEG study mentioned above, Pergola et al. (5) showed that the distinctive neuronal activity underpinning food processing is modulated by the body mass index (BMI) of participants. Specifically, they investigated the N400 amplitude and latency in response to food stimuli. N400 amplitude and latency reflect the incongruence or congruence between stimuli, and is measured by placing electrodes at specific locations on the scalp. Its amplitude and latency reflect the strength of the signal and the delay between the stimuli and the signal, respectively (6–8). In their study these stimuli were photographs depicting either a natural or a processed food (e.g., pineapple or pizza, respectively) and sentences that described either a sensory attribute (e.g., "It tastes sweet") or a functional attribute defined as the context in which the food is eaten (e.g., "It is suitable for a wedding meal"). In the task, a sentence was followed by an image, and the sentence-image pairs were either congruent ("It tastes sweet" with pineapple) or incongruent ("It tastes salty" with pineapple). Results revealed modulations of N400 amplitude and latency caused by sensory-functional primes only for processed food (e.g., lasagna) in participants with obesity, whereas only for natural food in underweight participants (e.g., an apple).

Furthermore, interactions between these two types of variables that influence food categorization, namely those cueing energy density and an individual's characteristics have been recently evidenced in behavioral studies. Coricelli et al. (9) conducted an exploratory analysis that revealed that restrained eaters (individuals who strictly control their tendency to eat for an extended period to lose or maintain body weight) were significantly slower at categorizing processed food as such compared to unrestrained eaters. The authors explained this effect by referring to work conducted by Papies et al. (10) who put forward that in restrained eaters, the attraction of food palatability might have interfered with their goal of dieting. Coricelli and colleagues argued that a similar conflict between enjoying food transformation and dieting could be what increased the reaction times of the restrained eaters in their study [see (11) for the background theory about such a conflict].

Restrained eating is considered to be a core symptom of anorexia nervosa (12). Interestingly, an interaction between an individual's characteristics and food categorization in subjects suffering from anorexia nervosa has been documented by Urdapilleta et al. (3) in a social psychology study. The authors explicitly asked eating disorder patients (restrictive anorexic, binge/purge anorexic, and bulimic) and control subjects to categorize 27 food names. Results revealed that restrictive anorexic patients relied more on moral criteria (i.e., deontic terms such as obligation and permission "I can/cannot eat this") to form food categories compared to other patients. This observation echoed religious asceticism that is historically deeply connected to what is sometimes called "holy anorexia", illustrated by the case of Catherine of Siena or food deprivation that monks and clerics voluntarily endured in early Catholicism, anchored in ascetic practices defined at the end of Antiquity (13).

Morally-laden food perception and reasoning in anorexia nervosa has been highlighted in particular by Giordano (14), who put forward the idea that eating disorders are a particular expression of some moral beliefs. Especially anorexia nervosa could be driven by the pursuit of lightness and moral purity. Nowadays, words such as purity, decadence, heaven, and temptation are even recurrent in advertisements about food and in Western societies. The constant use of the lexicon of holy anorexia in advertisements has even been suspected to contribute to the maintenance of associations between eating certain foods and moral values, which might represent a risk factor of developing eating disorders (15). Interestingly, negative moral attributes such as "luscious", "decadent", and "temptation" in advertisements are generally associated with highly processed foods (14, 15). Furthermore, it has been suggested that similar mechanisms (e.g., disgust) might underpin the impurity judgments resulting from the transgression of moral laws, and the impurity judgments resulting from the transgression of regulation of eating or hygienic rules (16). The hypothesis that a same cognitive system anchored originally in distaste is now recruited by the moral domain would explain why some attributes might occur both in the food and the moral domain (e.g., lightness and purity). A similar theory that cultural domains such as morality invade older brain circuits such as disgust has been put forward by Dan Sperber [Sperber and Hirschfeld, (17)] and discussed in neuroimagery studies (18, 19).

This idea of an incursion of the moral judgment of food into the general population can be supported by the emergence of a specific eating attitude which has received a great deal of attention in recent decades: Orthorexia Nervosa, ON hereafter (20). This refers to an obsession about healthy eating that leads to emotional and psychosocial consequences such as anxiety and social isolation. Orthorexic traits are measured by self-declarative questionnaires, one of the most commonly used being the ORTO15 questionnaire (21). People suffering from ON exhibit a food restriction based on the healthiness and quality of food. Furthermore, they tend to exclude foods not considered sufficiently healthy or pure, two food attributes that seem to fall more into the category of pseudo-moral aspects than into the category of objective qualities of food (22).

The present studies aimed to determine whether certain food properties (especially those related to the energetic value of food) might trigger moral categories in subjects suffering from eating disorders and in the general population. More precisely, Study 1 aims to test whether patients suffering from anorexia nervosa (AN) would be more prone to lade food with moral properties than would the general population. Two specific research hypotheses have been tested in Study 1:

H1: Processed foods are implicitly associated with moral impurity whereas natural foods are associated with moral purity.

H2: Patients suffering from AN associate moral attributes with food more strongly than control subjects.

Study 2 further explored the relationship between food and moral attributes in the general population with and without orthorexia nervosa, by manipulating the objective calorie content (kcal/100 g) of the food instead of food processing as in Study 1. Two specific hypotheses were tested in Study 2:

H1': High-calorie foods are implicitly associated with moral impurity whereas low-calorie foods are implicitly associated with moral purity.

H2': Subjects exhibiting disordered eating behaviors associate moral attributes with food more strongly than control subjects.

STUDY 1

Method

Participants

A total of 75 participants completed the experiment. The patients with anorexia nervosa (AN group) were recruited by psychiatrists from three mental health units hosting patients suffering from eating disorders between March and August 2018. The inclusion criteria were (1) to be a woman aged from 18 and 35 years old, (2) to be diagnosed as suffering from anorexia nervosa (restricting or binge/purge types) according to the DSM-5 (23), (3) to not present any severe comorbidity (e.g., major depressive disorders), and (4) mastery of the French language. Moreover, participants with a BMI below 12 as well as those who were too heavily medicated (e.g., having a prescription of benzodiazepine that can alter reaction time), according to the psychiatrists, were not asked to participate. A total of 32 patients were included in the AN group, all with high education. All were diagnosed at least 1 year prior to testing, 2 were in remission, 17 were in relapse. The duration of the condition ranged from 1 to 18 years.

A first control group was formed from May to June 2018 with 32 students from the Paul Bocuse Institute, a school of management in hospitality and culinary arts, therefore students had background knowledge in nutrition and cooking. According to the literature, students in food-related studies, especially nutrition, have a higher prevalence (between 35 and 57%) of dysfunctional eating behaviors than the average of the general population (6.9%), particularly orthorexia nervosa (24, 25). Orthorexia nervosa appears to share a number of characteristics with anorexia nervosa, such as the presence of intrusive thoughts about food and a subordination of lifestyle and behavior to food imperatives (22). Considering these similarities and the fact that the present study focused on the relationship to food and on comparing healthy subjects with subjects suffering from AN, the orthorexic traits that were potentially present in the control group could bring a confounding variable to the study, and therefore needed to be assessed. The orthorexic traits of the students in the first control group were not tested. It was therefore decided to set up a second control group in the same population or in populations with a similar prevalence of orthorexia nervosa, such as medical students or students innutrition or agronomy, with an evaluation of orthorexic traits using the ORTO15 questionnaire. Participants included in the second healthy control group (HC group) were recruited through several email databases of French universities (AgroParisTech and Ecole Normale Supérieure Ulm) between May and July 2019. The inclusion criteria for the control group were (1) to be a woman from 18 to 35 years old and (2) to not present a potential eating disorder. This age group was targeted in order to have a sufficiently small age range to avoid a confounding factor of age on reaction times, and also to be able to compare the results of the HC group with those of a population suffering from anorexia nervosa (AN group), this mental illness affecting mainly adolescent and young adult populations. Of 43 respondents, 11 respondents presented eating disorder symptoms (i.e., with a score higher than the cut-off of 18 on the symptom index of the EDI-II short form) and were removed from the analyses. A total of 32 respondents were included in the HC group; they were students (65%) in agronomy, health, philosophy or psychology studies and employees (35%). A total of 64 participants were included in the analyses, 32 patients in the AN group and 32 in the HC group.

The experiment was approved by the local ethics committee (ID-RCB Number: 2015-A01194-45).

Measures

Participant Information

Data of patients with AN were collected through anonymous medical questionnaires filled out by the referring psychiatrist. This medical questionnaire comprises questions in order to document age, body mass index (BMI), type of anorexia nervosa, and other relevant anorexia nervosa-related information. Age and BMI of participants from the HC group were documented through anonymous questionnaires filled out by the participants themselves.

Eating Disorder Inventory II—Short Form

The short form of the Eating Disorder Inventory is a self-administrated questionnaire including 24 items that included 8 subscales (26). In this study, only symptom index score (mean score of the bulimia, body dissatisfaction, and drive for thinness subscales) was used. The respondent answered through a Likert scale ranging from 0 (Never) to 5 (Always). In the present study, Cronbach's alpha (α) was 0.74. Only respondents in the HC group were asked to complete this questionnaire.

Food Questionnaire

The subject's reaction time may be altered depending on the frequency of exposure to the food, which is itself related to its consumption. In order to avoid any recognition bias, the participants in the HC group filled out a questionnaire asking them to mention the foods they do not eat and the reasons why.

ORTO-15

ORTO-15 was used to assess orthorexic traits (21) among the HC group. The lower the scores, the higher the intensity of orthorexic behavior (21). All of the respondents in the HC group were asked to complete this questionnaire. The range of scores went from 31 to 43. In the present study, Cronbach's alpha (α) was 0.56. During the development and validation procedure, ORTO-15 questionnaire reached satisfactory values for the cut-off point of 40 points (sensitivity = 100%, specificity = 73.6%, positive predicative value = 17.6%, and negative predicative value = 100%) (21). However, according to Dunn et al. (27) the frequency of ON as measured by ORTO-15 is too high. Cut-off point of 40 does not reflect the real prevalence of ON (28). Therefore, in some studies the cut-off point was lowered to 35 points (29, 30). In our study, 1 control subject had a score under 35, and 14 subjects had a score between 35 and 40. It is also important to mention that psychometric properties of the ORTO–15 scored as Donini et al. (21) suggested seemed to be poor (25, 31–33). Meule et al. (34) suggested that the poor psychometric properties of the ORTO–15 were largely due to the originally proposed scoring procedure. It consisted of having the items scored with the following response options: 1 = always, 2 = often, 3 = sometimes, 4 = never, except for six items: four of them were reversely coded (items #2, #5, #8, and #9) and two items (#1 and #13) had a rather unusual recoding procedure: 2 = always, 4 = often, 3 = sometimes, 1 = never. According to Meule and colleagues, who examined the psychometric properties of ORTO15 among 511 adults, principal component analysis revealed that only two items (#5 and #8) should be inverted, other items being scored as 1 = always, 2 = often, 3 = sometimes, 4 = never. After recoding, they found that internal reliability of the ORTO–15 items was acceptable (Cronbach's α = 0.72) (34). Therefore, in the present study Meule and colleagues' recommendations were followed.

Go/No-Go Association Task

A go/no-go association task (GNAT) described by Nosek and Banaji (35) was administrated to the participants through E-prime© software (Psychology Software Tools, Version 2.0 Professional). The GNAT assesses the strength of association between a target category and two poles of an attribute dimension (35). In this GNAT, the two target categories are natural food and processed food and the two poles of the attribute correspond to the notion of purity or impurity. Throughout the experiment, attributes referring to the notion of purity are called "pure words", and those referring to the notion of impurity are called "impure words."

Food stimuli were selected from the FoodPics database validated by Blechert et al. (36). Two sets of stimuli were created: one with 24 natural foods and the other with 24 processed foods, following Blechert and colleagues' classification. Moreover, it has been shown that green might cue low energy density and that red is associated with a higher level of arousal compared to other colors (37). Thus, our two sets of stimuli (natural and processed) included the same proportion of green and red foods (12 green and 12 red food stimuli). To determine the extent to which these food variables are associated with the moral dimension of purity/impurity, we used a subset of attributes taken from a larger list of words constituted by Graham et al. (38). Graham and colleagues used the Linguistic Inquiry and Word Count program (LIWC; see Pennebaker et al. (39) to analyze liberal and conservative sermons. Then for each uses of these word, the consistency between the 2–3 sentences surrounding context of the word with the moral dimension (e.g., purity/impurity) was assessed by four independent raters who achieved a reliability of 0.79. Two sets of attributes were used in the present experiment, 12 attributes referring to moral purity and 12 attributes referring to impurity, to match the number of word attributes with the number of food stimuli and to have a balanced stimuli design. The stimuli are available in **Supplementary Table 1**.

The GNAT included four practice single blocks, and four combined blocks (see **Figure 1**). For each block, participants had specific instructions. Depending on the instructions, participants were asked to press the space bar if they saw a stimulus in a specific target category, and not to press the bar if they saw any other stimulus.

The four practice single blocks consisted of two blocks with visual food stimuli, and two blocks with word stimuli. In the first practice block, participants had to press the bar if they saw a natural food on the screen, and not to press the bar if any other stimulus appeared on the screen (Practice 1), so the target category was natural food. In the second practice block, the target category was processed food (Practice 2), in the third practice block it was words associated with purity (Practice 3), and in the fourth practice block it was words associated with impurity (Practice 4).

The four combined blocks each had instruction aimed at two target categories. In Block 1, participants had to press the bar if they saw a natural food or an impure word on the screen, and not to press the bar if any other stimulus appeared on the screen, the target categories therefore being natural food and impure words (Block 1). Target categories for the second combined block were natural food and pure words (Block 2). For the third combined block, target categories were processed food and impure words (Block 3), and for the fourth combined block, processed food and pure words (Block 4). Among the four combined blocks, two were congruent blocks and represented the congruent condition, in which the association between the target categories was hypothesized to be stronger (Block 2 and Block 3). The two other blocks represented the incongruent condition, where the association between the target categories was hypothesized to be weaker (Blocks 1 and 4). For each block (practice or combined), distractor stimuli were the opposite of the target stimuli. For example, if the target stimuli were natural

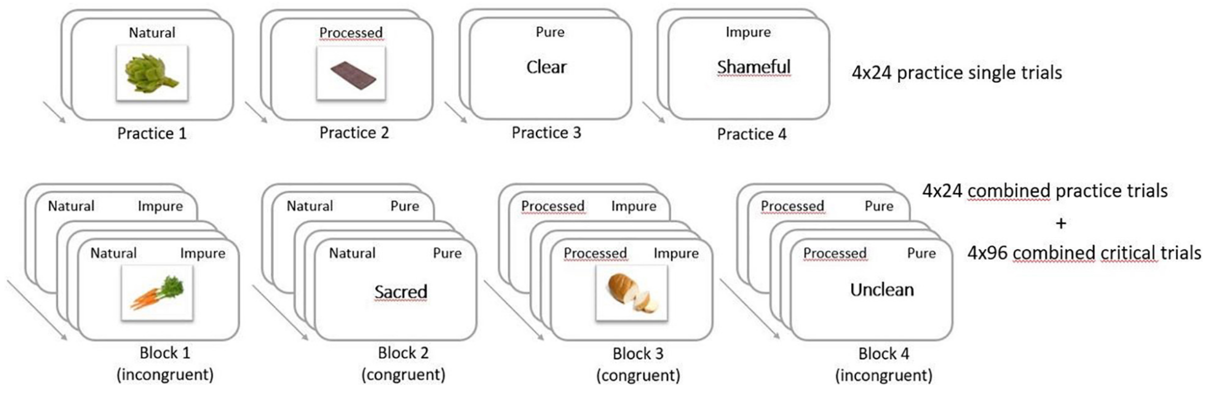

FIGURE 1 | Design of the Go/No-Go Association Task to determine the strength of association between processed versus natural foods and morally "pure" versus "impure" attributes. In this study, the GNAT was administrated in French. For the purpose of this paper, this figure is an English translation of the task.

foods and pure words, then processed foods and impure words were both distractor stimuli.

Each practice block consisted of 24 stimuli with 12 stimuli from the target category and 12 distractor stimuli. Each combined block consisted of 120 trials with 120 stimuli, with first a familiarization phase and then a critical phase. The familiarization phase consisted of 24 stimuli with 6 training stimuli from each category of stimuli (i.e., natural food, processed food, pure words, and impure words). Then, following the same instructions, participants had to complete the critical phase consisting of 96 stimuli with 24 critical stimuli from each category of stimuli randomly presented to participants once each, with a ratio of 50% go stimuli and 50% no-go stimuli.

Each stimulus from the practice blocks and the combined blocks was visually presented for 1,000 and 850 ms (respectively) or until the participant decided to "go" and press the space bar. For the time window, a pre-test on 5 control subjects led us to choose a stimulus presentation duration of 850 ms, the performance obtained being relevant and consistent for this duration (error rate < 30%, success rate 84% on average) according to the literature (40, 41).

Prior to the task, participants were instructed to press the space bar of the keyboard as quickly as possible (GO) when the stimulus belonged to one of the two categories they were instructed to detect (e.g., Pure word or Natural food). If the stimulus did not belong to one of the target categories, then the participant had to inhibit the response (NO-GO). Emphasis was put on rapidity over accuracy. However, participants were also instructed to make as few mistakes as possible. Only for the practice single blocks, a green circle appeared on the screen when the participant had pressed the space bar when a target stimulus was shown (hit) or inhibited the response when a distractor was shown (correct rejection). A red cross appeared on the screen when the participant categorized a distractor as a target and pressed the space bar (false alarm) or missed a target stimulus by not pressing the space bar (miss). The green circle or the red cross were presented for 500 ms followed by a blank screen for 150 ms.

The reaction times (RT hereafter) in the practice single blocks and the RT in the familiarizing phase of each of the combined blocks were not recorded. Only RT in the critical phase were recorded and used in the statistical analyses.

Procedure

The experiment was conducted in a quiet testing room. The participants sat on a chair 70 cm from a liquid-crystal display (LCD) computer monitor with a resolution of 1,600 × 900 pixels (60 Hz refresh rate). After answering questions about which foods they did not eat and why, participants of both groups rated their state of satiety on a 7-point visual scale ranging from "not at all" to "extremely". The GNAT instructions were verbally provided to participants by the experimenter and the GNAT was performed. To avoid the influence of task order highlighted by Nosek et al. (42), the order of the blocks was counterbalanced between participants. At the end of the experiment, the participants were asked to rate their level of familiarity of the words presented in the GNAT. The rating was made through a 5-point visual scale ranging from "Not known at all" to "Perfectly known." The entire procedure took about 35 min.

Data Analysis

Analyses were conducted using Rstudio® software (Version 3.6.0). Nosek and Banaji (35) and Greenwald et al. (43) recommend removing RT equal to or less than 300 ms as well as participants with more than 10% of trials faster than 300 ms. After examination, 19 trials met this criterion and were removed, and no participants were removed. Likewise, data were examined to verify that no participant exhibited an error rate greater than 40% on a given block or a 30% error rate overall. On the basis of these criteria, no participant was removed either. Reaction time and type of responses were recorded during the task. To analyze RT data, it was firstly screened for normality. The results of the Shapiro–Wilk [$W(142) = 0.99$, $p = 0.387$] indicated normal distribution for RT means, results of Anderson-Darling for the residuals ($A = 470.03$, $p < 2.2e\text{-}16$) analysis of linear model with RT as dependent variable indicated a non-normal distribution of the residuals.

The mean and standard deviation of age, BMI, satiety score, and word familiarity scores were computed and compared

TABLE 1 | Study 1 participants' characteristics by group and comparison of scores between groups.

Sample characteristics	AN group		HC group		t	p
	M	SD	M	SD		
Age	24.56	4.77	23.15	3.23	1.36	0.180
BMI	16.03	1.79	20.79	1.93	−10.21	<0.001
EDI-II-24	–	–	36.63	10.55	–	–
ORTO-15	–	–	39.38	4.04	–	–
Satiety score	2.09	1.58	3.31	1.79	−2.83	0.006
Word familiarity score	4.16	0.87	4.31	0.73	−0.77	0.405

M, mean; SD, standard deviation; BMI, Body mass index; EDI-II, Eating Disorder Inventory—24 items; t, test statistic for the comparison test of each variable between the two groups; p, p value of each test.

between groups, and Spearman correlations were calculated to check for correlations between satiety scores and RT.

In order to test hypothesis H1, according to which food processing is implicitly associated with impurity whilst food naturalness is implicitly associated with purity, the RT were analyzed. As RT were normally distributed, Student tests were computed on RT, between the congruent associations and the incongruent associations in each group. With the same test, RT were analyzed between conditions (congruent versus incongruent) and groups, then between blocks to see whether an effect is driven by particular block(s). Power analysis was performed *post hoc* on each group with G*Power© software (44).

To measure the influence of group (AN or HC group) and condition (congruent or incongruent) factors on RT, a linear mixed model was conducted, because our data are repeated measures with the participant and the item as random factors. As the residuals are not normally distributed, a log transformation was made on RT. The models were constructed by iteratively adding predictive variables to the null model (M0, the intercept and no predictor), using the Akaike Information Criterion [AIC; (45)] as a basis for model selection. Group and condition were included in all models as fixed effects as well as possible interaction terms. Item and subject were included in all models as random effects. The R-squared (R^2) was computed to determine the proportion of the variance explained by the model.

To test hypothesis H2, according to which the strength of the associations differ between AN and HC groups, D-measures were calculated as effect-size measures from the participants' RT. Conceptually similar to Cohen's d, the D-measure is the difference between the means of the RT in critical incongruent blocks and critical congruent blocks divided by the standard deviation of all the RT in these blocks (43). Since the D-measure does not seem to be improved by the deletion of responses faster than 400 ms in the Greenwald paper, all responses were kept.

Results Study 1

Participants' Characteristics

A total of 32 female participants with AN (Age: $M = 24.40$, $SD = 4.7$; BMI: $M = 16.10$, $SD = 1.8$) and 32 matched female control participants (Age $M = 23.20$, $SD = 3.20$; BMI: $M = 20.8$, $SD = 1.9$) were included in the analysis. The participants' characteristics are presented in **Table 1**. Participants from the AN and HC groups did not differ in age, but differed in BMI. Results indicated also that state of satiety was significantly lower in the AN group. The Spearman correlation coefficient between state of satiety and RT (*Rhô* = −0.12, $p = 0.403$) indicated that state of satiety was not significantly related to RT. The familiarity of the words did not differ between AN and HC groups.

Level of Purity and Naturalness of Food

In both groups, the means of RT in congruent conditions were significantly shorter than for incongruent conditions [AN group: $t(63) = -4.12$, $p < 0.001$; HC group: $t(62) = -4.30$, $p < 0.001$] (see **Figure 2**). This result was also found in each group (AN and HC group) with statistical powers of the association of 0.58 and 0.52 in each group, respectively. Then, the same analyses were conducted to compare RT between blocks for each group (see **Supplementary Table 2**). The means of the AN group's RT were significantly shorter when natural foods were paired with words belonging to the pure moral category (Block 2) than when natural foods were paired with words belonging to the impure moral category (Block 1) [$t(62) = -3.45$, $p = 0.012$, D-measure = 0.35]. The same result was found in the HC group: RT means were significantly shorter in Block 2 than RT means in Block 1 [$t(61) = -4.26$, $p = 0.001$, D-measure = 0.38].

Concerning the attitude toward processed food, RT means were significantly shorter when processed foods were paired with words belonging to the impure moral category (Block 3) than when paired with words referring to the pure moral category (Block 4) [AN group: $t(62) = -4.54$, $p < 0.001$, D-measure = 0.45; HC group: $t(61) = -3.82$, $p = 0.003$, D-measure = 0.35].

The mixed model conducted showed a significant effect of the condition [$\chi^2(1,64) = 500.82$, $p <$ 2e-16] with the incongruent condition being significantly and positively different from the congruent condition [*beta* = 3.23, 95% CI (3.05, 4.08), $t(10{,}481) = 16.18$, $p < 0.001$). The model showed neither an influence of the group on RT $\chi^2(1,64) = 2.82$, $p = 0.093$], nor an influence of the interaction between the group and the condition [$\chi^2(1,64) = 0.32$, $p = 0.572$] on RT. Results are gathered in **Supplementary Table 3**. The model's total explanatory power was: $R^2_C = 0.27$.

D-measure (effect size) was also computed for each group according to the blocks and conditions. Results, presented in **Supplementary Table 4**, revealed that D-measures of each group were in the same target range, indicating a small effect size in all groups.

Discussion, Study 1

The first hypothesis of this study (H1) was that food transformation is implicitly associated with impurity whereas food naturalness is implicitly associated with purity. Our results confirmed this hypothesis by revealing a facilitating effect on RT (shorter RT) in congruent compared to incongruent conditions. These results echoed Rozin and colleagues' conclusions that consumers tend to exhibit a strong preference for natural foods over processed foods when they have the same chemical composition, the same taste, or when they are considered equally healthy (46). Indeed, according to Rozin and colleagues this preference could be grounded in beliefs that natural food would

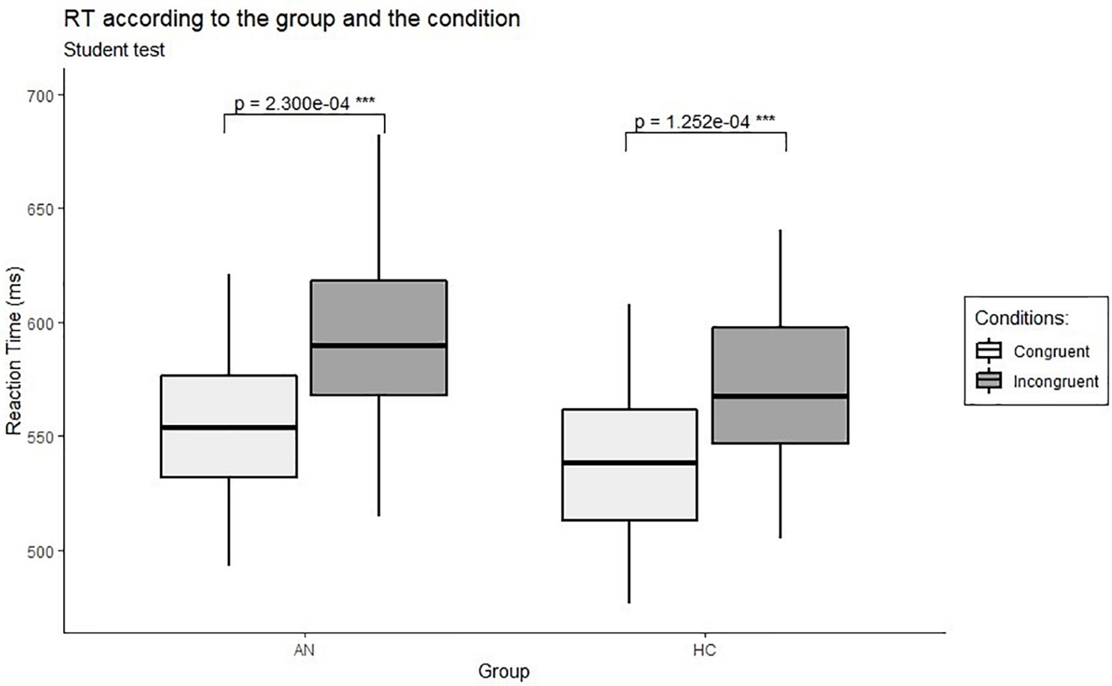

FIGURE 2 | RT (ms) comparisons between conditions within-group. RT, reaction times; AN, AN group; HC, HC group. ****p < 0.001*, the difference between the two groups designated by the trait is significant.

be purer and "morally superior" because it is "prior to human intervention" [(46), p.2]. However, these results seem to run counter to the findings of Coricelli et al. (47) that processed foods have been shown to trigger higher reward value and are more advantageous in terms of nutrients than unprocessed foods, so they have been favored as resource foods throughout evolution (47). Nevertheless, the study here explored the relation of food processing with morality, which is quite different from the nutritional aspects. Whereas processed foods are preferred in terms of taste and nutrients, morality speaking natural foods seemed to be more prone to be preferred as they are directly linked to nature and healthiness (46).

Furthermore, it is worth mentioning that the congruence effect does not result from the association between naturalness and purity only. This effect is also driven by the association between transformation and impurity. This result is consistent with the general belief that processed foods are more likely concealing unhealthy properties compared to natural counterparts. Such an unfavorable stance toward processed food could result from the principle of contagion, according to which the contact with an undesirable entity can render an object less desirable (48). Human intervention being considered to damage nature in modern Western societies (46), the contagion principle could lead one to associate processed food with negative moral attributes such as "decadent," which are commonly used nowadays in advertisements (14, 15). Therefore, the association found in Study 1 between food transformation and morality corroborate the observations made by Rozin and colleagues. However, our findings revealed for the first time the existence of such an association at an implicit level. An association is automatic or implicit if it can occur even if participants do not have particular goals, a substantial amount of cognitive resources, a substantial amount of time or awareness (49, 50).

The second hypothesis of this study (H2) was that the strength of the implicit associations differs in patients suffering from anorexia nervosa and healthy control subjects. More precisely, and consistently with the literature on morally-laden food categories in patients with AN, we expected a stronger association in patients with AN than in healthy control subjects. As shown by the analysis of the D-measures and the generalized mixed model on the RT where no difference between groups was observed, the results did not confirm our second hypothesis.

Limitation and Perspectives, Study 1

One of the limitations could lie on the fact that the subjects included were all young women with high level of education. Therefore, no conclusion can be made for the general population regarding the results of the study. This choice was made because patients suffering from AN are described in the literature as mainly being adolescent or young women with high level of education (51, 52). Therefore, the population taken as a control group had to match these criteria in order for the two groups to be comparable.

Another limitation lied on the effect size of the mixed model: condition (congruent or incongruent) was considered to significantly influence reaction time, however, the effect size seemed to be relatively low: the incongruent condition being significantly and positively different from the congruent condition with an estimate of 3.23 [95% CI (3.05, 4.08)], compared to the intercept, which had an estimate of 1,445.32 [95% CI (1,433.29, 1,464.26)]. Therefore, these results should therefore be put into perspective.

Also, the initial ambition was to designed an implicit association task that was sensitive enough to capture individual characteristics of persons suffering from anorexia nervosa. Even if we confirmed the existence of an association between food transformation and morality, the strength of the association did not differ between control subjects and patients suffering from anorexia nervosa. One hypothesis why we might have failed to see such a difference lies in the food processing/naturalness variable, which might be a too subjective variable and therefore not the most appropriate here. We then decided to design a second task on the general population only to determine whether associations between objective energetic value and moral purity could be discriminant between ON and HC. This time we chose to test the second version on the general population before testing it on patients. Indeed, we wanted to confirm first that the task was properly calibrated and sensitive enough to capture disordered eating before using it to predict eating disorders relying on the assumption that if the task might detect ON it will detect a far more severe form of eating disorder.

Finally, the degree of processing is a subjective variable as it is highly dependent on the subject's interpretation (53) and might therefore hide some subtleties about inter-individual differences in the studied association of moral attributes with food. Thus, a second study seemed necessary to disambiguate and extend the results found in Study 1.

STUDY 2

According to Foroni et al. (37) who conducted a rating scale study in which participants were asked to rate the perceived calorie content and the arousal of food items, results reveal that the degree of processing is interpreted as an indicator of the energy density of food. The more processed a food is perceived to be, the more calories it is perceived to contain. In Study 2, we decided to conceptually replicate the association between energy density and moral categories by manipulating an objective food variable (calorie content per 100 g) as it is less open to interpretation by the subject and could help us to disambiguate the results generated by Study 1.

This replication was carried out using another technique measuring implicit associations: the Implicit Association Test (IAT). Indeed, as Nosek and Banaji (35) pointed out during the development of the GNAT, IAT and GNAT both measures the implicit attitudes toward concepts and attributes with the same variable (RT), and they tend to generate comparable results. The difference lies on the fact that the structure of the IAT constrains evaluations to be relative comparisons between two opposing categories, and therefore being a relative measure, whereas the GNAT allows for a separable assessment of categories, with framing evaluation of a target concept in a context of other concepts. As significant differences were found in Study 1 between congruent and incongruent blocks with the GNAT, we decided to replicate using an IAT in order to see if this technique would also show a significant difference between our categories in a relative comparison. Indeed, as the authors pointed out, "experimental reports that replicate implicit effects across techniques provide extra confidence that the effects are not due to a particular procedural aspect of any single tool" [(35), p.661].

As the present COVID-19 pandemic came across, the research had to be done online with the IATgen (54) and the Qualtrics (55) software.

Method Study 2

Participants (Recruitment)

Participants were recruited through several French university mailing lists. The survey was circulated on June 1, 2021 and was available through June 30, 2021. Women and men from 18 to 35 years old were included. Indeed, as the prevalence figures show an equal proportion of men and women with orthorexia nervosa (27, 56, 57), men were first included in the recruitment. Of 180 respondents, 29 were excluded because of missing data and 8 were excluded due to aberrant response times. A total of 143 participants (116 women and 27 men) were included in the analysis. Participants were students (85%) in agronomy, health, or gastronomy studies; employees (5%); executives (9%); or inactive (1%). Four groups were formed: the "Orthorexic" group of participants ($N = 21$) with a high level of orthorexia-related symptoms (i.e., having an score on the ORTO-12-FR scale < 30), the "Pathologic" group of participants ($N = 17$) with a high level of eating disorder symptoms (i.e., having a score on the EDI-II-24 scale > 52), the "Ortho_Patho" group of participants ($N = 43$) with a high level of both orthorexia-related symptoms and eating disorder symptoms, and the "Control" group of participants ($N = 62$) not detected by either the ORTO-12-FR or the EDI-II-24 (score above 30 on the ORTO-12-FR and score below 52 on the EDI-II-24 scale).

Measures

Demographics Measures

The participants anonymously answered questions regarding their gender and age. They were asked to indicate their height and weight as well as their socio-professional category (58).

ORTO-12-FR

In this present study, ORTO-12-FR was used to assess orthorexic traits among the sample (59). ORTO-12-FR is a shorter French version of the ORTO15 developed by Donini et al. (21), with three items deleted after a confirmatory factor analysis (items 5, 6, and 8). All of the respondents were asked to complete this questionnaire. As in Study 1, Meule and colleagues' recommendations (2020) (34) were followed for the scoring procedure. The range of scores went from 21 to 38. In the development of the ORTO-12-FR, no cut-off was established. However, Agopyan et al. (60) found that a cut-off of 30 could separate people exhibiting orthorexic traits (score below 30) and people without orthorexic traits (score above 30). As cut-off scores are not well established yet, we used both

Agopyan and colleagues' cut-off and ORTO-12-FR total score as a continuous variable. In the present study, Cronbach's alpha (α) was 0.76.

Eating Disorder Inventory II - Short Form (EDI-II-24)

As in Study 1, participants completed this short form of the Eating Disorder Inventory including 24 items (26). In Study 2, Cronbach's alpha (α) was 0.73. All of the respondents were asked to complete this questionnaire, and total scores ranged from 18 to 96. Respondents with a score higher than the cut-off of 52 (26), indicating the presence of an eating disorder or an unusual concern about body weight, were considered as pathologic.

Assessment of Their Satiety State

Participants were asked about their satiety level with a 7-point Likert scale ranging from "not hungry at all" to "very hungry".

Implicit Association Task

A slightly modified version of the IAT described by Greenwald et al. (61) was programmed with IATgen software (54). The IAT was then imported on Qualtrics© software. The IAT created was based on the original IAT described by Greenwald et al. (61) with further guidance from Greenwald (62). The first block of 24 trials consisted of practice on the calorie-content food classification task. The second block of 24 trials consisted of practice on the moral attribute classification task. The third and fourth blocks consisted of the first combined task (16 and 48 trials, respectively), including the classification of both foods and words related to morality. Half of the participants started with the same key for low-caloric food and impurity. For the other half of participants, the low-caloric food and words related to purity were initially associated with the same response key. The fifth block of 24 trials consisted of practice, this time for the low-caloric/high-caloric food classification task with reversed response key associations. The sixth block consisted of the second (reversed) combined task. As was suggested by Nosek et al. (42), the number of trials in this block was increased to 32 trials. The seventh and final block was made of 48 trials of the reversed combined task (see **Figure 3** for a summary of the IAT blocks). It should be noted that blocks three and six served as practice for blocks four and seven, respectively. The participants completed 216 trials in total.

For the food stimuli, 24 food pictures were selected from the database FoodPics of Blechert et al. (36) with their energy density per 100 g and per stimulus (see **Supplementary Table 5**). Through this information, the selection of food stimuli was made to have two groups of 12 stimuli each, one representing low-caloric food and the other high-caloric food, and with the most contrasting averages and significant differences of kcal/100 g [$H(1) = 252.00$, $p < 0.001$] and kcal/picture [$H(1) = 256.00$, $p < 0.001$] between the low-calorie food and high-calorie food (see **Table 2**). Moreover, the selection was also made to ensure similar values within low-calorie and high-calorie food groups for both kcal per 100 g and kcal per stimulus.

Regarding the word stimuli, the same 24 words selected from Graham et al. (38) in Study 1 were used: 12 words related to the notion of moral purity and 12 words related to the notion of impurity.

Participants were instructed to categorize as rapidly and accurately as possible the visual stimuli by pressing one of the two response keys (E or I) on the computer keyboard with their left and right index fingers. Emphasis was put primarily on rapidity over accuracy; however, the participants were instructed to also

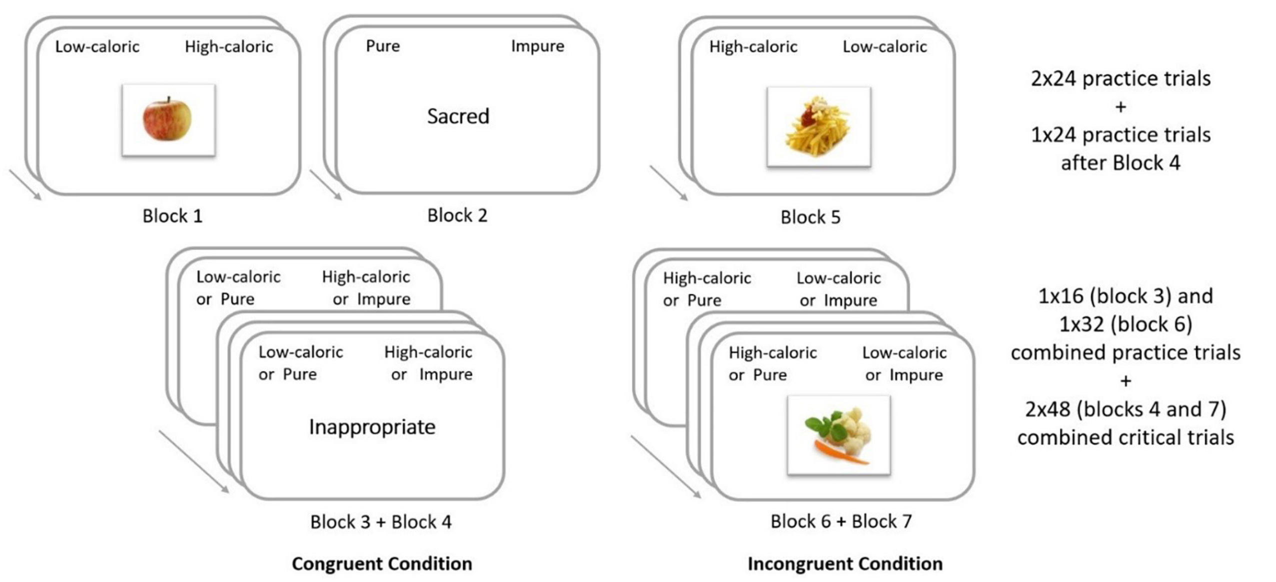

FIGURE 3 | Design of the Implicit Association Test between low-caloric versus high-caloric foods and morally "pure" versus "impure" attributes. Interstimulus Interval (ISI): 1,650 ms in practice blocks with feedbacks, ISI: 1,150 ms in combined blocks. In this study, the IAT was administrated in French. For the purpose of this paper, this figure is an English translation of the task.

TABLE 2 | Study 2 means (M) and standard deviation (SD) Kcal per 100 g and Kcal per picture for each of the two groups of food stimuli constituted.

	Kcal per 100 g		Kcal per picture	
Food stimuli groups	**M**	**SD**	**M**	**SD**
Low-caloric	47.05	25.58	49.88	32.84
High-caloric	355.27	184.30	594.70	375.05

try and avoid errors as much as possible. Instructions about the mapping between the categories and the relevant response keys consisted of a schematic representation of the two response keys with the corresponding categories that was displayed on the screen. There was no time limit to learn the new categories–response mapping that remained in written form at the top-left and top-right corners of the screen as a reminder throughout each block of the experiment. In each trial, the participants started by looking at a fixation cross at the center of the screen for 1,000 ms. Then, a target stimulus was displayed. Feedback, consisting of a red cross, was provided after each incorrect target-response and remained on the screen for 500 ms. Each trial was separated by a blank screen corresponding to the inter-trial stimulus interval (ISI) of 1,000 ms. Participants' RT and accuracy were recorded.

Post-test Categorization Task

Participants were asked to classify each stimulus as either low-caloric/high-caloric or pure/impure.

Procedure

After all participants gave their informed consent, participants were asked to answer gender and age questions. The IAT experiment was then performed by participants. To avoid the influence of task order (61), the key-response attribution of the qualifiers ("Low-caloric"/"High-caloric"; "Impure"/"Pure") were counterbalanced across participants. Then, participants were asked to perform the post-test categorization task. Then, they completed the self-reported questionnaires (ORTO-12-FR and EDI-II-24) and some socio-demographic information. Finally, they indicated their satiety state. The entire procedure took about 15 min.

The procedure was in accordance with the Declaration of Helsinki and followed institutional ethics board guidelines for research on humans.

Statistical Analysis

Demographic Data Analysis

BMI was calculated from the height and weight reported by the participants. Pearson correlations were calculated between the BMI, the satiety level, the age, ORTO-12-FR score, and EDI-II-24 total scores.

IAT Analyses

All statistical analyses were performed using R. 3.6.0 studio software. The significance level was set to 5% ($p < 0.05$). According to Greenwald's suggestions for improvement, RT under 300 ms or above 3,000 ms were also excluded. The normality of the RT distributions was checked with Q-Q plots and tested with the Shapiro test for each group in every block analyzed, which were the critical blocks (blocks 4 and 7). As the distributions did not follow the normality law, the Wilcoxon test was used to compare RT means in the two IAT conditions (congruent and incongruent) for each group. A Kruskal–Wallis test was also assessed to measure the differences between all groups.

To measure the IAT effect, D-measures were also calculated as effect-size measures from the participants' RT. D-measures were computed as the difference between mean RT for blocks 3 and 6 (mean for block 6—mean for block 3) and blocks 4 and 7 (mean for block 7—mean for block 4), for which each resulting difference was divided by the pooled standard deviation of the two corresponding blocks.

A linear mixed model was also computed with RT (log-transformed) from the trials in which the participants responded correctly as the dependent variable, with the within-participants factors of Congruency (congruent associations: low-calorie food + word related to purity, high-calorie food + word related to impurity; incongruent associations: high-calorie food + word related to purity, low-calorie food + word related to impurity) and the Group (control, orthorexic, orthorexic and pathologic, pathologic) as the fixed effects. The participant number and the stimulus number were entered into the model as random effects. The models were constructed by iteratively adding predictive variables to the null model (M0, the intercept and no predictor), using the Akaike Information Criterion [AIC; (45)] as a basis for model selection. The R-squared (R^2) was also computed to determine the proportion of the variance explained by the model.

As cut-off scores are not well established yet, ORTO-12-FR total score was also used as a continuous variable and additional generalized models were computed.

Post-test Analysis

The error rate of stimulus categorization was calculated per person, per group, and per stimulus type, and differences between groups and stimulus type were computed with Fisher's exact test.

All of the statistical analyses above mentioned were also carried out without including men in the analyses (since we did not include them in Study 1). As no differences were found in the results, we decided to keep them in the sample analysis and results presented here.

Results Study 2

Participants' Characteristics

A total of 143 respondents were included in the analysis, aged from 18 to 35 years old (Age: M = 22.89, SD = 3.54; BMI: M = 21.92, SD = 3.15). Participants' characteristics are gathered in **Supplementary Table 6**. Results indicate that state of satiety was not different from one group to another [$F(3, 139) = 1.33$, $p = 0.269$]. The Pearson correlation coefficient between state of satiety and RT [$r(141) = -0.03$, $p = 0.727$] ensures that state of satiety is not significantly related to RT.

No correlations were found between the demographic variables. As expected, a significant correlation was found

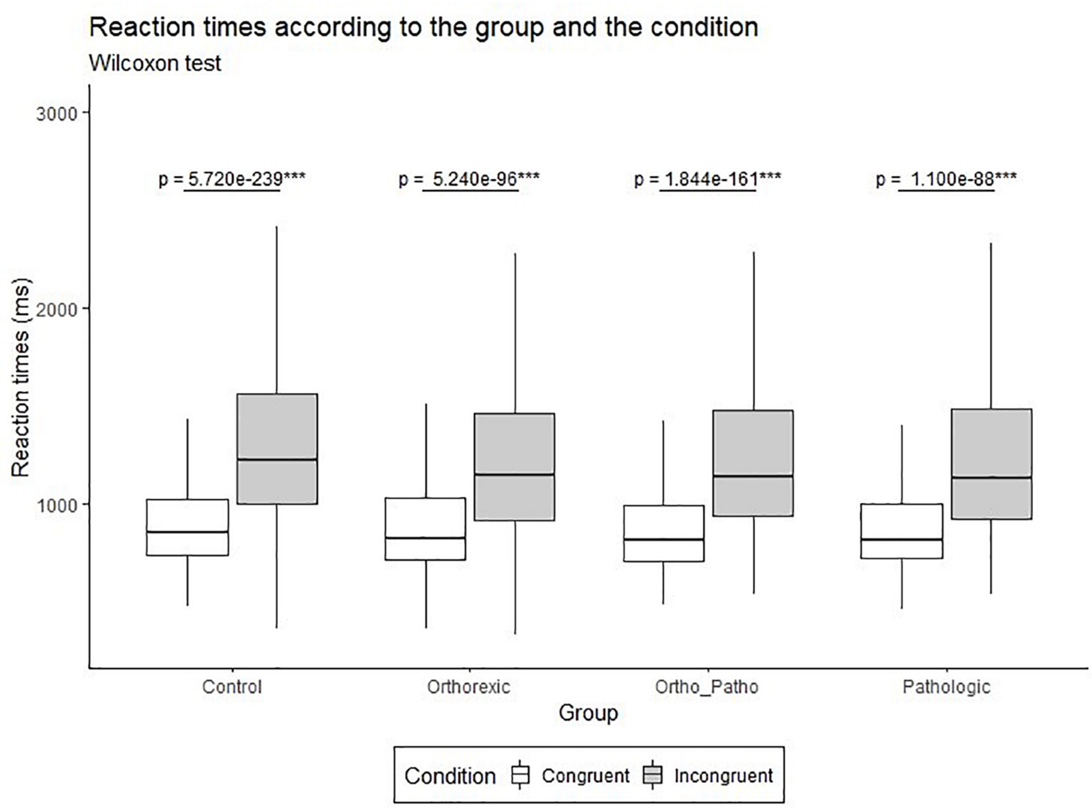

FIGURE 4 | RT (ms) according to the group and the condition with Wilcoxon-test *p*-value results. ***Indicates significant differences between congruent and incongruent conditions.

between the ORTO-12-FR scores and the EDI-II-24 scores [$r(141) = -0.43$, $p < 0.001$].

IAT Results

Results for H1

Overall, mean RT was significantly different between the congruent and incongruent conditions ($U = 2{,}115$, $p < 0.001$). This result was also found in each of the four groups (Control, Orthorexic, Ortho_Patho, Pathologic; see **Figure 4**) with statistical powers of the association of 0.99, 0.97, 0.99, and 0.93 in each group, respectively. Overall, the mean effect size was 0.86, with a standard deviation of 0.4. Detailed results are in **Supplementary Table 7**.

Results for H2

Overall, no significant difference was found between our four groups [$H(3) = 1.68$, $p = 0.642$]. Mann–Whitney-tests between each pair of groups specify that no difference was found between groups. No significant difference between groups has been seen either regarding the effect size [$H(3) = 3.05$, $p = 0.383$].

The mixed model conducted showed a significant effect of the condition [$\chi^2(1{,}143) = 3{,}564.95$, $p < 2\text{e-}16$] with the incongruent condition being significantly and positively different from the congruent condition [*beta* = 14.17, 95% CI (13.88, 15.03), $t(11{,}749) = 38.15$, $p < 0.001$]. The model showed neither an influence of the group [$\chi^2(3{,}143) = 3.17$, $p = 0.366$] on RT, nor an influence of the interaction between the group and the condition [$\chi^2(3{,}143) = 2.94$, $p = 0.401$] on RT. Results are gathered in **Supplementary Table 8**.

The model's total explanatory power was: $R^2_C = 0.37$.

This analysis conducted with the orthorexic score taken instead of the group variable did not show any significant influence [$\chi^2(1{,}143) = 2.50$, $p = 0.114$].

Post-test Results

No significant difference between groups was shown [$F(3{,}282) = 0.46$, $p = 0.708$] regarding the post-test results. Nevertheless, a significant difference regarding the type of stimuli was seen, with stronger error rates for food stimuli [Food stimuli: $M = 0.94$, $SD = 1.4$; Word stimuli: $M = 0.17$, $SD = 0.4$; $F(1{,}284) = 41.2$, $p < 0.001$]. Overall, the mean error rates were really low, therefore stimuli were considered to be sufficiently correctly categorized for the IAT task.

Discussion, Study 2

In this second study, we observed shorter RT in the congruent condition (block 4) than the incongruent condition (block 7) in all groups of participants. In addition, the calculation of the D-measure showed a large effect size in all groups. These findings support our hypothesis that high-calorie foods are implicitly associated with "impurity" whereas low-calorie foods are implicitly associated with "purity." Moreover, this result extended our findings from Study 1 and suggest that both a subjective cue for energy content such as food transformation and an objective food variable such as calorie content per 100 g trigger moral attributes in healthy controls, subjects exhibiting orthorexia nervosa dispositions, and subjects exhibiting anorexia nervosa.

Stein and Nemeroff's (1995) (63) analysis of a moralization of fat can shed light on the association found between high-calorie food and "impurity". Indeed, in their study, the "fatty-food-eater" (people who eat "steak, hamburgers, French fries, doughnuts, and double-fudge ice cream sundaes" versus those who eat "fruit, especially oranges, salad, homemade wholewheat bread, chicken and potatoes") were considered significantly less "moral" on a morality score composed of evaluations along dimensions such as considerate-inconsiderate, ethical-unethical, and kind-hearted-cruel on 8-point Likert-type scales.

Interestingly, Stein and Nemeroff obtained no evidence of a difference between restrained and unrestrained eaters in their moral inferences based on eating habits. In the same vein, hypothesis H2' was not confirmed by our findings. The strength of the implicit associations was comparable between subjects exhibiting disordered eating behaviors and healthy control subjects: the analysis of the D-measures did not reveal any differences between the groups.

As a limitation, it should be noted that this experiment had to be done online due to the COVID-19 pandemic. Therefore, participants' environments, which could have effects on reaction times, could not be controlled. Moreover, participants were young adults between 18 and 35 years old with high level of education, therefore, no conclusions regarding the general population can be drawn from the results.

GENERAL DISCUSSION

The present studies aimed to determine whether certain food properties might trigger such moral categories in the general population as well as in subjects suffering from eating disorders, without using declarative methods. Our findings revealed for the first time the existence of robust associations between food variables cueing energy value and moral attributes related to purity or impurity at an implicit level, in subjects suffering from eating disorders as well as in subjects exhibiting disordered eating behaviors and dispositions and control subjects. Furthermore, the studies reported here represent a first and successful attempt to capture the moral properties that various populations ascribed to food without relying on declarative data that might be liable to social desirability, declarative data being only used to described the population itself in these studies. In other words, they represent a first body of evidence that implicit methods might be fruitfully deployed to better understand moral categorization of foods in various populations.

In today's Western societies, advertisers and marketers make extensive use of the vocabulary of morality when it comes to selling food products (15). Some foods that are usually highly processed and/or have a high calorie content have become "guilty pleasures" or "irresistible temptations." At the same time, the development of nutrition education programs has contributed to the growth of the classification of foods into good and bad foods. Historically, moral adjectives were attributed to food when referring to people suffering from "holy anorexia," also called "anorexia mirabilis" (i.e., people suffering from eating disorders using their religious beliefs to justify the way they eat and to protect themselves from judgments) (64, 65). Nowadays, the lexicon of morality seems to have pervasively influenced the manner in which the general population characterizes food. For instance, Brennan and colleagues (66) conducted recorded interviews with young adults about healthy eating. The interviews were so laden with moral terms that they decided to classify their participants into religious categories such as "Saint, Sinner, and Person in the Pew". Study 1 and Study 2 revealed that these associations between moral categories and food variables are observable at an implicit level as well, in patients with anorexia nervosa, in subjects with orthorexia nervosa, and in healthy control subjects. Therefore, reasonable doubts about the idea that moralization of food would result only from social desirability or self-presentation concerns might be raised. Indeed, the measurement of robust implicit associations between moral attributes and food variables pave the way for further research on an evaluative system of categories about food that subjects cannot always control but that can still contribute to the expression of food behaviors and attitudes.

Limits and Perspectives

An important limitation of our studies lies in the questionnaires used to categorize our participants into sub-groups. Firstly, the EDI questionnaire is made of different subscales that measure different dimensions of ED (drive for thinness, bulimia, body dissatisfaction, inefficacity, perfectionism, interpersonal distrust, interoceptive awareness, maturity fears). Here, only the EDI overall score was taken, as the sum of the scores for each dimension. Thus, anorexic as well as for instance bulimic symptoms have been taken into account. The inclusion of people with eating disorders other than AN may have reduced the effect size of the association, which may have been larger in only people with AN considering the previously discussed literature on AN. Nevertheless, no literature has been found about subjects with dietary disinhibition or binge eating concerning the association studied here. A promising perspective is thus to pursue the investigation of these associations between moral attributes and food variables in patients suffering from different eating disorders especially those characterized by a deficit of inhibition. Secondly, the ORTO15 was used to detect orthorexic traits. Even though it is the most widely used and translated measurement tool (67), several weaknesses have been raised such as its underlying structure, which was not assessed during its development (21), and its validity has been questioned with an overall accuracy of 0.70 (32). The corrected scoring procedure recommended by Meule et al. (34) showed internal consistencies of the ORTO15 and ORTO-12-EN of 0.56 and 0.76, respectively. These figures suggest that other tools may be more accurate in detecting orthorexia nervosa, but as new detection tools are under development, it seemed safer to use the most commonly used tool for these studies. Thirdly, it is important to note that these detections of orthorexia nervosa or eating disorder traits as well as the BMI of the participants were done with declarative data, which may present a social desirability bias. Indeed, as traits of eating disorders are not always well-regarded socially and even though the studies were anonymous, participants may have tended to respond in a way that they felt was more socially acceptable than their 'real' response, in order to project a favorable image of themselves, as described by Edwards (68). Thus, the formation of groups in Study 2 is to be put into perspective.

To conclude, these findings revealed that associations between food properties that cue for the energetic value of food triggered moral representations of purity/impurity in the general population, in the population suffering from disordered eating such as orthorexia nervosa, and in patients suffering from eating disorders such as anorexia nervosa. Further studies should try to explore whether such associations are also present at the opposite end of the disordered eating spectrum (i.e., loss of control) and whether such implicit associations have an impact on food behaviors on everyday food behaviors.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: The databases and R code are available at https://osf.io/3eku8/?view_only=cf962fa223b2462ea8e2b9cc6b84d052 and upon request from the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by CPP Ile-de-France; ID-RCB Number: 2015-A01194-45. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JL, SI, VM, LT, and CL contributed to the conception and design of the study. SI, PD, VM, LT, and CL contributed to the acquisition of data. LT and CL organized the database and performed the statistical analysis. CL wrote the first draft of the manuscript. JL and MO wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.884003/full#supplementary-material

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Judgments about appropriate foods for infants: Associations with parents' own food preferences

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When infants begin to eat solid foods (recommended at around 6 months of age), parents have a huge variety of choices in terms of what foods to offer. The present studies examine parents' judgments about foods for infants. Participants included parents recruited from Prolific (n = 99), who were shown descriptions of foods offered to infants (including familiar and unfamiliar foods at 6-, 9-, and 12-months) and a set of control foods eaten by adults. Participants rated each food based on how appropriate they thought it was for an infant and how much they personally wanted to eat the food. Parents rated foods as more appropriate for infants if they were familiar (vs. unfamiliar) and offered to younger infants (6- vs. 12-month-olds, or infant foods vs. adult foods), but demonstrated the opposite pattern when considering whether they wanted to eat each food. Participants' own food pickiness was related to their judgments about what they would eat, but not whether foods were appropriate for infants. Parents' judgments of individual foods were inversely related: The more appropriate they rated each food for an infant, the less they were interested in eating that food. These findings are discussed in terms of potential barriers to engaging in social modeling (i.e., parents demonstrating eating and liking the foods they offer to their infants).

KEYWORDS

cognitive bias, feeding practices, food selection, infant feeding, food beliefs

Introduction

Guidelines from the American Academy of Pediatrics on feeding infants solid foods (1) focus on the process of eating, rather than what to eat. These guidelines highlight physical cues indicating that infants are ready for solids (e.g., able to hold their head up, open their mouth when food approaches, move food from a spoon into their throat, have doubled their birth weight) and a few properties solid foods should have (e.g., soft or pureed foods, fortification with iron and zinc, and single-ingredient foods). Many aspects of these guidelines are designed to avoid infant choking or pinpoint allergic reactions, two critical goals for infant safety while eating. Nonetheless, a huge range of foods adhere to these guidelines, leaving parents with many decisions as they introduce new foods. Parents may feel inundated with choices and information. As guidelines note, parents may feel "confused because you have received too much advice from family and friends with different opinions" (1). Indeed, qualitative studies highlight messages from relatives and friends as key sources of information about infant feeding, but also as sources of conflict or stress (2–6).

Given the sparse information from pediatric guidelines in the United States about what foods to select, what are the differences in opinions that the guidelines reference and how might family and friends come to form these different opinions? One potential source of these opinions may be pre-existing concepts, knowledge, or assumptions about what foods are appropriate in a particular context. In a recent study of American adults' judgments about breakfast foods, rigid thinking about what foods are appropriate for breakfast was observed (e.g., orange juice and cereal were considered more appropriate for breakfast than chili or lamb chops), even if other foods might be more nutritious (7). These patterns can be observed early in life, with American 4- and 5-year-old children making similar judgments as adults about breakfast foods (8), and American 5-year-olds negatively judging people who ate unusual food combinations (9). However, these studies focus on people's own food preferences or assessments of the food choices of adults, rather than considering parents' role in selecting foods on behalf of their infants, another ecologically important context.

In addition to these experimental studies, several qualitative studies have examined parents' beliefs about feeding. Many studies have focused on mothers, as mothers are still primarily responsible for infant feeding and decisions about feeding (3, 4). Similar to pediatric guidelines, a key theme emerging from qualitative studies concerns infants' ability to eat solid foods (2, 4). Additional parent considerations include whether infants would get enough nutrition from breastmilk/formula alone (6), helping infants sleep (4–6), and resources needed to prepare foods (2). In one study that referenced specific foods to offer, a qualitative study of Latino parents in Northern California referred to traditional practices to select infants' first solid foods, with chicken soup with vegetables mentioned as the earliest food offered (10). Although several studies refer to infants' food preferences as an important consideration (2, 3), parents' own preferences for the foods were not discussed. One study referenced snacks as a way for parents and infants to share foods, but did not directly refer to parents' own food preferences (6). Nonetheless, parents' food preferences may influence what foods they choose for infants in important and understudied ways.

The present study examines parents' judgments of what foods are appropriate for infants, and whether those judgments vary based on participants' own food preferences. Parents of young children were recruited from Prolific and asked to rate foods offered to infants at different ages (6, 9, and 12 months) and a control group of adult dinner foods based on how appropriate those foods are for infants and how much participants would like to eat those foods. Participants also completed the Food Fussiness subscale of the Adult Eating Behavior Questionnaire (11) as a measure of their general food pickiness.

TABLE 1 Sample demographics (*N* and % or mean and SD).

Variable	N (%) or mean (SD)
Age	32.83 (5.78)
Gender	
Female	59 (59%)
Male	39 (39%)
Something else/not reported	2 (2%)
Race/ethnicity	
White, not Latinx	77 (77%)
Black, not Latinx	7 (7%)
Latinx, any race	7 (7%)
Multiracial, not Latinx	3 (3%)
Asian, not Latinx	5 (5%)
Not reported	1 (1%)
Income	
Less than $15,000	5 (5%)
$15,000–$25,000	3 (3%)
$25,000–$40,000	11 (11%)
$40,000–$60,000	16 (16%)
$60,000–$90,000	23 (23%)
$90,000–$120,000	20 (20%)
More than $120,000	21 (21%)
Not reported	1 (1%)
Child age (years)	
All children	4.35 (4.12)
Youngest child	1.61 (0.98)

N = 99.

Method

Participants

Participants included adults on Prolific (age range = 21–50 years; 59% reported gender as female, 39% reported male, 2% reported something else) who reported that their youngest child was born from 2019 to 2021 (to ensure that participants recently had a child in the 6–12-month range). One hundred people completed the study. All participants completed at least 70% of the test questions and on average completed 99.84% of questions. One participant was excluded for selecting "no" when asked if they were a parent. See **Table 1** for sample demographics.

Materials and procedure

Participants completed a Qualtrics survey in which they were asked to rate a set of 80 foods based on appropriateness for infants and their own preferences. Participants were told, "You will see descriptions of foods that someone might or might not feed to a baby. Imagine a baby that is eating solid foods and is 6- to 12-months old. For each description, we want you to provide two ratings: First, do you think the food is a good food to feed to a baby? The more appropriate and typical you think this food is for a baby, the higher the rating you should provide. Second, would you like to eat this food yourself? The more interested you are in eating the food (now as an adult) exactly as it is described, the higher the rating you should provide."

From a corpus of 805 foods from observations of mothers offering familiar and unfamiliar foods to their infants at 6, 9, and 12 months (DeJesus et al., in preparation), 10 familiar and 10 unfamiliar foods were randomly selected from each infant age (60 total). In that study, mothers completed a questionnaire about the food they offered in each feeding, including an open-ended question: "What food did you offer your baby during this feeding? Please provide as much detail as possible." Written descriptions of the foods from that question were cleaned to display similar units (e.g., "ounces" and "oz" were standardized to "ounces") and formatting (e.g., "Banana—Fresh" was converted to "Fresh banana"). Participants were also shown a control group of 20 adult foods compiled by surveying lab members on what they ate for dinner that week. The purpose of this control group was to assess whether participants would all rate foods as appropriate for infants and/or undesirable to eat, regardless of the actual description. For all foods, participants were only given written descriptions of the foods, without information about the food's familiarity, the age the food was offered to, or any other descriptors beyond what was provided by mothers in the original study. Foods were displayed in random order. Full text of food descriptions and counts of missing data per item are available on the Open Science Framework (OSF): https://osf.io/etq9y/. Examining missing data per food item, <1% of items were missing for familiar foods, <1% of items were missing for unfamiliar foods, and <1% of items were missing for control foods.

Participants rated the appropriateness and their liking of each food on a 1–5 scale: (1) "not at all," (2) "slightly," (3) "moderately," (4) "very," and (5) "extremely." Participants were told, "For both questions, the lowest rating is 'not at all' (not at all good for a baby or not at all something you would like to eat) and the highest rating is 'extremely' (extremely good for a baby or something you would be extremely happy to eat)." This question format was selected based on a pilot study (reported in supplemental materials on OSF) in which participants were asked to rate foods on a 0–100 scale, but a high rate of incomplete responses was observed and participants tended to use the ends of the scale the most often and used the 25–75 range less often.

Participants then completed the Food Fussiness subscale of the Adult Eating Behavior Questionnaire (11): (1) I often decide that I don't like a food, before tasting it; (2) I refuse new foods at first; (3) I enjoy tasting new foods; (4) I am interested in tasting new food I haven't tasted before; and (5) I enjoy a wide variety of foods. Each question had the following response options: (1) Strongly disagree, (2) disagree, (3) neither agree nor disagree, (4) agree, and (5) strongly agree. Scores were averaged with higher scores indicating more pickiness (questions 3, 4, and 5 were reverse coded). Participants then completed a demographic questionnaire.

Data analysis plan

First, parents' control food ratings were compared to their infant food ratings. For each question (appropriateness and preference), a mixed-model linear regression (controlling for multiple responses per parent) was performed, with food type (familiar, unfamiliar, and control) as a predictor of parents' ratings. This was a confirmatory analysis in which we anticipated familiar foods would be rated as most appropriate and control foods rated as highest in terms of participants' own preferences (but did not have specific predictions about all pairs significantly differing from one another).

Parents' judgments about the infant foods were then examined. For each question (appropriate, preference), a mixed-model linear regression was performed, with food type (familiar, unfamiliar), infant age (6, 9, and 12 months), and parent food pickiness as predictors of their ratings. Food type again was confirmatory (as we anticipated that familiar foods would be rated as more appropriate), but other variables were exploratory, as we did not have strong expectations about effects of infant age or parent pickiness within infant foods.

To examine associations between parents' two ratings for each food (appropriateness vs. preference), a mixed-model linear regression was performed, with parents' own preferences as a predictor of their appropriateness ratings; the model was repeated for individual food types (familiar, unfamiliar, control). This was an exploratory analysis, as we did not have strong expectations regarding the association between questions (i.e., if preference ratings were generally low, there might be no association between preference ratings and appropriateness ratings).

For each model, we report the conditional and marginal R^2 as indices of model fit (12, 13). See **Figures 1–3** for data visualizations and OSF for full regression tables,

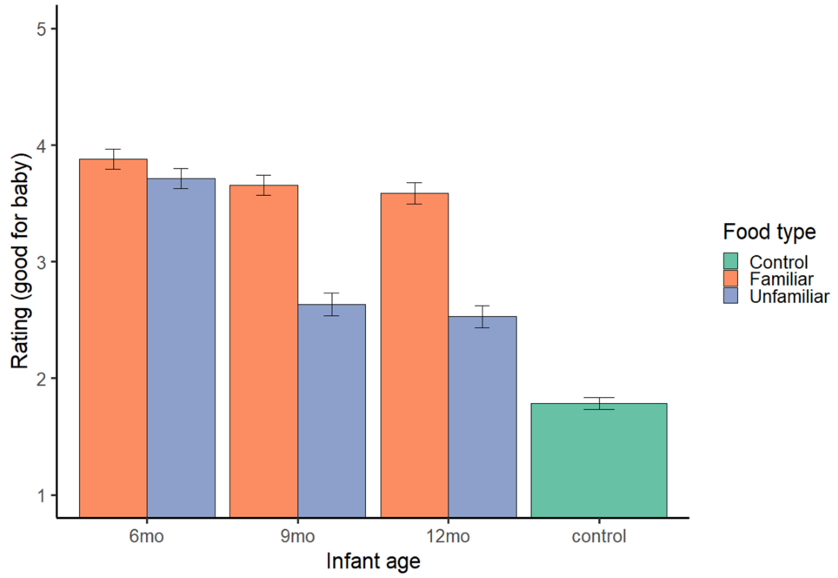

FIGURE 1
Appropriate and preference judgments. Error bars represent standard error.

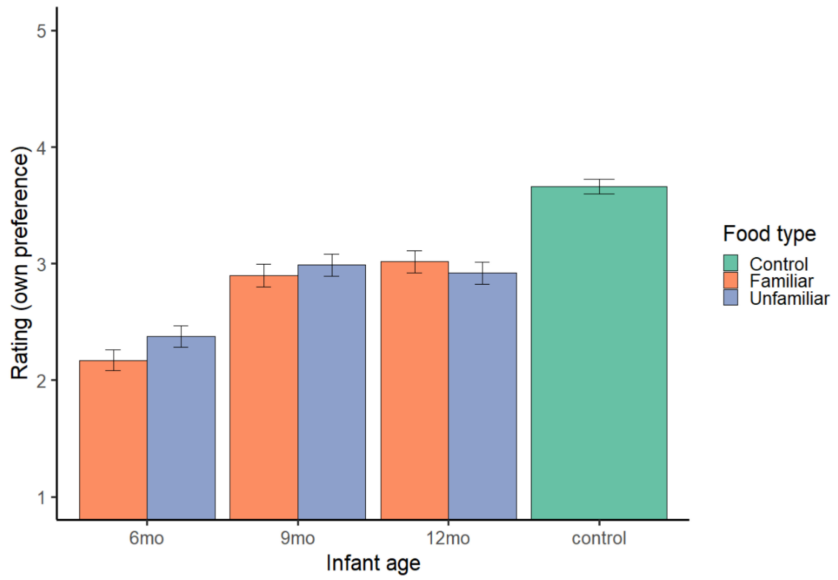

FIGURE 2
Own preference ratings. Error bars represent standard error.

additional visualizations, deidentified data, and analysis code: https://osf.io/etq9y/. In addition to the pilot study, supplemental analyses include analyses using just the neophobia-related questions of the AEBQ FF and analyses of just participants identifying as female to examine potential gender effects. For both, we observed similar results to the analyses that follow with the full sample and full AEBQ FF subscale.

Results

Appropriateness for infant

Infant vs. control foods

Parents rated familiar foods ($M = 3.71$, 95% $CI = 3.66, 3.76$; $b = 1.93$, $SE = 0.04$, $t = 50.81$, $p < 0.001$) and unfamiliar foods ($M = 2.96$, 95% $CI = 2.90, 3.01$; $b = 1.17$, $SE = 0.04$, $t = 30.96$,

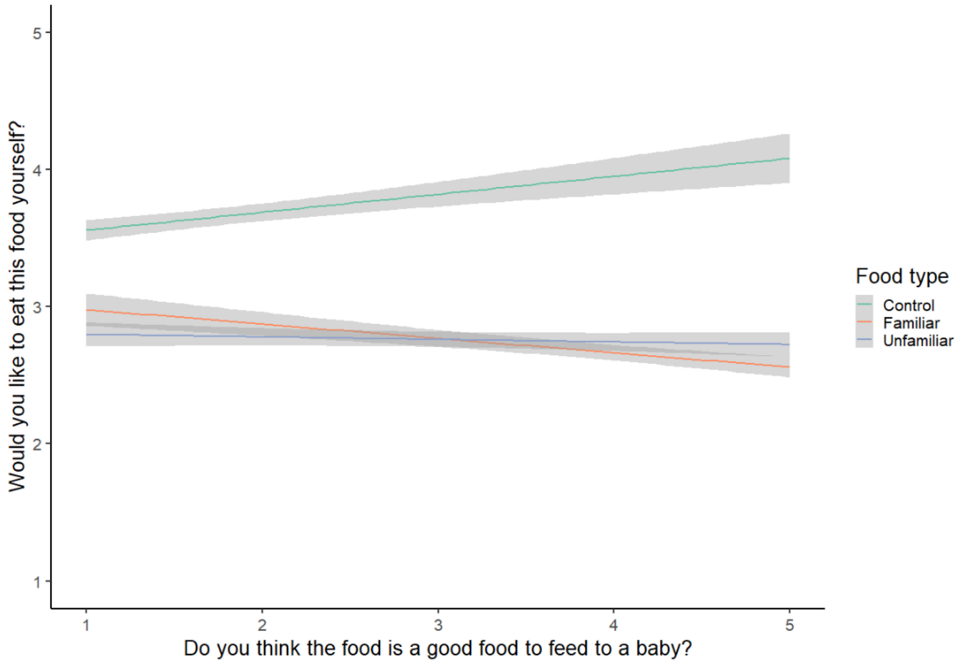

FIGURE 3
Appropriate vs. preference ratings.

$p < 0.001$) as more appropriate for infants than control foods (M = 1.78, 95% CI = 1.73, 1.84); model $R^2{}_c$ = 0.35, $R^2{}_m$ = 0.21 (see Figure 1).

Familiar vs. unfamiliar infant foods

Food type and infant age predicted parents' appropriateness ratings (model $R^2{}_c$ = 0.25, $R^2{}_m$ = 0.10). Parents rated familiar foods (M = 3.71, 95% CI = 3.66, 3.76) as more appropriate than unfamiliar foods (M = 2.96, 95% CI = 2.90, 3.01; b = −0.75, SE = 0.04, t = −21.39, $p < 0.001$). Parents also rated foods for 6-month-olds (M = 3.80, 95% CI = 3.74, 3.86; b = 0.74, SE = 0.04, t = 17.19, $p < 0.001$) and 9-month-olds (M = 3.14, 95% CI = 3.08, 3.21; b = 0.09, SE = 0.04, t = 2.01, p = 0.044) as more appropriate than foods for 12-month-olds (M = 3.06, 95% CI = 2.99, 3.13). Parents' own pickiness ratings were not associated with their appropriateness judgments (b = −0.002, SE = 0.06, t = −0.03, p = 0.978) (see Figure 1).

Parents' own preferences

Infant vs. control foods

Parents rated familiar foods (M = 2.70, 95% CI = 2.64, 2.75; b = −0.96, SE = 0.04, t = −23.91, $p < 0.001$) and unfamiliar foods (M = 2.76, 95% CI = 2.71, 2.82; b = −0.90, SE = 0.04, t = −22.25, $p < 0.001$) as less desirable than control foods (M = 3.66, 95% CI = 3.60, 3.72); model $R^2{}_c$ = 0.22, $R^2{}_m$ = 0.07 (see Figure 2).

Familiar vs. unfamiliar infant foods

Infant age and parent pickiness predicted preference ratings (model $R^2{}_c$ = 0.20, $R^2{}_m$ = 0.06). Parents rated foods for 6-month-olds (M = 2.27, 95% CI = 2.21, 2.34; b = −0.69, SE = 0.04 t = −15.86, $p < 0.001$) as less desirable than foods for 12-month-olds (M = 2.97, 95% CI = 2.90, 3.03); foods for 9-month-olds (M = 2.94, 95% CI = 2.87, 3.01; b = −0.02, SE = 0.04, t = −0.57, p = 0.569) did not differ. Parent pickiness was negatively associated with their preference ratings (b = −0.21, SE = 0.06, t = −3.43, $p < 0.001$): The pickier the parent, the less they wanted to eat the described foods. Parent preference ratings did not differ by food type (familiar: M = 2.70, 95% CI = 2.64, 2.75; unfamiliar: M = 2.76, 95% CI = 2.71, 2.82; b = 0.07, SE = 0.04, t = 1.85, p = 0.064) (Figure 2, right).

Associations between ratings

Parents' preference ratings were negatively associated with their appropriateness ratings for each food, b = −0.21, SE = 0.01, t = −18.52, $p < 0.001$, meaning the more parents reported they would eat a food, the less appropriate they rated that food for infants (model $R^2{}_c$ = 0.20, $R^2{}_m$ = 0.04). This association held for familiar foods (b = −0.15, SE = 0.02, t = −8.76, $p < 0.001$, model $R^2{}_c$ = 0.19, $R^2{}_m$ = 0.02) and unfamiliar foods (b = −0.09, SE = 0.02, t = −4.76, $p < 0.001$, model $R^2{}_c$ = 0.17, $R^2{}_m < 0.01$), but was reversed for control foods (b = 0.09, SE = 0.02, t = 5.51, $p < 0.001$, model $R^2{}_c$ = 0.49, $R^2{}_m$ = 0.01) (see Figure 3).

Discussion

This study demonstrates associations between parents' food preferences and whether they view those foods as appropriate for infants. When presented with familiar and unfamiliar foods offered to infants at 6-, 9-, and 12-months and adult dinner control foods, participants rated the infant-directed foods as more appropriate for infants and less likeable compared to control foods, even though participants only had written descriptions of the foods (not who ate the food). Participants' own food pickiness was negatively associated with their willingness to eat the infant foods, but not their infant appropriateness ratings. Parents also showed an inverse relationship between their appropriateness ratings and their own liking; the more appropriate they rated each food for infants, the less they wanted to eat it themselves. This study makes an important contribution to the study of food cognition by demonstrating systematic associations (as opposed to random responding) between features of foods (whether another parent identified the food as familiar vs. unfamiliar for their infant and what at what age it was offered) and parents' judgments about those foods, just from written descriptions. In the absence of any sensory information about the foods (i.e., parents could not directly smell or taste the food or see the food's texture or color), participants still made systematic judgments about whether foods were appropriate for infants.

Another important contribution of this study to the field of food cognition is the finding that parents' appropriateness and preference judgments regarding infant foods were inversely related: The more appropriate parents rated a food, the less they personally wanted to eat it. This finding highlights potential challenges for employing social modeling to improve early food acceptance. Research on infant social learning highlights that attention to social partners, especially their communicative facial expressions, gestures, and vocalizations [e.g., (14–18)], is important for learning, including in food contexts (19–21). Therefore, social modeling may provide an important mechanism for infants to learn what foods are safe, healthy, and culturally appropriate [see (22)]. Social modeling is recommended to parents of toddlers and children (23–25), but may be limited in infancy if parents avoid eating foods they consider appropriate for infants [see (22)]. Indeed, in an observational study of infant solid food feedings at 6, 9, and 12 months (which provided the food descriptions here), spontaneous social modeling was rare (DeJesus et al., in preparation).

This study has important limitations to address in future research. First, participants only viewed written descriptions of the foods. Written descriptions may or may not convey information about food texture, which infant solid food feeding guidelines discuss in detail, or other sensory properties (e.g., taste, smell, and color). Second, parents were not asked to provide information about their feeding practices. A few parents made substantive comments at the end of the study (n = 10), including aspects of their feeding practices or judgments about infant foods, such as "As soon as they started eating solid food, we fed both of our kids everything we ate, just modified for appropriate sizes, spice level and safety," "I considered the sugar/sodium content for many of the decisions," and "There were a couple things that I wouldn't feed to a baby purely off of choking hazard." However, with a small sample of explanations, systematic conclusions cannot be drawn. Parents were also not asked about their infants' reactions to solid foods, which may shape parents' views about what foods are appropriate for infants. Future studies would benefit from interviews with parents about their feeding practices and their infants' food reactions. Finally, directly asking parents what is appropriate for a baby could be liable to self-presentation or social desirability biases, as parents are very sensitive to the link between feeding choices and perceptions of good parenting [e.g., (3, 4, 26)]. Parents could also be influenced by the description of what it meant for a food to be "good for a baby" (i.e., more appropriate and typical). Asking parents to report separately on specific aspects of this idea, such as appropriateness, typicality, health properties, and infant liking, could yield more nuanced findings. Converging evidence from more indirect or implicit methods would be valuable to provide further insight into parents' judgments about infant foods.

The present study contributes to a growing body of research on infant feeding practices. Qualitative studies, in which parents (particularly mothers) were interviewed about their judgments about feeding highlight several challenges, including competing information and social comparison with friends and family (2–4, 6), and successful feeding as a part of participants' identity as mother (4). If successful feeding is central to one's feeling of competency as a mother, then choosing appropriate foods may feel like a high stakes process, particularly in a confusing information landscape, in which official guidance is sparse but unofficial guidance (e.g., from family members, friends, and social media) may be prominent. Future research is needed to reduce the stress that may result from this confluence of factors.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://osf.io/etq9y/.

Ethics statement

The studies involving human participants were reviewed and approved by the UNC Greensboro.

The patients/participants provided their written informed consent to participate in this study.

Author contributions

JD designed the study, analyzed the data, and wrote the manuscript.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Tears for pears: Influence of children's neophobia on categorization performance and strategy in the food domain

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Preschoolers' neophobic dispositions mainly target fruits and vegetables. They received a great deal of attention in the past decades as these dispositions represent the main psychological barrier to dietary variety. Recently, children's food neophobia has been found to be negatively correlated with their categorization performance (i.e., the accuracy to discriminate between food categories). We investigated categorization strategies among neophobic children, tendencies to favor one type of error over the other (misses over false alarms), in order to compensate for their poor categorization performance. To capture children's categorization strategies, we used the Signal Detection Theory framework. A first experiment assessed 120 3-to-6-years old children' sensitivity to discriminate between foods and nonfoods as well as their decision criterion (i.e., response strategy). In a second experiment, we manipulated the influence of food processing. The hypothesis was that food processing acts as a sign of human interventions that decreases uncertainty about edibility and thus promotes feelings of safety in the food domain. 137 children were tested on a food versus nonfood categorization task contrasting whole and sliced stimuli. In both experiments, increased levels of food neophobia were significantly associated with poorer categorization sensitivity and with a more conservative decision criterion (i.e., favoring "it is inedible" errors). Additionally, results from Experiment 2 revealed that food processing did not influence neophobic children, whereas their neophilic counterparts adopted a more liberal decision criterion for sliced stimuli than for whole stimuli. These findings are the first demonstration of a relationship between a decision criterion and food neophobia in young children. These results have strong implications for theories of food neophobia and laid the groundwork for designing novel types of food education interventions.

KEYWORDS

food neophobia, categorization, signal detection theory, food processing, children

Introduction

Why avoid patting an animal we see for the first time? Why not pick up an unfamiliar fruit from its tree to stave our hunger? Fearful reactions toward unfamiliar stimuli or situations are referred to as *neophobia* (1–3). Neophobia is a widespread disposition in human and non-human animals, on a continuum from less neophobic (or even neophilic) to neophobic individuals (4). On the neophobic endpoint, individuals show aversive reactions (e.g., avoidance) toward every stimulus or situation they are uncertain about. On the opposite endpoint also called neophilia, individuals are attracted by novelty (4). They tend to actively seek new sensations (5) and are open to novel experiences (6).

A great deal of interest in neophobia comes from its manifestation in the food domain, especially in human children [see refs. (7, 8) for reviews]. This is because high levels of food neophobia can have negative consequences for healthy development by hindering dietary variety, particularly the consumption of fruits and vegetables (9). Related to food neophobia, yet distinct, food pickiness is another barrier to children's dietary variety, defined as the rejection of a substantial number of familiar, including already tasted, foods (10). Controversy exists concerning their relationship. For some authors, food neophobia is a subset of pickiness [e.g., ref. (7)], whereas others claim that they are distinct theoretically and behaviorally (4, 11, 12) as they have different predictors. Although food neophobia and pickiness have an increased prevalence during childhood, such dietary habits and behaviors prevail well into adulthood (13). It is therefore critical to understand the cognitive underpinnings of food neophobia and picky/fussy eating as well as the factors that could contribute to mitigating these two types of food rejection.

Recent studies have evidenced that the intensity of food neophobia was negatively related to children's performance in food categorization and induction tasks [e.g., ref. (14)]. Although much research has examined children's ability to discriminate categories of items in the food domain, less is known about their categorization strategies. In an uncertain situation (e.g., when the food is novel or when discrimination is difficult), knowing that errors differ in their consequences (for instance deciding whether black, small, and juicy-looking berries are edible), there are two possible strategies. The first, conservative, strategy is to exercise caution as these berries are difficult to identify and could be toxic. The second, liberal strategy is more daring and consists in accepting the berries as edible, despite the uncertainty. Both strategies have advantages and disadvantages. Being conservative avoids dangers, choking, poisoning, death. However, this strategy can deprive individuals of a nutrient source but also of the opportunity to expand their knowledge of new foods. By being liberal, an individual accepts the risks associated with uncertainty but benefits from the opportunity to expand both their food repertoire and their category of edible items. The present study compares both the categorization performance and strategies of neophobic and neophilic children. In what follows, we start with a summary regarding food neophobia and the differences between neophobic and neophilic children. Then, we review more specifically the association between food neophobia and categorization.

Food neophobia is generally observed during early childhood (between 2 and 6 years). It refers to the tendency to reject novel or unknown foods at mere sight (15). This rejection occurs before the food is tasted and is thought to have an evolutionary protective function for children, minimizing the risk of ingesting novel and potentially harmful items (16). However, severe food neophobia has been linked to poor dietary habits such as a reduced dietary variety and lower consumption of vegetables (7, 11, 17). Numerous studies have shown that the intensity of food neophobia is stable between 2 and 6 years (12, 18–22). For instance, Kozioł-Kozakowska et al. (21) tested whether the proportions of children scoring "low," "average," and "high" on a food neophobia scale varied across age groups between 2 and 7 years. Their results showed that the majority of children, almost 80%, was scoring in the middle of the scale. The 20% of children left were equally divided into neophilic (i.e., low neophobia) and highly neophobic. Importantly, the authors did not find any significant difference in the proportion of these three groups when they compared the youngest children and the oldest children. Moreover, the impact of a child's food neophobia extends beyond childhood, since dietary habits acquired during this period partly determine dietary patterns in adulthood (13). Considering the importance of dietary variety across the lifespan, researchers have focused on understanding the mechanisms underpinning food neophobia in young children.

Since eating is socially grounded, social and environmental factors are important during the period of food neophobia. The caregiver's characteristics significantly affect children's food neophobia. For instance, children's food neophobia has been found to be positively correlated with parental food neophobia (12, 23) and negatively correlated with socioeconomic status (24–26) and educational level (27). Parental feeding practices are also important in weakening or strengthening children's food neophobia (28). For example, common parental feeding strategies such as food rewards, or pressure to eat, increase children's food neophobia tendencies (29). In contrast, introducing a high variety of vegetables at weaning has a positive impact (30). Another major influence of the social context on children's reaction to food is social facilitation (31), defined as an increase in the probability of performing a class of behavior in the presence of conspecifics performing the same class of behavior at the same time. It has been shown, for instance, that children are more willing to taste a new food if they see an adult (32) or a peer (33, 34) eat it.

Other studies have associated food neophobia with temperamental traits, or individual differences in emotional and behavioral reactivity and regulation [e.g., refs. (35, 36)]. Differences in temperament lead to different responses to the same stimuli across individuals (37). Several temperamental traits have been found to be associated with food neophobia [for reviews, see Lafraire et al. (8) and Nicklaus and Monnery-Patris (28)]. Food neophobia is associated with higher levels of negative emotionality (38), shyness (39), lower levels of sensation-seeking (5) and approaches to novel stimuli (35). In addition, it has been shown that tactile defensiveness, overreactions to the experiences of touch or withdrawals from some typically harmless tactile stimuli (e.g., grass or sand) is related to high levels of food neophobia (40). More central to the present research, food neophobia is often connected to anxiety (11) or even disgust, over new foods (41, 42).

Recently, Maratos and Staples (43) showed that, although all children demonstrate attentional biases (e.g., facilitated visual engagement) toward new foods, these biases were heightened in children displaying higher levels of food neophobia. The three components (anxiety, disgust, and attentional biases) are standard markers of phobias (44). Moreover, high levels of neophobia are correlated with stronger typical physiological fear responses to new foods, such as galvanic skin response and an increase in pulse or respiration rhythm (45) which suggests that food neophobia is a true phobia (see ref. (46) for a review). In addition, children justify their fear by providing reasons related to the dangers of eating something they do not know (47). For instance, Johnson et al. (47) asked children between 3 and 5 years of age their reasons to avoid tasting new foods, and more than half of their justifications referred to the fear of negative consequences following ingestion (e.g., nausea, falling sick, choking, dying). An additional finding of their study is that neophobic children rated the foods less favorably than more neophilic children. Studies on non-human species also suggest that food neophobia is a real fear. For example, in rats, a lesion of the amygdala (48, 49) and infusions into this region of adrenergic agents (50, 51) are associated with a reduction in food neophobia.

Although it has been shown that food neophobia was correlated with several social and temperamental factors, there is surprisingly little research investigating whether cognitive factors could explain differences between neophobic and neophilic individuals. However, recent developmental studies point to the importance of investigating cognition as a way to further understand food-related decision-making and foster more healthy eating behaviors in children (52, 53).

At the cognitive level, recent studies uncovered a negative relationship between children's food neophobia and category-based abilities [e.g., categorization and induction (14, 54, 55)]. For instance, in a forced-choice task, Rioux et al. (54) tested 2- to-6-year-old children's abilities to discriminate between two taxonomic categories, vegetables and fruits. Higher levels of food neophobia predicted lower performance (see also ref. (56) for similar results). Rioux et al. (55) revealed that food neophobia and taxonomic category-based induction performance were also negatively correlated. Neophilic children tended to generalize blank properties (e.g., "contains zuline") according to taxonomic category membership (e.g., from a green zucchini to an orange carrot) as adults generally do, whilst neophobic children tended to generalize the properties according to perceptual similarity [e.g., from a green zucchini to a green banana (55)]. Interestingly, the negative relationship between food neophobia and categorization abilities is not restricted to taxonomic knowledge but extends to thematic knowledge [e.g., the ability to associate a burger patty with a burger bun (14)]. This evidence shows a strong negative association between children's food neophobia and their categorization performance.

However, performance is not the only indicator of participants' behavior. The same level of performance may result from liberal or conservative strategies. For example, when asked whether some items are food or not, the accuracy of two participants can be 50%. However, one participant may have answered that all items were food (i.e., a liberal strategy), and the other that they were all nonfood (i.e., a conservative strategy).

The Signal Detection Theory [SDT (57)] separates a participant's categorization performance and strategy into sensitivity and decision criteria respectively. The decision criteria may vary as a function of the relative costs of missing the signal (i.e., *misses*, here an opportunity to feed oneself) and responding to the noise as if it was the signal (i.e., *false alarms*, here getting poisoned). A propensity to categorize any stimulus as noise, which will result in a high proportion of misses, is described as a conservative decision criterion, whereas categorizing them as the signal, giving a high proportion of false alarms, is a liberal decision criterion.

In the food domain, Rioux et al. (54) found that food neophobia was negatively associated with sensitivity in children between 2 and 6 years of age. The authors did not observe any relationship with the decision criterion. However, they tested children's ability to categorize vegetables and fruits, a task in which errors have no obvious costs or benefits. The task might have no effect on the decision criterion which is known to vary as a function of the perception of the risk, that is when miscategorization carries some costs [e.g., when failing to correctly identify someone as angry incurs punishment that would otherwise have been avoided (58)]. For instance, anxious individuals who have difficulties identifying facial expressions are more likely to categorize both fearful and positive emotional facial expressions as threatening than their non-anxious counterparts (59, 60). Therefore, in order to find a link between categorization strategies and food neophobia we need a task in which errors are associated with risks. A recent study by Foinant et al. (61) supports this hypothesis. The authors found that children with high levels of food neophobia had an increased likelihood of extending the negative properties from one food (such as sickness, e.g., "This food makes Feppy throw up") to another food compared to more neophilic children, which is compatible with the hypothesis that neophobic children want to minimize the risks in the case of food. The current research tested the influence of food neophobia on children's decision criteria in edibility judgments categorization tasks in which errors carry a risk (i.e., getting sick after eating something inedible).

As mentioned above, neophobic children have poor sensitivity in the food domain, compared to their neophilic counterparts. Decreased sensitivity makes errors more likely. We hypothesized that neophobic children mitigate this increased risk by adopting decision criteria that differ from neophilic children's. In Experiment 1, we tested 4-to-6-year-old children who had to discriminate fruits and vegetables from nonfoods matched on color and shape [e.g., a red tomato and a red Christmas ball; see refs. (62, 63) for similar designs]. This task allowed us to measure both children's sensitivity (i.e., categorization performance) and decision criterion (i.e., categorization strategy).

The SDT framework allows predictions on the probability of making errors as a function of perceived risk but also predictions regarding perceived uncertainty (1, 58). When a risk is involved (e.g., consuming something inedible), increased uncertainty triggers safer strategies whereas a decrease in perceived uncertainty should lead to riskier strategies (e.g., considering most of the stimuli in the environment as safe). In Experiment 2, we manipulated uncertainty through the degree of food processing, contrasting whole and sliced items. Indeed, recent studies have shown that food processing (i.e., signs of human interventions such as slicing) decreases uncertainty about edibility and is associated with food safety in adults (64–66) and children (67, 68). Manipulating the processing state of the items had two purposes. First, we tested whether children categorized differently whole and sliced items. Second, we tested whether the processing state would influence the decision criterion of neophobic and neophilic children in the same way. We formulated two opposite hypotheses. (1) Neophobic children would rely more on the cues of food processing than their neophilic counterparts who can rely on their greater accuracy. (2) Conversely, only neophilic children may rely on cues of food processing and neophobic children may display caution independently of the item states.

Based on the available literature, we expected that neophobic children would show a poorer sensitivity and a more conservative decision criterion, a tendency to say *no*, in judging items as edible or inedible compared to their neophilic counterparts. We also hypothesized a more liberal decision criterion for sliced items as compared to whole items based on the edibility cues. We expected the state of the items (i.e., whole and sliced) to reveal neophobia-related differences in categorization strategy if such differences existed. Finally, based on the above distinction between food neophobia and pickiness, we assessed whether these two conditions would differ in terms of sensitivity and decision strategies when categorizing edible and inedible substances. Differences between the two dispositions would contribute to the current debate regarding their nature and possible differences.

Experience 1: Materials and methods

Participants

Participants were 120 children (63 girls and 57 boys; age range = 48.20–76.20 months; mean age = 63.50; SD = 7.29). This sample size was chosen to match previous studies that found an effect of food rejection on categorization [e.g., refs. (14, 54, 61)]. They were predominantly Caucasian and came from middle-class urban areas. Informed consent was obtained from their school and their parents. The procedure was in accordance with the Declaration of Helsinki and followed institutional ethics board guidelines for research on humans.

Materials and procedure

To measure children's food neophobia we used the Child Food Rejection Scale [CFRS (22)]. The CFRS was developed to assess, by hetero-evaluation, 2-to-7-year-old children's food rejection on two subscales: one is measuring children's food neophobia and one is measuring their pickiness on a 5-point Likert-like (*Strongly disagree*, *Disagree*, *Neither agree nor disagree*, *Agree*, *Strongly agree*). Caregivers were asked to rate to what extent they agree with statements regarding their child's neophobia (e.g., "*My child rejects a novel food before even tasting it*") and pickiness ("*My child rejects certain foods after tasting them*"). Each answer was then numerically coded with high scores indicating higher food neophobia and pickiness (scores could range from 6 (highly neophilic) to 30 (highly neophobic) for neophobia, $M = 14.9$, SD = 5.06; from 5 (highly non-picky) to 25 for pickiness (highly picky), $M = 16.4$, SD = 4.92). We also computed a global food rejection score from 11 (highly neophilic and non-picky) to 55 (highly neophobic and picky) by adding the food neophobia and pickiness scores ($M = 31.4$, SD = 8.88). The observed range of scores is similar to the one typically found in French preschool-aged children [e.g., refs. (14, 22, 69)].

Children were tested individually for approximately 10 min in a quiet room at their school and told they will play a computer game. The experiment consisted of a familiarization phase followed by a test phase.

The categorization task was presented on a computer and designed with OpenSesame. Children were seated at 50 cm from a computer screen. They were instructed to respond as quickly and as accurately as possible by pressing the target button whenever a food picture appeared and by pressing the non-target button when a nonfood picture appeared. We used a real puppet named "Yoshi" in order to minimize children's risk of transferring their own food preferences or consumption habits into the task. We adapted Rioux et al. (63) and told the children: 'I need your help; at home, I have many things that look like foods but which sometimes are not foods. Yoshi who comes to visit me always puts anything in his mouth. But we do not want him to get sick because he ate something that was not food. Do you agree with me? Yoshi should not get hurt. Can you help me to tell him what he can eat and what he cannot eat? You press this button (pointing to the target button) when you see something that can be eaten. When you see something that cannot be eaten you press this other button (pointing to the non-target button). But be careful, Yoshi should not put things in his mouth that cannot be eaten." The task started with a familiarization phase of eight trials (four edible plant-based foods and four nonfoods). In the familiarization phase, we explained the meaning of "things that cannot be eaten" that were real non-edible items, and that we did not refer to poisonous or unlikable (by children' standards) foods. During the familiarization phase children also trained themselves with the response buttons and feedbacks were provided by the experimenter when they did an error. Failed trials were repeated until children succeeded. The test phase consisted of 10 target (i.e., the signal) and 10 non-target (i.e., the noise, distractors) trials presented in random order. All foods were fruits and vegetables as these two categories are the main targets of food rejection (7). Besides, the foods and nonfoods used were individually matched in color and shape (see **Figure 1**). For each trial, the stimulus (apparent size: 20° × 13.5°) was displayed until the child's answer.

FIGURE 1
Test stimuli used in Experiment 1.

Data analyses

The type of response for each food stimulus (hit or miss) and each nonfood stimulus (correct rejection or false alarm) was recorded. Each participant was assigned a hit score (i.e., number of food stimuli categorized as food), a miss score (i.e., number of food stimuli categorized as nonfood), a correct rejection score (i.e., number of nonfood stimuli categorized as nonfood), and a false alarm score (i.e., number of nonfood stimuli categorized as food). Hit, miss, correct rejection, and false alarm scores could vary between 0 and 10. These scores were used to calculate a categorization performance score, the sensitivity index A′, and a categorization strategy score, the Beta, derived from SDT (57), adapting them to experiments based on small numbers of stimuli [see ref. (70)]. SDT is used to analyze data derived from tasks where a decision is made regarding the presence or absence of a signal (i.e., the foods) embedded in noise (i.e., the perceptually similar nonfoods). The A′ represents the distance between the mean of the signal distribution and the mean of the noise distribution. The greater the A′ the better an individual is at discriminating the signal from the noise. A′ ranged from 0 to 1, with 0.5 indicating responses at chance level, and 1 maximum discriminability.

$$A' = log\left[\frac{N_H+0.5}{N_M+0.5}\right] - log\left[\frac{N_{FA}+0.5}{N_{CR}+0.5}\right]$$

The decision criterion Beta represents the individual's strategy to categorize stimuli as the signal rather than the noise. Beta ranged from –1 to 1, with negative values indicating a liberal strategy (i.e., children tending to categorize any stimulus as food), and positive values indicating a conservative strategy (i.e., children tending to categorize any stimulus as nonfood).

$$Beta = -log\left[\frac{N_H+N_{FA}+0.5}{N_M+N_{CR}+0.5}\right]$$

N_H, N_M, N_{FA}, and N_{CR} correspond to the numbers of hits, misses, false alarms, and correct rejections, respectively.

Results

We assessed A′ and Beta in order to test the hypothesis that children's categorization was impacted by their food neophobia (see **Table 1**).

Given the relatively broad age range of the children reported in this study, as shown in **Table 2**, preliminary Pearson's correlations tested for significant associations between children's age with the key variables (children's food neophobia and

TABLE 1 Descriptive statistics children's categorization scores.

	Children (n = 120) *Mean* (SD)
Hit	79.8% (17.0%)
Miss	20.2% (17.0%)
Correct rejection	74.7% (16.8%)
False alarm	25.3% (16.8%)
A′	0.714 (0.120)
Beta	−0.028 (0.116)

SD, standard deviation.

pickiness scores, categorization A′ and Beta). In addition, independent t-tests examined differences in children's age, food neophobia scores, food pickiness scores, and categorization scores for girls and boys. The t-tests did not reveal any differences between girls and boys on any of these measurements ($p > 0.05$).

We performed partial Pearson's correlations between children's food neophobia scores and categorization scores, after controlling for age. The results revealed that food neophobia scores were significantly related to both A′ and Beta. Consistent with previous findings [e.g., ref. (54)], food neophobia was negatively associated with children's sensitivity (A′; r = −0.211, p = 0.021). However, recall that our main question was whether neophobic (i.e., children scoring high on the food neophobia subscale) and neophilic children (i.e., children scoring low on the food neophobia subscale) would adopt the same decision criterion. Our results show that food neophobia was also positively correlated with Beta (r = 0.182, p = 0.047) which means that, as predicted, highly neophobic children adopted a conservative, protective strategy, categorizing more often actual edible substances as nonfoods and avoiding mistaking inedible substances as food compared to their more neophilic counterparts.

Although food pickiness was not correlated with A′ (r = −0.096, p = 0.297) nor Beta (r = −0.021, p = 0.824), we used the *linearhypothesis* function from the *car* package in R (71) to test the hypothesis that the difference between the regression coefficients of food neophobia and pickiness for explaining the categorization scores differed from 0. Results did not reveal a significant difference between food neophobia and pickiness to predict A′ (t = −1.41, p = 0.162). However, the results revealed that food neophobia was a stronger predictor of Beta than food pickiness (t = 2.33, p = 0.022).

Discussion Experiment 1

In line with previous evidence [e.g., refs. (14, 54)], neophobic children in Experiment 1 performed more poorly on the categorization task than their neophilic counterparts. Our main result was that high levels of food neophobia predicted a safer categorization strategy. Indeed, neophobic children did overall more errors, even categorizing actual edible substances as nonfood. However, they also avoided dangerous errors since they categorized inedible substances as food less often than neophilic children. These results show that food neophobia was associated with a more conservative decision criterion, which was not the case for food pickiness.

Experiment 2: Materials and methods

In the following experiment, we investigated whether food processing cues would influence children's categorization strategies and would interact with their levels of food neophobia. According to recent evidence, food processing is a visual cue that can reduce uncertainty about edibility and thus promote feelings of safety in the food domain (61, 64–66, 68). Contrary to unprocessed food which is natural food with no signs of human intervention, processed food is defined as food that exhibits signs of human intervention (e.g., sliced). For instance, Foinant et al. (61) showed that children between 4 and 6 years generalize significantly fewer negative health properties (e.g., "makes Feppy throw up," p. 5) to a food if it is sliced compared to whole. Here, we investigated whether children would adopt different categorization strategies for whole and sliced items and if the processed state of an item would interact with food neophobia.

Participants

Children were recruited at their schools from the same population as in Experiment 1. None of the participants took part in the first experiment. They were 137 children (77 girls and 60 boys; age range = 57.14 to 72.07 months; mean age = 64.50; SD = 3.72). As in Experiment 1, the caregivers filled out the CFRS (food neophobia scores, M = 15.3, SD = 5.28; food

TABLE 2 Pairwise Pearson correlation coefficients between children's age and their A′, Beta, food neophobia, and pickiness scores.

	A′	Beta	Food neophobia scores	Food pickiness scores
Age	r = 0.177 p = 0.053 p_{Holm} = 0.372	r = 0.190 p = 0.038 p_{Holm} = 0.302	r = −0.148 p = 0.106 p_{Holm} = 0.629	r = −0.119 p = 0.196 p_{Holm} = 0.784

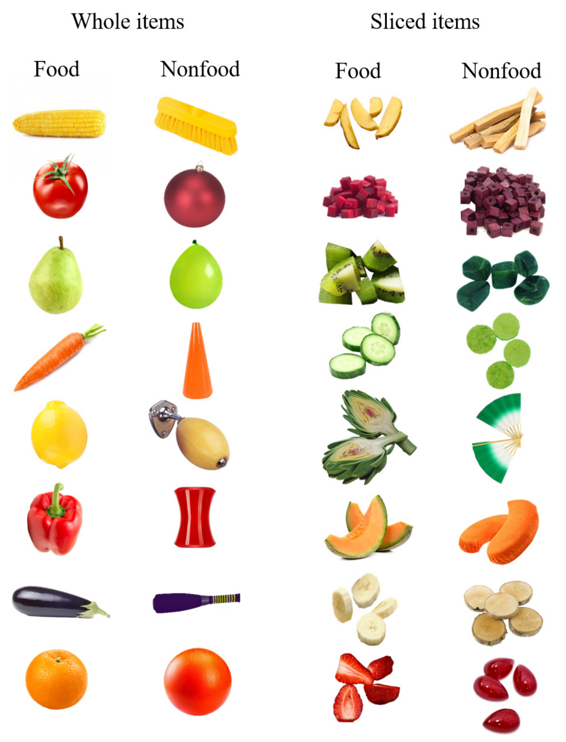

FIGURE 2
Test stimuli used in Experiment 2.

pickiness scores, M = 16.8, SD = 4.41; and global food rejections scores, M = 32.1, SD = 8.81). As in Experiment 1, children's CFRS scores were similar to previous studies [e.g., ref. (22)].

Materials and procedure

The procedure for the categorization task was the same as Experiment 1, however, we introduced the factor "item state" (whole versus sliced items) in the design. The test phase consisted of 16 target (i.e., the signal) and 16 non-target (i.e., the noise, distractors) trials presented in random order. The target trials were composed of eight whole edible food items and eight sliced edible food items. The non-target trials were composed of eight whole non-edible items and eight sliced non-edible items (see Figure 2).

Results

We assessed A′ and Beta to test the hypothesis that children's categorization was influenced by their level of food neophobia and item states (Whole and Sliced; results are set out in Table 3).

As shown in Table 4, preliminary Pearson's correlations tested significant associations between children's age and the study's main variables (children's food rejection scores and categorization scores). In addition, independent t-tests examined differences in children's food rejection and categorization scores for girls and boys. The t-tests did not reveal any differences between girls and boys on any of these measurements ($p > 0.05$). In view of these preliminary analyses, linear mixed-effects models were used, with children serving as a random factor to account for shared variances within-subjects, controlling for age. Predictors were kept in the adjusted models following their ability to improve the model through the goodness of fit assessed using the Akaike Information Criterion [AIC (72)].

Sensitivity: A′

As shown in Table 5, the models were constructed by iteratively adding predictive variables to the null model (M0, the intercept and no predictor). Based on the procedure of decreasing the AIC (72), we constructed the model that was the best fit to the data with A′ as the outcome measure. Our best fit model (M2) contained random effects (participants), and within-subjects fixed-effects: item state (Whole or Sliced) and food neophobia (continuous factor). This model explained 15.8% of the variation across our sample, as demonstrated by the adjusted R^2. We report the ANOVA output results for the model throughout.

Results revealed an effect of item state (F = 18.63, $p < 0.001$, d = 0.74) with significantly more accurate discriminations for whole (M = 0.816, SD = 0.113) than for sliced (M = 0.726, SD = 0.111) items. There was also a significant effect of food neophobia (F = 4.73, p = 0.031, d = −0.35). Food neophobia scores and A′ were significantly negatively correlated (r = −0.205 p = 0.017). The highly neophobic children had a lower discrimination accuracy to distinguish between food and nonfood items than the more neophilic children.

Decision criterion: Beta

As with A′, we iteratively ran the models on children's Beta. As shown in Table 6, the best fit model (M3) contained random effects (participants), and within-subjects fixed-effects: item state (Whole or Sliced), food neophobia (continuous factor), and the interaction item state: neophobia. This model explained 23.1% of the variation across our sample, as demonstrated by the adjusted R^2.

Results revealed an effect of item state (F = 32.75, $p < 0.001$, d = 0.98) with significantly more sliced items categorized as food (M = −0.206, SD = 0.194) than whole items (M = −0.081, SD = 0.39), indicating that children were more willing to decide that a sliced item was a food rather than a whole item. There was also a significant effect of food neophobia (F = 19.36, $p < 0.001$, d = 0.20), with highly neophobic children categorizing fewer items as foods than other children, thus being more conservative. Food neophobia scores and Beta

TABLE 3 Descriptive statistics for children's categorization scores as a function of item states.

Children (n = 137) *Mean* (SD)	**Whole items *Mean* (SD)**	**Sliced items *Mean* (SD)**
Hit	92.6% (9.04%)	90.7% (13.1%)
Miss	7.4% (9.04%)	9.3% (13.1%)
Correct rejection	78.5% (15.8%)	57.9% (23.7%)
False alarm	21.5% (15.8%)	42.1% (23.7%)
A′	0.816 (0.113)	0.726 (0.111)
Beta	−0.081 (0.096)	−0.206 (0.194)

SD, standard deviation.

were significantly positively correlated (r = 0.354, p < 0.001). Figure 3 shows a significant interaction between item states and food neophobia scores (F = 10.02, p = 0.002, d = 0.54). Food neophobia scores were more strongly positively correlated with Beta for sliced items (r = 0.346, p < 0.001, blue line in Figure 3) than for whole items (r = 0.205, p = 0.016, red line in Figure 3). The neophilic children were more liberal for sliced items than their neophobic counterparts, categorizing more often the sliced items as foods. On the other hand, neophobic children treated whole and sliced items similarly, adopting a more conservative strategy than their more neophilic counterparts.

Discussion experiment 2

Experiment 2 built upon the findings from Experiment 1 and assessed the effect of the state of the stimuli with whole and sliced items. We found that higher levels of food neophobia were predictive of poorer sensitivity and a more conservative strategy. An important additional finding of this second experiment is that neophilic children were more liberal for sliced stimuli than for whole stimuli. Neophobic children, on the other hand, were conservative, independently of the item states. Finally, as in the first experiment, only food neophobia has been retained in the models. No significant effect was obtained regarding food pickiness.

General discussion

The present research aimed to assess the contributions of performance and strategy in the categorization of edible and inedible items by neophobic and neophilic children. In two experiments, we used a discrimination paradigm within the framework of SDT.

In line with previous studies (14, 54–56, 63) neophobic children in the present research performed poorly in the categorization tasks compared to their neophilic counterparts.

TABLE 4 Pairwise Pearson correlation coefficients between children's age and their A′, Beta, food neophobia, and pickiness scores.

	A′	**Beta**	**Food neophobia scores**	**Food pickiness scores**
Age	r = −0.198 p = 0.037 p_{Holm} = 0.187	r = −0.028 p = 0.768 p_{Holm} = 0.768	r = 0.105 p = 0.272 p_{Holm} = 0.544	r = 0.236 p = 0.013 p_{Holm} = 0.101

TABLE 5 The goodness of fit of the linear mixed-effects models with A′ as the outcome measure.

	Model	**Df**	**AIC**	**Pseudo R^2**	***p***
M0	1		−383.81		
M1	. . . + item state	1	−441.47	0.138	<0.001
M2	**. . . + item state + food neophobia**	**2**	**−444.12**	**0.158**	**0.033**
M3	. . . + item state * food neophobia	3	−444.55	0.162	0.122
M4	. . . + item state + food neophobia + food pickiness	3	−442.13	0.157	0.946

The best model is indicated in bold. M2 had the lowest AIC and, thus was the best model explaining children' sensitivity A' given the data.

TABLE 6 The goodness of fit of the linear mixed-effects models with Beta as the outcome measure.

	Model	**Df**	**AIC**	**Pseudo R^2**	***p***
M0	1		−205.64		
M1	. . . + item state	1	−257.33	0.144	<0.001
M2	. . . + item state + food neophobia	2	−273.44	0.211	<0.001
M3	**. . . + item state * food neophobia**	**3**	**−281.11**	**0.231**	**0.002**
M4	. . . + item state * food neophobia + food pickiness	4	−279.11	0.231	0.985

The best model is indicated in bold. M3 had the lowest AIC and, thus was the best model explaining childrenŠs decision criterion Beta given the data.

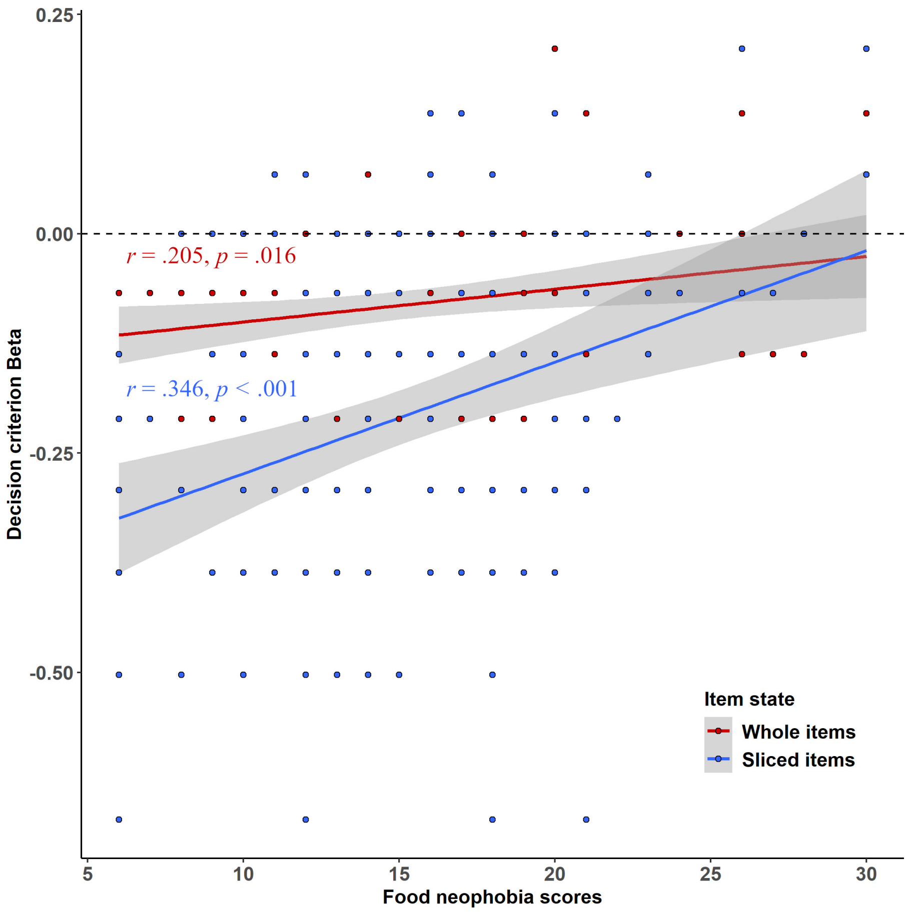

FIGURE 3
Children's decision criterion scores Beta as a function of their food neophobia scores and item state. The Pearson coefficient correlation indicated significant and positive correlations between the children's food neophobia scores and decision criterion Beta, for whole ($r = 0.205$, $p = 0.016$, the red line) and sliced items ($r = 0.346$, $p < 0.001$, the blue line).

Our main contribution is that food neophobia affected children's taxonomic categorization ability of both edible and inedible items, hence not only food categories (e.g., vegetables and fruits). Taken together, the evidence suggests that neophilic children have better discrimination abilities and are, therefore, expected to be protected from trying to consume inedible substances, whereas neophobic children are expected to be at risk of consuming them. However, although neophilic children in our experiments were better at discriminating food from nonfood items, their strategies put them at a higher risk of accepting nonfoods as edible than neophobic children.

Previous studies on neophobia within the SDT framework did not reveal any difference in categorization strategies between neophobic and neophilic children [e.g., ref. (54)]. In the present experiments, neophobic children favored increased misses whereas neophilic children had a higher rate of false alarms, categorizing more nonfood items as edible. Because neophobic children cannot accurately identify foods from nonfoods, they may compensate with more conservative strategies to avoid errors. Paradoxically, neophilic children, who were more accurate at discriminating foods from nonfoods, adopted a more liberal and riskier strategy. This is adapted in most daily situations in which food safety is the norm. Indeed, in our contemporary food environment and modern societies, food safety is controlled in food supply chains, and conservative strategies are less useful. Experiment 2 is in line with this interpretation. We expected that combining perceptual similarity between foods and nonfood items with signs of food processing would increase the number of edibility judgments for sliced items compared to whole items. Interestingly, the item state did not affect neophobic children's categorization, whereas neophilic children adopted a more liberal strategy for sliced items than for whole items. In other words, only the neophilic children detected or used the safety cues conveyed by food processing (64–68).

Together, the neophobic lower performance in discriminating foods from nonfoods is consistent with their strategy to report more items as inedible, including processed foods, suggesting lower levels of confidence. The present findings illuminate the fact that neophobic children seem less impacted by interventions that aim to overcome food rejection (56, 73, 74) because they experience such eating situations as more threatening than other children.

Last, it is worth mentioning that only the neophobia dispositions significantly correlated with children's categorization and were kept in our models. We obtained no significant effect of food pickiness [contrary to ref. (54)]. This contrast between food neophobia and pickiness was also found in several previous studies [e.g., refs. (61, 63)]. For instance, Foinant et al. (61) witnessed that only food neophobia but not food pickiness was predictive of an increased likelihood of generalizing negative properties of a food to other foods. These results suggest that these two dispositions do not have the same influence on children's decisions about food. From a theoretical standpoint, it seems more compelling that food neophobia, rather than food pickiness, has a more robust link with increased conservative decision criteria. Indeed, reviews on food neophobia postulate that food neophobia is considered to be an adaptive mechanism that promotes survival (1, 30, 75). Furthermore, as mentioned in the introduction, food neophobia increases feelings of anxiety and physiological response, an outcome not evidenced in food pickiness (11).

Several limitations of this research need to be addressed. First, our food stimuli were only made of fruits and vegetables, which are the main targets of food neophobia (7). However, it would be interesting to investigate children's categorization abilities to discriminate between foods and nonfoods with categories that are less prone to neophobia (such as starchy food). Second, we equated food processing with slicing. Evidence suggests that food processing is a matter of degree (65). For instance, other processing techniques modifying organoleptic properties of foods, such as cooking, could affect edibility judgment not only in neophilic children but also in neophobic children. Indeed, current evidence regarding the interaction of food neophobia and food processing is scarce and, possibly, neophobic children may need stronger safety cues to overcome their fear about a potential food source. Similarly, morphing techniques (e.g., to create stimuli on finely graded continua ranging, for instance, from an edible unfamiliar food of red color to an inedible, even poisonous, unfamiliar food in green) would allow performing analyses at various points along the continuum of threat intensity. Third, food neophobia is not the only individual characteristic that can influence food categorization. In adults, previous work has shown that hunger level, dietary habits, and BMI could also explain differences in food categorization [e.g., ref. (76)]. It might be informative to measure these individual characteristics alongside children's food neophobia. Finally, we used a puppet procedure to decrease the risk of children using their preferences and consumption habits to answer the task. This procedure is widely used in many categorization and generalization tasks, and far beyond, in the cognitive development literature. Although some researchers have questioned the validity of using puppets [e.g., ref. (77)], they have not yet been backed by empirical evidence. Instead, studies that assessed the use of puppets in research on young children's cognitive development found that "it makes no difference if the protagonist is presented as a real person, a puppet, a doll, a pictured storybook character, or a videotaped person" [p. 664, ref. (78), regarding false belief understanding; see also Li et al. (79) regarding knowledge learning]. Nevertheless, future studies could consider comparing the impact of people and puppets on children's edibility judgments.

Despite these limitations, the current research has strong implications for theories of food neophobia. Food neophobia may shape children's strategies that may reinforce the rejection of novel but perfectly safe foods. As neophobic children engage in risk-avoidant decision-making, consequent behavioral avoidance may prevent children from gaining experience and knowledge in the food domain, thereby eliciting a self-perpetuating cycle. If children exhibit conservative strategies, caregivers may be discouraged from exposing them to new foods and eating situations. Consequently, the learning opportunities of foods and eating situations may be greatly reduced, maintaining poor knowledge about food and the conservative strategy compensating it. The current experiments provide only indirect evidence for this cycle. Further research is needed to examine the possibility that risk-avoidant decision-making serves to reinforce pre-existing individual differences in neophobia.

Current studies also have implications for theories of neophilia. While we worry that neophobic children will reject new foods that are important for healthy development, in the present research, neophilic children dangerously accepted as edible nonfood items. It is currently believed that the number of accidental poisoning among young children is due to difficulties in making the distinction between food and nonfood items (80). However, our data suggest that the attraction toward trying inedible substances may, instead, reflect a dangerously liberal decision criterion.

Finally, the current findings open up new perspectives for practical interventions to promote healthy eating. Current interventions aiming at fostering dietary variety tend to deploy the same program equally to all children of the same age group. However, our data strongly underline the crucial importance to take into account the individual factors that may modulate the extent to which children may benefit from such interventions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by official agreement between the Academia Inspection of Côte d'Or and the University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

DF, JL, and J-PT conceived the hypotheses and the design of the study. DF collected the data and performed the statistical analyses. All authors contributed to the manuscript writing, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Neural circuits mediating food cue-reactivity: Toward a new model shaping the interplay of internal and external factors

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Introduction

Growing evidence suggests that food and drug cues may activate similar brain networks (1), pointing to shared brain abnormalities in obesity and substance use disorder. These are of crucial importance, given the worldwide cost in individuals' health, wellbeing, and direct and indirect health costs (2, 3). Neuroimaging research has focused on the cue-reactivity paradigm (4), an experimental procedure involving the examination of neurofunctional responses to the controlled exposure to stimuli (food- or drug-related) inducing craving, namely the strong and intense desire to seek and consume a substance. These studies have revealed a distributed network of brain regions recruited during exogenous (i.e., perceptual food pictures, odors, or tastes) and endogenous (i.e., imagery) cue-reactivity [see (5) for a review and (6, 7) for meta-analyses].

At the functional level, these regions can be categorized into two main circuits: those underlying the sensory and motivational responses ("cue-reactivity"), and those supporting higher-order attentional, decision-making, and inhibitory control processes ("cue-regulation"; Figure 1A). Although the former is more tightly related to "bottom-up" processes prompted by the exposure to cues, and the latter to "top-down" processes, we underline that these two circuits do not always operate separately and, as such, do not represent a dichotomous system. Indeed, they are better represented by a dynamic system in which "interface areas," such as the orbitofrontal cortex (OFC) (8, 9), may act as a target region where a balance between the circuits is reached in order to orient behavior toward cues or prompting executive control. In other words, similarly to what proposed for substance use disorder, we speculate that the OFC lies at the center of two opposing processes (reward-related go-signals and executive-related no-go signals) (9, 10), therefore acting as a "target" around which the two processes exert their influence over behavior [for a discussion see also (11)].

Recently, Jasinska et al. (12) proposed a model to examine individual-specific (e.g., addiction severity) and study-specific factors (e.g., drug availability) that modulate the neural reactions to drug cues.

Here, we propose a first attempt to translate Jasinska et al.'s model to the domain of food cue-reactivity (Figure 1B): this framework fits well the current literature of eating behaviors (normal and pathological), and it may help identifying transdiagnostic processes that can be targeted by treatment and prevention strategies. Slightly differently from the original model (12), we suggest that the neural response to food cues might be modulated by internal (depending on the status of the organism), and external factors (depending on the environmental and sensory conditions).

We will first describe these internal and external factors, and then address how they might have a role for giving rise to specific brain activation patterns. Finally, we will discuss the importance of our model for framing new research ideas in the domain of food behavior.

Factors affecting neural food cue-reactivity

Internal factors: Biological and psychological

Biological factors such as one's genetic make-up can strongly influence the neural reactivity to food cues (both craving and intake). Young adults with the A2/A2 allele (TaqIA rs1800497 polymorphism in chromosome 11) express 30–40% more dopamine D2 receptors (13), a neurotransmitter that is crucial in modulating the motivational value of rewards. This greater availability of dopamine D2 receptors is accompanied by increased activity in the basal ganglia (i.e., the caudate) in response to food cues (i.e., milkshakes), which also predicts greater future weight gain (14, 15) (opposite pattern shown in individuals with the A1 allele). Furthermore, the fluctuating levels of several peripheral homeostatic signals can modulate neural responses to food cues. Orexigenic signals that promote appetitive behaviors, such as the hormone ghrelin, can increase the neural activity of key regions of the cue-reactivity network (i.e., striatum, amygdala and insula) and cue-regulation network (i.e., OFC) in response to visual food cues (16). Conversely, anorexic signals such as insulin (17), leptin (18), or PYY (19) normally dampen such responses.

Of note, recent models on the Brain-Gut-Microbiome axis suggest that a diet rich in fat/sugar and low in fiber is associated with reduced microbial diversity, mucus-stimulating microorganisms, mucus thickness, and increased epithelial leakiness, leading to reduced intestinal barrier function and activation of the gut-associated immune system (20, 21). This state of "metabolic endotoxemia" is thought to reduce central satiety mechanisms by (i) influencing enteroendocrine secretion of satiety hormones such as PYY and cholecystokinin, and by (ii) reducing the expression of anorexigenic peptide receptors on vagal afferents and leptin receptors in the hypothalamus, leading to a disinhibition of satiety mechanisms (22, 23). Despite we are not aware of any study addressing the influence of the gut microbiome on the neural responses to food cues, we believe that this may represent another biological factor worth of investigation.

Growing evidence suggests that another modulating factor is weight status, usually measured with the Body-Mass Index (BMI)[1]. Compared to healthy weight, individuals with obesity show increased activity in areas involved in motivation and habit formation [caudate and nucleus accumbens (NAc)], salience and memory (insula and hippocampus), as well as in regions involved in reward evaluation and goal-directed behaviors (i.e., OFC), while viewing food cues (24–26).

Psychological factors such as the motivation to change one's own dietary habits can shape the neural response to food cues. Compared to ex-dieters, healthy weight individuals, who are currently on diet, show increased activity of regions involved in cognitive control prefrontal cortex (PFC) in response to food cues, suggesting that long-term goals of weight loss can increase the reactivity of the cue-regulation network (27). Interestingly, this difference across dieters was only evident in the fed condition, pointing to higher-level interactions between biological and psychological factors (27). Likewise, the explicit cognitive regulation of craving of foods (e.g., mindful attention, thinking about long-term costs of eating high-calories food) has been associated with increased cognitive control and goal-directed behavior (greater activity in dorsolateral PFC (dlPFC) and OFC) and a concomitant reduced motivation and salience of such cues (decreased activity in ventral tegmental area (VTA), NAc, and amygdala) (28).

Preliminary evidence points to the role of personality traits in this framework. Self-directedness (linked to emotional stability and goal-directed behavior) (29), was negatively associated with emotional regulation (amygdala activity) in response to appetizing food vs. non-foods (30), suggesting that it may represent a protective factor against cue-driven food cravings and intake. Conversely, increased disinhibited eating and trait impulsivity were positively associated with greater insula and amygdala responses to palatable foods (31).

External factors: Environmental and cue-specific

Environmental factors play an important role in driving the neural reactions to food cues. Compared to the domain of drug addiction (32, 33), fewer studies investigated the effects of food availability on the brain responses. When the food was made available during (or immediately after) cue exposure, healthy weight participants exhibited heightened activity of

1 The BMI is an indirect measure of adiposity and obesity severity. It is calculated as weight (in kilograms)/height squared (in meters). Healthy weight: 18.5 BMI < 25; underweight: BMI < 18.5; overweight: 25 BMI < 30; obese: BMI 30.

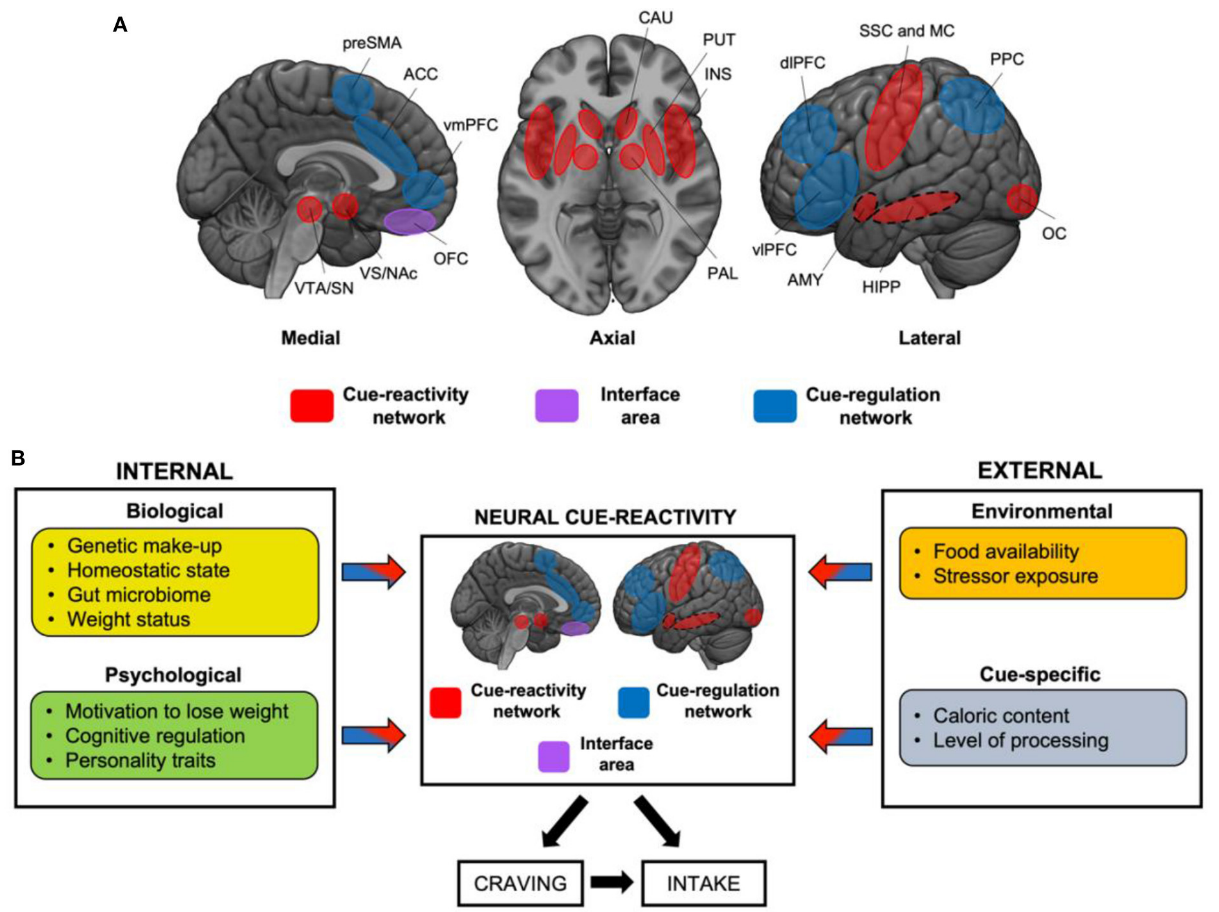

FIGURE 1
Neural circuits mediating food cue-reactivity: the influence of internal and external factors. **(A)** Cue-reactivity network (red), "interface area" (violet), and "cue-regulation" network (blue). Dashed circles represent medial structures on the lateral surface. OFC may represent an "interface" area, and serve as a target region around which a push-pull balance is reached between the cue-reactivity and the cue-regulation circuits. ACC, anterior cingulate cortex; AMY, amygdala; CAU, caudate; dlPFC, dorsolateral prefrontal cortex; HIPP, hippocampus; INS, insula; MC, motor cortex; NAc, nucleus accumbens; OC, occipital cortex; OFC, orbitofrontal cortex; PAL, pallidum; PPC, Posterior Parietal Cortex; preSMA, pre supplementary motor area; SN, substantia nigra; SSC, somatosensory cortex; VS, ventral striatum; VTA, ventral tegmental area. **(B)** This simplified model, adapted from (10), displays the main internal (biological and psychological) and external factors (environmental and cue-specific) that modulate the neural response to food cues. These factors are expected to act in isolation, by up- or down-regulating the responses of the cue-reactivity and/or cue-regulation network, or in interaction, giving rise to specific brain activation patterns. These, in turn, are expected to influence craving and, ultimately, food intake.

regions involved in appetitive behaviors, emotional regulation and reward evaluation (striatum, insula, amygdala, and OFC) (34, 35), suggesting the augmented reward value of food when it is readily available for consumption. Exposure to environmental stressors can alter the neural response to food cues and, ultimately, food intake. In women with high self-reported stress, exposure to high-calories food pictures induced greater activity of the striatum, amygdala, and anterior cingulate cortex (ACC) together with a decreased activation of dlPFC compared to low-calorie foods (36), suggesting that high stress may predispose overeating by increasing the motivational value of food and decreasing executive control. Using a guided mental imagery paradigm, overweight/obese women exhibited greater right amygdala activity in response to milkshake intake while imaging a stressful vs. relaxing scenario, and this activity was positively associated with their basal cortisol level (37).

Concerning the actual and perceived caloric content, high-calories vs. low-calories food pictures elicit greater activity of regions involved in motivation and habit formation (dorsal and ventral striatum), salience (amygdala, insula), and reward evaluation (OFC) (25, 38), especially in fasting conditions (38). This heightened reactivity to high-calories food is greater in overweight/obese individuals [see (39) for a meta-analysis]. Recent evidence showed that the level of processing of foods (i.e., raw carrots vs. roasted carrots vs. carrot cake) must be taken into account since this human intervention in modifying the natural state of foods also holds distinct brain representations that are by some means independent from the brain responses to caloric content (40).

Toward a new model of food cue-reactivity shaping the interplay of internal and external factors

The drive for pleasure is "hard-wired" in our brain (41, 42): from the gratification derived from the fulfillment of biological and social needs, that granted the survival of our species, to the enjoyment of beauty and discovery, which led to the realization of remarkable endeavors in arts and sciences. The relentless search for pleasure guided our evolution. Yet, there are situations where these adaptive motivational processes result in compulsive and addictive-like intake of rewards, whereby highly reinforcing stimuli, such as foods or drugs, disrupt the normal motivational processes and lead to maladaptive behaviors. Frustrating as it might be, greatly pleasurable stimuli such as high-calories food, and drugs of abuse, can "hijack" the same neurocognitive machinery evolved to grant our survival (43, 44).

Here we suggest that the core idea behind Jasinska et al.' model of drug cue-reactivity (12) can be translated in the domain of eating behaviors, unveiling intriguing similarities between the two. We highlighted the role of some major internal and external factors that can influence the neural reactivity to food cues and, ultimately, food craving and intake, suggesting that this grouping of the factors best captures the nature of feeding behaviors as arising from the integration of internal (e.g., homeostatic signals) and external (e.g., food availability) sources of information (45). We argue that Jasinska et al.' claim regarding the importance of the interactive effects of the factors (12) also holds for the domain of food cue-reactivity. Crucially, we propose that the described external and internal factors may act in isolation, by up- or down-regulating the responses of the cue-reactivity/cue-regulation network, or in interaction, giving rise to specific brain activation patterns. These factors are expected to influence craving and, ultimately, food intake. We anticipate that these networks most likely lie in a "dynamic balance:" interface regions such as OFC (8, 10, 11) may serve as a target region around which a push-pull balance is reached between the cue-reactivity and the cue-regulation circuits, as a function of the abovementioned factors. As shown by a recent meta-analysis by Devoto et al. (7), weight status interacts with the homeostatic signals and with the sensory modality of stimulus presentation, reinforcing the notion that individuals with obesity exhibit greater activity in regions involved in motivation (i.e., striatum) in response to visual food cues, despite their satiety state (46). We argue that this impaired central satiety signaling may depend on complex interactions across all levels of the Brain-Gut-Microbiome axis (22, 23): this is made plausible by the observation that obesity is frequently associated with a higher consumption of the kind of food that favors metabolic endotoxemia due to a "bad" gut microbiome. The interaction between food availability and the caloric content of food was also found (35), with higher striatal activity in response to high-calorie (vs. low-calorie) foods only when food was available for immediate consumption.

We believe that there are several reasons why this new perspective may prove useful, for both basic research and translational medicine. First, the evidence that different factors —in isolation and in interaction— can influence the neural response to food cues should lead future studies to acknowledge these effects by controlling for possible confounding variables.

Second, a deeper comprehension of the contextual factors that determine the neural food cue-reactivity and craving is indeed crucial for the development of effective treatments to tackle the current prevalence and rise of obesity (47). Cognitive-Behavioral interventions, particularly if they include the empowerment of cognitive and emotional regulation in response to food cues, may also benefit from the integration of contextual factors into their design. For instance, a Cognitive-Behavioral intervention aimed at reducing food cravings in individuals with obesity may be performed under specific circumstances (e.g., satiety) and with a particular cue (e.g., pictures of high-calorie food). Similarly, brain-centered treatments, whether they involve real-time neurofeedback (48) or the use of non-invasive brain stimulation techniques, were effective in reducing craving and intake for both food (in eating disorders) (49) and drug [in addiction; see (50) for a meta-analysis] and may easily integrate contextual factors into their design.

Dovetailing with this hypothesis, previous studies demonstrated that deep excitatory repetitive Transcranial Magnetic Stimulation (TMS) over the bilateral insula and PFC is effective in inducing weight loss in individuals with obesity (51), and resting-state neuroimaging data suggests that this effect is driven by a decreased reactivity to sensory stimuli, accompanied by an increased reliance on higher-order processes (49). It follows that a fine-grained characterization of the role of contextual factors at the neurofunctional level is essential to develop ecological and personalized treatments.

This fine-grained characterization can only be accomplished by the concomitant manipulation of different internal and external factors: in fact, food cues are usually perceived under specific internal (e.g., homeostatic state) and external contingencies (e.g., food availability; social factors), rather than in the vacuum. With this respect, our opinion paper provides a first pool of factors that can be manipulated by the researcher interested in the brain reaction to food cues. For instance, one might be interested in the differential responses to food cues in healthy weight vs. individuals with obesity, under different homeostatic states (hunger vs. satiety), and when food is available (vs. unavailable).

We acknowledge that the model presented here does not include other factors that can modulate brain responses to food cues, such as sex (52), age (53), sensory modality (7), and length of stimulus presentation. Future studies will help to determine, by modeling internal and external factors in factorial designs, which main effects and interactions are crucial to understand the neurocognitive bases of normal and pathological eating behaviors. As in the domain of drug addiction (12), elucidating such interactions will pave the way to more effective, ecological, and tailor-made (behavioral or brain-centered) interventions.

Finally, we speculate that most factors illustrated here may influence the neural reactivity to different biological (e.g., sexually arousing) and non-biological (e.g., gambling) rewards, in the normal and pathological motivation. We anticipate that multidisciplinary researchers will take up the challenge, enriching our understanding on how the brain copes with pleasurable stimuli in our everyday life.

Author contributions

FD conceived the original idea of the manuscript. FD and CC wrote the manuscript. FD, CC, EP, and LZ reviewed and finalized the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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The impact of diet and lifestyle on wellbeing in adults during COVID-19 lockdown

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A healthy diet and lifestyle may protect against adverse mental health outcomes, which is especially crucial during stressful times, such as the COVID-19 pandemic. This preregistered longitudinal online study explored whether diet and lifestyle (physical activity, sleep, and social interactions) were associated with wellbeing and mood during a light lockdown in Germany. Participants (N = 117, 72 males; 28 ± 9 years old) answered mental health and lifestyle questionnaires (social connections, sleep, activity) followed by submitting 1 week of food and mood-lifestyle diary (food intake, positive and negative mood, mental wellbeing, sleep quality, physical activity level, quantity and quality of social interactions) *via* a smartphone app. We used multivariate linear and mixed-effects models to associate mood and wellbeing with dietary components and lifestyle factors. Interindividual analyses revealed that sleep and social interaction significantly impacted mood and wellbeing. Interestingly, fruit and vegetable intake correlated with wellbeing, even when controlling for all lifestyle factors. Fruit and vegetable intake also significantly correlated with daily fluctuations in wellbeing within individuals next to sleep, physical activity, and social interactions. We observed gender differences in fruit and vegetable intake and anxiety levels. Our results emphasize the importance of diet contributing to individual wellbeing, even in the challenging times of a pandemic. Future research is necessary to test if our findings could extend to other populations.

KEYWORDS
eating behavior, mental health, COVID-19, gender, activity

Introduction

COVID-19 lockdowns and social isolation have taken a toll on mental wellbeing (1–3). Lifestyle factors, including diet and physical activity, are shown to effectively reduce the risk of mental health disorders (4). However, it is unclear whether and how such lifestyle factors contribute to mental wellbeing during the pandemic.

A diet high in fruit and vegetables reduced depression risk (5–7) and anxiety (8). On the other hand, diets high in trans fatty acids from processed foods (9) and fast food increased depression risk over 6-years (10, 11). Dietary intake can have relatively instant effects on mood and wellbeing. Studies investigating daily associations found that higher fruit and vegetable intake was associated with wellbeing (12) and positive mood the same day or the next day (13). While eating salty snacks correlated with higher negative mood the next day in people with a high Body Mass Index (BMI) (13). Similarly, higher saturated fat intake correlated with negative mood 2 days later in college students (14).

Importantly, diet-induced neuroinflammation is a key mechanism linking diet, cognitive function, and even gray matter volume loss (15). The dietary inflammatory index (DII) estimates a diet's inflammatory potential (16), and at least two meta-analyses have established a link with depression (17, 18), depressive symptoms, anxiety, and psychological distress (19, 20). Importantly, DII and mental health profiles were less associated in men than in women (19), pointing to gender differences.

Besides diet, physical activity and sleep play a major role in wellbeing (21, 22), depression (23), anxiety (24, 25) and sleep quality (26). However, the pandemic has impacted lifestyle behaviors. For example, a recent study demonstrated that roughly 53% of 5,000 participants reported a change in activity level during the COVID-19 pandemic (27). Sleep disturbances were reliably associated with the risk for depressive symptoms and clinical depression (4) and correlated positively with mental health issues (28), suggesting that physical activity and sleep quality majorly contribute to wellbeing and mood during the pandemic.

Managing the COVID-19 pandemic required social distancing, making the link between social interaction and mental health outcomes of high interest. Social interaction is vital for mental health outcomes, including wellbeing and symptoms of depression or anxiety (29–31). For example, loneliness, the subjective feeling of the absence of a social network or a companion, is associated with adverse physical and mental health outcomes (30) and low physical activity levels in mental health patient groups (32, 33). During COVID-19-lockdown, social distancing restrictions led to increased feelings of social isolation, which coincided with more severe mental health outcomes (34). At the same time, a good relationship quality was crucial in maintaining mental health (3). Furthermore, wellbeing during the pandemic was associated with satisfaction of psychological needs at an inter- and intrapersonal level (35). Data from an Italian study during lockdown and when some restrictions were lifted showed that both emotional eating and binge-eating were increased in the presence of emotional distress, including higher levels of anxiety and depression, but also partially correlated with relationship quality and quality of life (36). An interesting question that remains is to what extent dietary intake can ameliorate the negative consequences of living through a pandemic in the context of physical activity, sleep, and social interaction quality.

In this preregistered online study,[1] we investigated whether diet, lifestyle factors, and social interaction were associated with wellbeing, anxiety, and feeling of excitement during COVID-19 lockdown. We hypothesized that food intake (i.e., fat, carbohydrates, fruit and vegetables) contributes significantly to (1) individual wellbeing, (2) anxiety, and (3) excitement, even when controlling for lifestyle factors. Next to these preregistered analyses, we tested whether inflammation, as a possible mechanism, plays a role in the relationship between food intake and wellbeing.

Materials and methods

Participants

We recruited participants *via* the online research platform Prolific. German-speaking individuals without prior mental health diagnoses, residing in Germany at the time of the study, with an Apple or Android smartphone for using the FoodApp, were eligible to participate. We excluded participants who showed above-threshold depressive symptoms (i.e., above 30, which is classified as "severe") determined by the Beck Depression Inventory [BDI; German version (37)]. Questionnaires were completed online on the SoSci Survey platform. The food and mood diary records were recorded using the FoodApp available for Android and Apple smartphones. Participants provided informed consent and received £28 for participation. Ethical approval was obtained from the Humboldt University of Berlin.

Study design

We conducted an online study using questionnaires assessing mental health, wellbeing, and lifestyle factors. Afterward, participants kept a food and mood diary and a record of sleep quality, activity, and social interactions for 7 days (**Figure 1**). In particular, in this study we wanted to

1 https://osf.io/nqhjf

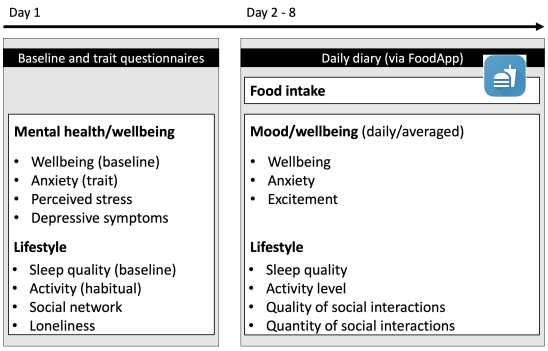

FIGURE 1
Study outline. Participants first answered questionnaires assessing baseline mental health and wellbeing as well as lifestyle-related questionnaires. Next, they completed a daily food, mood, and lifestyle diary for 7 days *via* a smartphone app.

investigate the relationship between food intake as independent variables (i.e., fruit and vegetable, fat and carbohydrate intake) and mood (i.e., wellbeing, anxiety, excitement) as dependent variables while controlling for lifestyle factors (i.e., activity, sleep and social interaction quality and quantity). Data were collected between 11 and 24 November 2020 at which time there was a light lockdown in Germany. During this time, people were asked to reduce social contacts to the minimum. In public, one was only allowed to meet with people of one's household and one additional household (from: 28.10.2020).[2]

Assessment of food-mood and lifestyle diary

The food-mood and lifestyle diaries were completed using a smartphone FoodApp for 7 days [following (14)]. For food intake, we recorded the following information: date, time, type of meal, companionship during the meal, food items, and weight consumed. Food items could be chosen from a list of about 10,000 food and beverage items commonly available in Germany, for example, "potatoes peeled boiled" or "wholemeal bread with margarine and currant jam." Participants chose the food item matching their consumption along with an estimate of how much they consumed in grams or milliliters. Participants were free to log their food intake after a meal, or later during the day. A reminder was sent to participants who did not submit their data by 7 p.m. that day. Dietary intake was evaluated using the German Federal Food Key data table [Bundeslebensmittelschlüssel (38)] made available by the Max-Rubner Institut (MRI). Data from days with extreme daily caloric intake were excluded from analysis (for women: < 500 or > 3,500 kcal/day, for men: < 800 and > 4,000 kcal/day considered as unrealistic amounts) following (39).

For dietary intake, we calculated energy-adjusted (ea) values to account for an individual's total energy intake (i.e., g/1,000 kcal/day) as suggested by Agnoli et al. (40). Additionally, we computed daily energy derived from each macronutrient. For this, we multiplied the daily intake of carbohydrate and protein (g/d) by 4 kcal, and fat intake by 9 kcal (**Table 1**). Outliers in dietary data were winsorized separately for men and women.

Finally, we calculated the Dietary Inflammatory Index (DII) score for each participant following (16). First, we selected the nutrients available to us, then we calculated z-scores by subtracting the standard global mean and dividing by the global standard deviation (the standard global mean and deviation are both found in **Table 2** of Shivappa et al. (16). Then, we converted these z-scores to normal percentiles and multiplied them by 2, and subtracted them by 1. Each score was multiplied by its respective inflammatory effect score. Lastly, all scores were summed up to derive the overall DII score for each participant.

Mood and lifestyle ratings were unlocked after 5 p.m. each day. Participants rated their wellbeing [using the short Warwick-Edinburgh Mental Wellbeing Scale (41)], anxiety, and excitement levels on a 5-point Likert scale. We added excitement and anxiety to daily measures to supplement functional wellbeing. Finally, sleep quality, activity level, quantity, and quality of social interactions were rated on a scale from 1 to 100.

Questionnaires

We used the Warwick Edinburgh Mental Wellbeing Scale [WEMWBS (41)] to assess baseline wellbeing. This 14-item questionnaire assesses different aspects of positive mental health including balance of feeling and functioning. Example items include, "I've been feeling optimistic about the future" and "I've been thinking clearly." We used the 7-item short form of the WEMWBS to assess daily wellbeing during the week of food-mood-lifestyle diary entries. This scale emphasizes functioning items over feeling items. Both versions are responsive to change (42).

Participants also completed mental health and lifestyle questionnaires, including trait anxiety [STAI (43)], depressive symptoms [BDI; German version (37)], and perceived stress [PSQ (44)]. Finally, the Community Assessment of Psychic Experiences (45) was analyzed as part of a separate study.

Statistical analyses

All data was downloaded from the FoodApp server, Prolific, and SoSci survey and imported into R studio. Plots were made using ggstatsplot (46). We reported descriptive statistics for demographic characteristics, food intake, daily ratings as well as baseline and trait questionnaire scores.

2 https://www.bundesregierung.de/breg-de/themen/coronavirus/corona-massnahmen-1734724

TABLE 1 Sample characteristics by gender.

	Total (N = 117)[a]	Women (N = 45)[a]	Men (N = 72)[a]	p-value[b]
Age	28.12 (8.91)	30.76 (10.44)	26.47 (7.42)	**0.009**
BMI	24.21 (4.18)	23.50 (4.27)	24.65 (4.09)	**0.016**
Daily averaged food intake				
Kilocalories	1,727.09 (504.04)	1,513.31 (437.25)	1,860.71 (499.53)	**<0.001**
Protein% of kcal	16.44 (4.26)	15.27 (2.62)	17.17 (4.89)	**0.020**
Carbohydrate% of kcal	47.85 (6.79)	48.49 (7.20)	47.44 (6.54)	0.4
Fat% of kcal	34.47 (6.59)	34.81 (7.90)	34.25 (5.67)	0.8
Fruit and vegetable (g/1,000 kcal)	73.82 (43.70)	91.96 (35.17)	62.48 (44.89)	**0.009**
Dietary inflammatory score	0.00 (1.92)	0.15 (1.86)	−0.09 (1.97)	0.6
Daily averaged mood and lifestyle factors				
Wellbeing	22.26 (2.84)	22.11 (3.01)	22.35 (2.75)	>0.9
Excitement	3.07 (0.64)	3.01 (0.74)	3.10 (0.56)	0.6
Anxiety	1.88 (0.66)	2.10 (0.65)	1.74 (0.64)	**0.003**
Sleep quality	60.89 (17.42)	57.75 (17.26)	62.86 (17.36)	0.2
Activity level	41.21 (18.82)	43.09 (16.31)	40.04 (20.25)	0.3
SI[c] quality	64.22 (14.26)	67.56 (14.92)	62.14 (13.52)	**0.021**
SI[c] quantity	52.79 (19.10)	56.62 (18.36)	50.39 (19.29)	0.14
Baseline and trait questionnaires				
Baseline wellbeing	46.35 (9.05)	45.42 (9.33)	46.93 (8.89)	0.5
Trait anxiety	41.38 (12.15)	44.51 (12.54)	39.42 (11.57)	**0.035**
Depressive symptoms	9.26 (6.19)	10.13 (6.77)	8.71 (5.77)	0.4
Perceived stress	43.85 (18.18)	47.81 (18.81)	41.37 (17.45)	0.12

[a]Mean (SD); n (%).
[b]Wilcoxon rank-sum test; Pearson's Chi-squared test; Fisher's exact test.
[c]Social interaction. The bold values mean $p < 0.05$.

Weekly averages of daily data

First, we examined between-person relationships with each averaged daily dependent variable (wellbeing, anxiety, and excitement) separately. Independent variables were fruit and vegetable, fat and carbohydrate intake and lifestyle behaviors (i.e., activity, sleep, social interaction). We performed multiple linear regression using the *stats* package (47). The full models were specified as shown in equation (1). Gender was dummy-coded.

(1) DV $\sim$ fruit & vegetables + fat + carbohydrate + activity + sleep + quality of social interaction + quantity of social interaction + gender

Mediation analyses

To investigate if averaged daily measures of lifestyle mediated an effect of fruit and vegetable intake on wellbeing, we performed simple mediation analyses using the *MeMoBootR* package (48). We wanted to conduct three separate mediation analyses for the outcome variable wellbeing. The mediator variables were averaged from the daily diary; (1) physical activity, (2) sleep, and (3) social behavior. Covariates were, fat, carbohydrate, sleep, quality and quantity of social interaction, and gender.

Daily and lagged analyses

Next, we performed same-day and 1- and 2-day lagged analyses to test intra-individual relationships between dependent variables (daily wellbeing, anxiety, excitement) and independent variables (i.e., fruit and vegetable, fat and carbohydrate intake) using multilevel modeling using the lme4 package (49). We included fruit and vegetable, fat and carbohydrate each as the level-1 independent variables and daily wellbeing, anxiety, excitement each as the level-1 outcome. We also included the dependent variable's score of the previous day as a covariate (DV_{T0}).

We assessed same-day associations between fruit and vegetable, fat and carbohydrate intake, wellbeing, anxiety and excitement along with lifestyle covariates [T1; see equation (2)].

One-day lagged associations tested whether eating fruit and vegetable, fat or carbohydrate intake on 1 day (T0) correlated with changes in wellbeing, anxiety and excitement the next day (T1) while controlling for mood on the first day. Lifestyle variables (i.e., activity, sleep, social interactions) were entered as covariates and not lagged [see Equation (3)].

TABLE 2 Association between diet and lifestyle factors and measures of wellbeing and mood, using multiple linear regression models.

DV	IV	Coefficient	95% CI	*P*
Wellbeing	Intercept	6.48	−1.10–14.07	0.093
	Fruit and vegetable	0.01	0.00–0.02	**0.013**
	Fat	0.01	−0.06–0.08	0.725
	Carbohydrates	0.03	−0.01–0.08	0.142
	Activity	0.02	−0.00–0.04	0.067
	Sleep	0.05	0.03–0.07	**<0.001**
	SI[a] quality	0.10	0.06–0.13	**<0.001**
	SI[a] quantity	0.00	−0.02–0.02	0.996
	Gender (male)	0.86	0.01–1.71	**0.048**
	R^2/R^2 adjusted	0.528/0.493		
Anxiety	Intercept	1.91	−0.42–4.24	0.107
	Fruit and vegetable	−0.00	−0.01–0.00	0.171
	Fat	0.01	−0.01–0.03	0.289
	Carbohydrates	0.01	−0.01–0.02	0.396
	Activity	0.00	−0.01–0.01	0.776
	Sleep	−0.00	−0.01–0.00	0.452
	SI[a] quality	−0.01	−0.02 to -0.00	**0.007**
	SI[a] quantity	0.01	−0.00–0.01	0.145
	Gender (male)	−0.45	−0.72 to -0.19	**0.001**
	R^2/R^2 adjusted	0.186/0.125		
Excitement	Intercept	1.52	−0.63–3.68	0.164
	Fruit and vegetable	−0.00	−0.00–0.00	0.999
	Fat	−0.00	−0.02–0.02	0.707
	Carbohydrates	0.00	−0.01–0.01	0.956
	Activity	0.01	−0.00–0.01	0.111
	Sleep	0.01	0.00–0.02	**0.012**
	SI[a] quality	0.01	−0.00–0.02	0.062
	SI[a] quantity	0.01	−0.00–0.01	0.096
	Gender (male)	0.14	−0.10–0.38	0.252
	R^2/R^2 adjusted	0.242/0.186		

[a]Social interaction.
All independent variables were entered simultaneously. The bold values mean $p < 0.05$.

Similarly, 2-day lagged analyses tested whether eating fruit and vegetables, carbohydrates, or dietary fats on 1 day (T0) were associated with wellbeing, anxiety or excitement 2 days later [T2; see Equation (4)]. Gender was dummy-coded.

$$(2)\ DVT1 \sim \text{fruit \& vegetables } T1 + \text{fat } T1 + \text{carbohydrate } T1 + \text{activity } T1 + \text{sleep } T1 + \text{quality of social interaction } T1 + \text{quantity of social interaction } T1 + \text{gender} + DVT0 + (1 \mid id)$$

$$(3)\ DVT1 \sim \text{fruit \& vegetables } T0 + \text{fat}T0 + \text{carbohydrate}T0 + \text{activity } T1 + \text{sleep } T1 + \text{quality of social interaction } T1 + \text{quantity of social interaction } T1 + \text{gender} + DVT0 + (1 \mid id)$$

$$(4)\ DVT2 \sim \text{fruit \& vegetables } T0 + \text{fat}T0 + \text{carbohydrate}T0 + \text{activity } T2 + \text{sleep } T2 + \text{quality of social interaction } T2 + \text{quantity of social interaction } T2 + \text{gender} + DVT1 + (1 \mid id)$$

Exploratory analyses

Exploratory associations between self-reported average fruit and vegetable, fat and carbohydrate intake, sleep, activity, social interaction quality and quantity and mental health questionnaires were tested with Pearson correlations. Significance levels were Bonferroni-corrected for multiple comparisons for each DV separately. Estimated marginal means analysis allowed us to test independent variable × gender effects on wellbeing and were carried out using the *emmeans* package (50). Mediation with covariates was conducted using the *MeMoBootR* package (48).

Preregistration

Preregistered hypotheses and analyses are available on the public data repository Open Science Framework (see text footnote 1). We had not preregistered analysis by gender initially, however, after a more in-depth literature analysis it became clear, that gender differences play a larger role than we had previously assumed (8, 19). Therefore, we included gender as a covariate in all models, and tested correlations between wellbeing and (a) fruit and vegetable intake; and (b) social interaction quality stratified by gender.

We intended to include baseline wellbeing as a covariate in the wellbeing model, and similarly, perceived stress (PSQ) and trait anxiety (STAI) as covariates in the anxiety weekly averaged models. However, after observing high correlation between these measures we decided not to include these to avoid biased coefficients (51). In the mixed-effects models we included their wellbeing, anxiety, or excitement levels of the previous day as a covariate following (13) to test associations with daily wellbeing, anxiety, and excitement.

Finally, we originally wanted to use difference scores between habitual and concurrent lifestyle behaviors as mediators. However, at the time of conducting the study, light lockdown had been re-instated for more than 2 weeks. We reasoned that habitual data would reflect lockdown habits rather

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than pre-lockdown behaviors. Therefore, we used concurrent data of lifestyle behaviors instead.

Results

Participants

A total of 135 individuals participated in the study. After data collection, we excluded participants with severe symptom severity on the BDI (> 30, $N = 3$) as well as participants who logged fewer than 4 days of food intake and mood diary ($N = 15$). This resulted in a total sample of 117 participants (women $N = 45$, men $N = 72$, other = 0). Prior to the study, a power analysis based on a small effect size (f = 0.15), alpha = 0.05, and power of 0.95, estimated a required sample size of 119. Our final sample of $N = 117$ would deem sufficient.

Averages of daily mood ratings and lifestyle factors are reported alongside baseline and trait questionnaire scores in Table 1. As shown in this table, in our sample women were significantly older than men, and had a lower BMI on average. Intake of kilocalories also differed between men and women

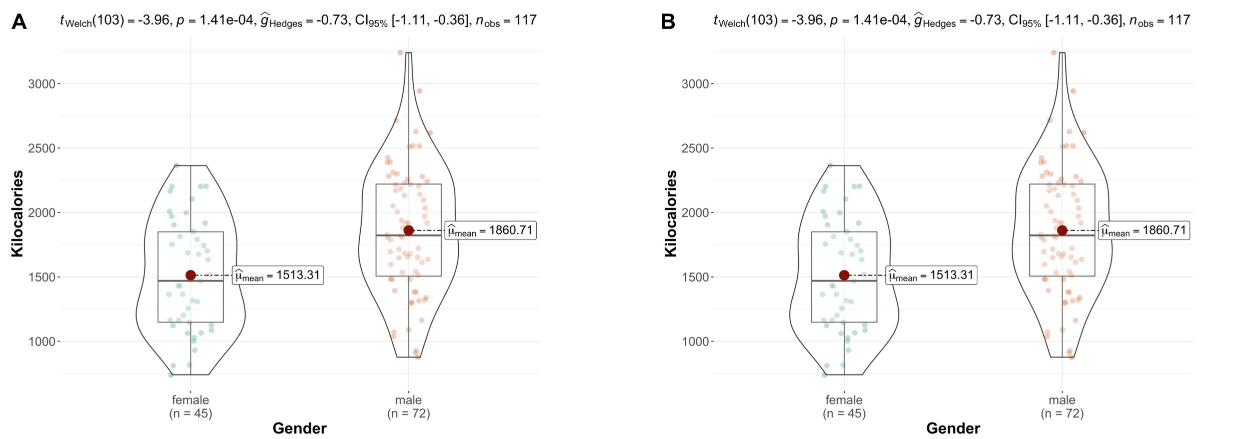

FIGURE 2
(A) Intake of kilocalories by gender; **(B)** energy adjusted fruit and vegetable intake by gender. Female participants consumed significantly more fruit and vegetables adjusted for total energy intake. Bars represent the interquartile range, with the median drawn in the middle. Whiskers depict the minimum and maximum values.

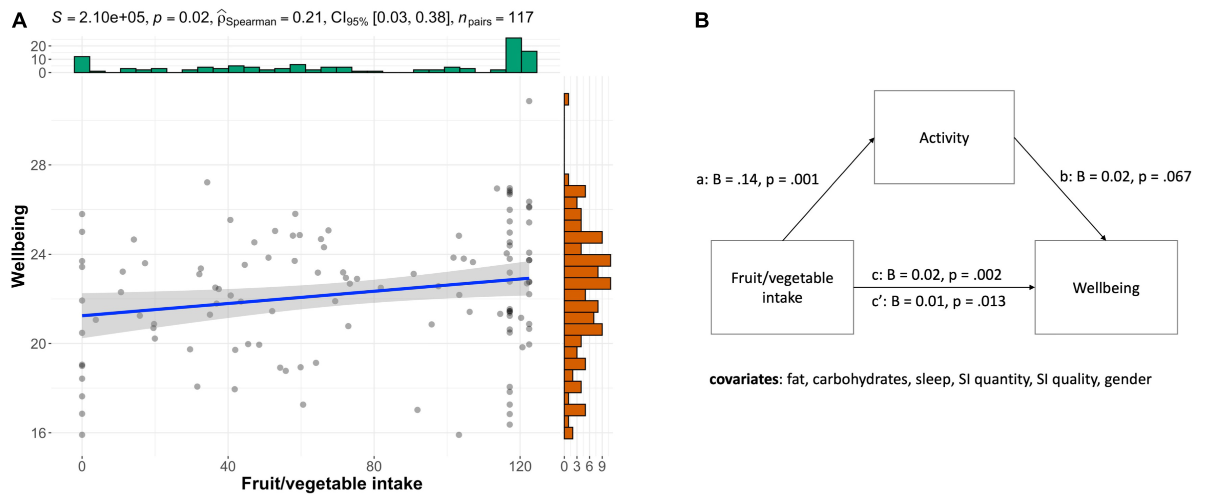

FIGURE 3
Fruit and vegetable intake affects wellbeing which is partially mediated by activity. **(A)** Scatterplot showing that fruit and vegetable intake correlates positively with wellbeing (rho = 0.21, $p = 0.021$). **(B)** Mediation model, illustrates that higher levels of fruit and vegetable intake were associated with more activity on average (*a*) and a higher level of wellbeing (*c*). Activity showed a non-significant positive trend for wellbeing (*b*). After accounting for the indirect effect, the direct effect remained significant, meaning fruit/veg intake contributes to wellbeing independently of activity (c').

(Figure 2A), whereby men had a higher total energy intake and consumed more protein than women. However, women had a significantly higher intake of fruit and vegetables (Figure 2B).

Daily mood and lifestyle ratings differed insofar that women reported higher levels of anxiety but also rated their social interactions of a higher quality. Trait anxiety levels were also higher in women than in men. No other significant differences between men and women were found.

Weekly averages of daily data

We investigated whether wellbeing, anxiety and excitement was associated with averages of the diary data in inter-individual models. Based on the multiple regression models, and as shown in Table 2, we found that fruit and vegetable intake correlated with wellbeing (B = 0.01, CI = 0.00–0.02, p = 0.013) alongside sleep (B = 0.05, CI = 0.03–0.07, $p < 0.001$), social interaction quality (B = 0.10, CI = 0.06–0.13, $p < 0.001$) and male gender (B = 0.86, CI = 0.01–1.71, p = 0.048). Anxiety was significantly associated with social interaction quality (B = −0.01, CI = −0.02 to −0.00, p = 0.007) and male gender (B = −0.45, CI = −0.72 to −0.19, p = 0.001). Finally, excitement correlated with sleep quality (B = 0.01, CI = 0.00–0.02, p = 0.012).

Mediation analyses

Next, we tested if concurrent lifestyle (activity, sleep, social interactions) mediated the effect of food intake on wellbeing while controlling for all other lifestyle factors. To validate using a mediation model, we first tested if fruit and vegetable, fat and carbohydrate intake each regress onto wellbeing, which revealed that only fruit and vegetable intake significantly correlated with wellbeing (B = 0.02, SE = 0, t = 3.20, p = 0.002). Next, we tested whether the independent variable fruit and vegetable intake regressed onto the mediators (activity, sleep, social interactions). Fruit and vegetable intake correlated with activity (B = 0.14, SE = 0.04, t = 3.35, p = 0.001) but neither sleep (B = −0.02, SE = 0.041, t = −0.51, p = 0.614) nor quality of social interaction (B = −0.00, SE = 0.03, t = −0.05, p = 0.960). Thus, we ran a mediation model to test whether activity mediated the effect of fruit and vegetable intake on wellbeing (Figure 3). Indeed, this model revealed that the difference in activity partially mediated the direct effect of fruit and vegetable intake on wellbeing (c', B = 0.01, SE = 0.01, t = 2.52, p = 0.013) compared to the total effect (c, B = 0.02, SE = 0, t = 3.20, p = 0.002; bootstrapped indirect effect (B = 0.03, SE = 0, 95% CI −0.00–0.01).

Daily and lagged analyses

We also tested intra-individual associations between daily fruit and vegetable, fat and carbohydrate intake and changes in wellbeing using linear mixed-effects models controlling for wellbeing, anxiety, or excitement of the same day, respectively. The results for same-day analyses are shown in Table 3. Same-day wellbeing correlated with fruit and vegetable intake while controlling for same-day sleep, activity and quality, and quantity of social interactions and the previous day's wellbeing. Neither anxiety nor excitement were associated with diet, but by same-day lifestyle factors.

We also tested 1-day (Supplementary Table 1) and 2-day-lagged (Supplementary Table 2) associations of fruit and vegetable, fat and carbohydrate intake on wellbeing, anxiety, and excitement each controlling for same-day lifestyle factors revealing similar patterns. For 1-day lags none of the dietary components correlated with wellbeing, anxiety or excitement (all $p > 0.296$). Instead, daily wellbeing was significantly associated with lifestyle factors sleep, activity, social interaction quality, and the previous day's level of wellbeing (all p = 0.001 or < 0.001). Anxiety was correlated with sleep and quality of social interactions (all $p < 0.001$), the previous day's level of anxiety (p = 0.002) as well as male gender (p = 0.029). Finally, excitement was associated with sleep, activity, social interaction quality (all p = 0.001 or < 0.001), and the previous day's level of excitement (p = 0.018). Two-day lagged associations did not reveal any significant diet associations when accounting for lifestyle factors in the same model (all $p > 0.184$).

Exploratory analyses

We explored correlations between mental health questionnaires and individuals' average dietary and lifestyle behaviors. In Table 4 we report Pearson correlations between baseline mental health and wellbeing questionnaires (as dependent variables) and diet and lifestyle variables. We found that fat intake correlates positively with trait anxiety (r = 0.30, p = 0.007). In addition, self-rated sleep quality and social interaction quality significantly correlate with all dependent variables.

Association with the dietary inflammatory index

As inflammation is a possible mechanism by which diet affects mental wellbeing, we tested if a high Dietary Inflammatory Index (DII) is associated with lower wellbeing and higher levels of anxiety. DII score correlated significantly with averaged daily wellbeing (r = −0.20, p = 0.027, Figure 4A) but not with anxiety (r = 0.17, p = 0.063) or excitement (r = −0.09, p = 0.332).

Based on the mediation effect we found above, we also tested if average daily lifestyle (i.e., activity, sleep, social interactions) mediated the effect of an inflammatory diet on wellbeing. DII

TABLE 3 Same-day associations between diet and lifestyle factors and measures of wellbeing and mood, using linear mixed-effects models.

DV	IV	Coefficient	95% CI	*P*
Wellbeing	Intercept	9.16	5.74–12.58	**<0.001**
	Fruit and vegetable	0.01	0.00–0.01	**0.002**
	Fat	0.01	−0.02–0.04	0.531
	Carbohydrates	0.01	−0.01–0.02	0.552
	Sleep	0.03	0.02–0.04	**<0.001**
	Activity	0.02	0.01–0.03	**<0.001**
	SI[a] quality	0.07	0.06–0.08	**<0.001**
	SI[a] quantity	0.01	0.00–0.03	**0.018**
	Previous day wellbeing	0.15	0.09–0.22	**<0.001**
	Gender (male)	0.56	−0.16–1.28	0.129
	Random effects			
	N_{id}	109		
	Observations	475		
	Marginal R^2/Cond. R^2	0.462/0.588		
Anxiety	Intercept	2.11	1.03–3.19	**<0.001**
	Fruit and vegetable	−0.00	−0.00–0.00	0.686
	Fat	0.00	−0.01–0.01	0.611
	Carbohydrates	0.01	−0.00–0.01	0.075
	Sleep	−0.01	−0.01 to -0.00	**0.001**
	Activity	−0.00	−0.00–0.00	0.445
	SI[a] quality	−0.01	−0.01 to −0.00	**0.001**
	SI[a] quantity	−0.00	−0.01 to −0.00	**0.044**
	Previous day anxiety	0.12	0.04–0.20	**0.004**
	Gender (male)	−0.29	−0.52 to -0.05	**0.019**
	Random effects			
	N_{id}	109		
	Observations	479		
	Marginal R^2/Cond. R^2	0.144/0.336		
Excitement	Intercept	1.21	0.14–2.27	**0.027**
	Fruit and vegetable	0.00	−0.00–0.00	0.964
	Fat	0.00	−0.01–0.01	0.756
	Carbohydrates	−0.00	−0.01–0.00	0.560
	Sleep	0.01	0.00–0.01	**0.001**
	Activity	0.01	0.00–0.01	**0.001**
	SI[a] quality	0.01	0.01–0.02	**<0.001**
	SI[a] quantity	0.00	−0.00–0.01	0.119
	Previous day excitement	0.08	−0.00–0.16	0.055
	Gender (female)	0.18	−0.05–0.41	0.129
	Random effects			
	N_{id}	109		
	Observations	477		
	Marginal R^2/Cond. R^2	0.241/0.407		

[a]Social interaction.
All independent variables were entered simultaneously. The bold values mean $p < 0.05$.

negatively correlated with wellbeing (*B* = −0.20, SE = 0.10, *t* = −2.00, *p* = 0.047). As for possible mediators, DII negatively correlated with activity (*B* = −2.58, SE = 0.86, *t* = −3.00, *p* = 0.003) but neither sleep (B = −0.37, SE = 0.84, *t* = −0.44, *p* = 0.658) nor social interaction quality (*B* = −0.15, SE = 0.62, *t* = −0.23, *p* = 0.815). Therefore, we tested for a mediation of activity only. We found that activity fully mediated the direct effect (c') of the dietary inflammatory score on wellbeing (*B* = −0.14, SE = 0.11, *t* = −1.32, *p* = 0.191) compared to the total effect (c, *B* = −0.21, SE = 0.10, *t* = −2.00, *p* = 0.047; bootstrapped

TABLE 4 Pearson correlations between baseline mental health and wellbeing questionnaires and diet and lifestyle outcomes.

	Wellbeing	Anxiety	Depressive symptoms	Perceived stress
Fruit and vegetable	0.21	−0.10	−0.16	−0.12
Fat	−0.19	**0.30****	0.13	0.22
Carbohydrates	0.20	−0.24	−0.18	−0.19
Sleep	**0.39*****	**−0.34****	**−0.36*****	**−0.37*****
Activity	0.23	−0.20	**−0.27***	−0.21
Social interaction quality	**0.43*****	**−0.32****	**−0.39*****	**−0.29***
Social interaction quantity	0.19	−0.03	−0.17	−0.06

P-value adjustment method: Bonferroni; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Significance levels were corrected for multiple comparisons for each DV separately. The bold values mean $p < 0.05$.

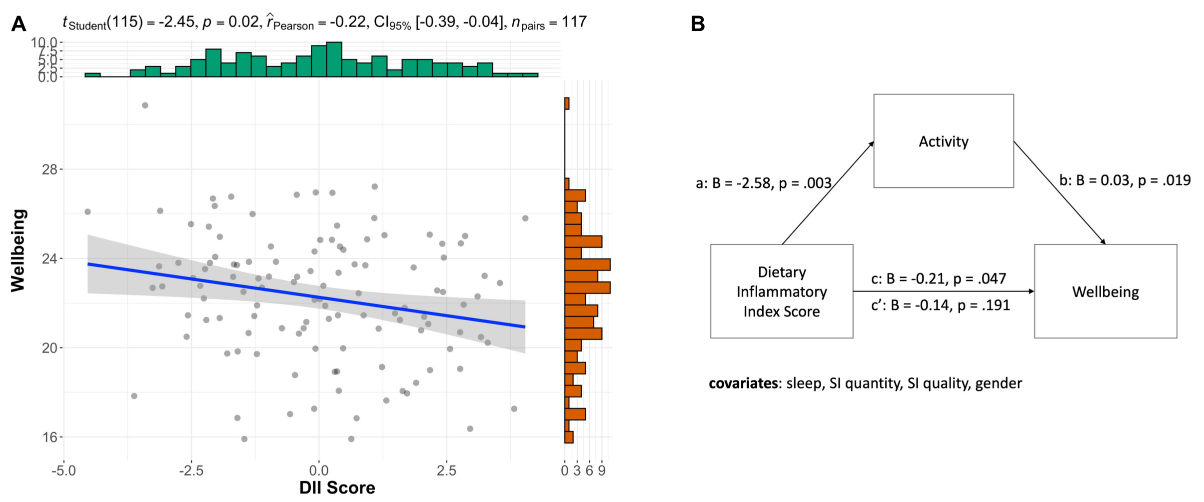

FIGURE 4
Dietary inflammatory index, wellbeing, and activity. **(A)** Negative correlation between DII and average wellbeing ($r = 0.22$, $p = 0.016$). **(B)** Mediation model illustrating that a more inflammatory diet was associated with being less active (*a*) and reporting lower levels of wellbeing (*c*). While more activity was also associated with higher wellbeing (*b*).

indirect effect ($B = -0.07$, SE = 0.04, 95% CI −0.15 to 0.00) as shown in Figure 4B.

Gender-specific effects

Given that female participants consumed significantly more fruits and vegetables compared to men [$M_{female} = 91.96$ (35.17), $M_{male} = 62.48$ (44.89), $p = 0.009$], we explored if the strength of the association between fruit and vegetable intake and wellbeing differed depending on gender. However, as shown in Figure 5, an estimation of the marginal means of linear trends did not show that the interaction between gender and fruit/vegetable intake was significantly different ($B = -0.01$, $p = 0.409$).

Given that age and BMI significantly differed between male and female participants (see Table 1), we wondered if these variables could account for the gender effects we found. While fruit and vegetable intake correlated negatively with BMI ($r = -0.18$, $p = 0.048$), wellbeing did not ($r = -0.07$, $p = 0.440$). However, age did not correlate with either wellbeing ($r = 0.05$, $p = 0.575$) or fruit and vegetable intake ($r = 0.13$, $p = 0.166$).

The effect of Dietary Inflammatory Index on wellbeing was also independent of gender ($B = -0.10$, $p = 0.732$). Furthermore, we were curious as to whether gender differently interacted with social interaction quality and wellbeing. This was not the case ($B = 0.05$, $p = 0.126$); for both genders, social interaction quality positively affected wellbeing (for women: $B = 0.15$, $p < 0.001$; for men: $B = 0.10$, $p < 0.001$). Likewise, sleep was positively associated with wellbeing in both genders (overall contrast: $B = 0.07$, $p = 0.007$, for women: $B = 0.12$, $p < 0.001$; for men: $B = 0.05$, $p = 0.003$).

Discussion

This preregistered study investigated how dietary intake affected mood and wellbeing alongside lifestyle factors during COVID-19-lockdown. Previous studies showed that dietary

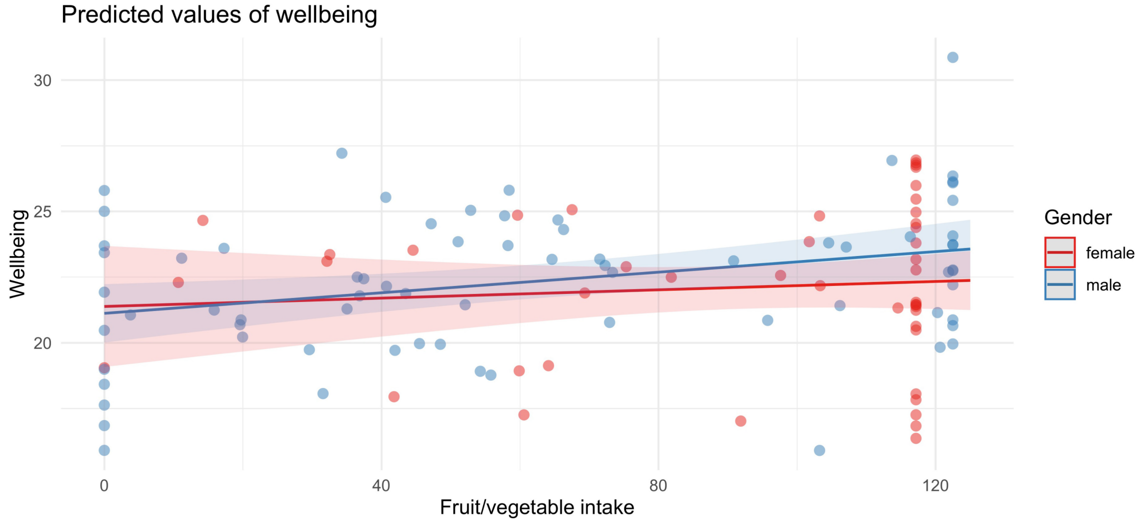

FIGURE 5
Both men (blue) and women (red) showed a positive association between fruit and vegetable intake and wellbeing.

components (7, 13, 14), exercise and sleep impacted on mental health and wellbeing (4). We were also interested in social interaction as a contributor to wellbeing (29), since social distancing measures were so prominent during lockdowns.

We hypothesized that food intake was associated with (1) wellbeing; (2) anxiety; and (3) excitement and tested between- and within-person relationships while controlling for concurrent lifestyle factors. Both in our regression models, as well as mediation analysis, we observed that fruit and vegetable intake correlated with wellbeing, while this was partially mediated by physical activity.

Diet and lifestyle in the context of COVID-19-lockdown

The pandemic context brought about changes in diet, sleep, and activity (52), which brought about increased negative mood (52–55) and lower wellbeing (1). Lower dietary quality was associated with poor mood and may have been used to regulate emotions (55). The present findings complement this by providing evidence that inversely, consuming healthier foods, i.e., fruit and vegetable, were linked with more wellbeing. Work by Cecchetto and colleagues' investigated whether social factors (amongst others) contributed to dysfunctional eating habits during the pandemic (36). However, a more holistic approach of lifestyle factors that include physical activity, sleep, dietary intake and social interaction to investigate their joint effect on wellbeing, anxiety and excitement had thus far been lacking.

Undergoing lockdown may have undermined the impact of diet on mood when accounting for other healthful behaviors. For example, mood affects the likelihood of making healthy food choices mediated by physical activity (56). The authors suggest that people engage in healthy *lifestyles* rather than isolated health behaviors, i.e., being physically active goes together with making healthier dietary choices (56). Our data support this notion; high intakes of fruit and vegetable as well as physical activity were associated with increased levels of wellbeing.

Additionally, other lifestyle factors may have gained importance during this period. Highly active people experienced significant declines in quality of sleep and wellbeing during lockdown as compared to sedentary individuals (2). Furthermore, dramatic declines in physical activity, especially walking, were recorded due to lockdown restrictions and increased home-office hours or job termination in this period (57). Being active outdoors compared to indoors may contribute further to mental wellbeing in addition to the exercise itself (58). The more time spent outdoors in daylight lowered the risk of depression, low mood and added to happiness (59). Thus, lockdown restrictions may have magnified beneficial effects of physical activity during lockdown, and even more so when activity happened outdoors.

Finally, social interactions were greatly affected by social distancing measures. For example, social media use increased during the pandemic (60) and was linked to poor mental health in a large cross-country sample (61), and increased the odds of experiencing anxiety in a Chinese (62) and American sample (60). While greater social connectedness was associated with less perceived stress during the pandemic (63). In line with the existing literature, we found that the quality but not quantity of social interactions correlated with mood and wellbeing in almost all analyses, echoing previous findings (64). To our knowledge, social interactions have not yet been considered in models alongside diet, sleep, and activity. Our findings suggest that during lockdown the quality of social interactions plays a key role when examining the relationship between diet, wellbeing, and mood.

Evaluating dietary intake

Dietary intake can be analyzed in many different ways. Here we focused on specific dietary components. Fat, carbohydrates, and fruit and vegetable intake had been identified in the literature to play a key role in mood and wellbeing (13, 14, 65). Our findings supported the role of fruit and vegetable intake in concurrent wellbeing. Furthermore, we found an association between trait anxiety and fat intake, whereby higher fat intake correlated with greater state anxiety. However, we did not find that total fat intake correlated with daily anxiety levels when controlling for other lifestyle factors.

Additionally, we calculated the dietary inflammatory index—a well-established measure of a diet's inflammatory potential (16). We found that DII score correlated negatively with average wellbeing but not with anxiety or excitement. DII score has been found to correlate with wellbeing before (66). We also found that the effect of DII on wellbeing was fully mediated by activity.

We examined whether dietary intake was associated with wellbeing, anxiety, and excitement. However, vice versa, it is an interesting question whether negative mood and mental health issues can drive low-quality food intake. Neither longitudinal (67) nor short-term evidence, 1- or 2-day lagged associations (13, 14) support this idea. However, a recent study conducted during COVID-19-lockdown found that mood states were linked to the intake of fruit, vegetables, and fish, which were partially mediated by physical exercise load (56). The authors suggested that some participants may have actively changed their exercise and food intake behavior to deal with the anticipated challenges on mental health during lockdown (56). Importantly, these authors included exercise as a lifestyle factor to investigate the relationship between mood and diet. In sum, the differences between studies may be due to the unusual circumstances of the pandemic as well as the mediating factor of physical exercise, which was affected by pandemic restrictions (27, 57). Finally, Amatori et al. did not report testing the reverse direction, i.e., whether dietary intake was correlated with mood states (56).

Gender-specific effects

Here we found gender differences in food intake, anxiety levels, and quality of social interaction. In particular, women consumed more fruit and vegetables but fewer calories from protein than men. This is in line with previous work demonstrating gender differences in dietary intake (68–70). For instance, women across 23 countries showed greater beliefs in the importance of healthy eating as evident by higher intake of fruit and fiber-rich foods (70). In this study, women reported higher baseline and concurrent anxiety levels than men in this study, consistent with previous findings (71). But we did not find that higher fruit and vegetable intake was associated with lower anxiety ratings, contrary to what has been reported elsewhere (8). Eating more fruit and vegetables also did not affect wellbeing to a greater extent than men. It is currently unclear why women's mood did not benefit from fruit and vegetable intake more so than men despite higher intake, or why anxiety levels were unaffected by higher fruit and vegetable intake. Thus, more research is needed to better understand mechanistic links between diet, body, brain, and gender interactions.

Strengths and limitations

A few limitations need to be considered. First, due to the acute nature of the pandemic, we lack a baseline dietary assessment, and cannot make claims whether dietary intake has changed in response to the lockdown. Second, as with any self-report study, these measures underlie self-reporting biases. For example, self-reported caloric intake is likely underreported. Underreporting is a common problem in self-reported dietary data (72). Note that we also chose to exclude individuals with mental health diagnoses and severe depressive symptoms, therefore our findings cannot be generalized to subclinical and clinical populations.

Strengths of this study include the use of preregistration of hypotheses and analyses before data collection. Considering that dietary intake alongside multiple lifestyle factors and social aspects is still understudied, highlights the need for a holistic approach to assess lifestyle with mood and mental health outcomes. Furthermore, we were able to collect a rich data set by assessing baseline parameters of mental health and lifestyle followed by a 7-day diary of food intake. Using such a food diary, rather than a 24-hr recall, alongside concurrent mood and lifestyle factors allowed us to explore both inter- and intra-individual fluctuations of these variables. The findings of this study are limited to a relatively young German population, and further research would be needed to determine if the same effects can be found for different age groups and specific health groups. An interesting avenue for future studies would be to investigate whether the dynamic between mood, diet, lifestyle, and social interactions still holds beyond the acute lockdown situation observed in this study, and whether this extends to different individuals such as clinical populations.

Conclusion

Our results showed that, on average, fruit and vegetable intake contributed to wellbeing alongside sleep and social interaction quality. Examining day-to-day associations showed that fruit and vegetable intake on the same day promoted wellbeing, while this was not the case for the next day or second day time lags. Instead, sleep, activity, and social interactions were associated with wellbeing in the context of lockdown during the COVID-19 pandemic. Importantly, associations between fruit and vegetable intake were partially mediated by physical activity. These findings highlight the need for an integrated way of assessing lifestyle factors and gender in future studies. As pandemics are thought to appear more frequently due to diminishing biodiversity (73), strategies to protect mental health and wellbeing become more important than ever, especially because access to mental health care remains limited for many. Therefore, reducing the risk for adverse psychological effects *via* lifestyle behaviors such as diet, activity, and sleep remains a promising strategy [for a meta-review on lifestyle psychiatry see Firth et al. (4)].

In conclusion, a combination of physical activity, good sleep, and daily high-quality social interactions as well as a diet rich in fruit and vegetables and a low inflammatory potential (i.e., diets high in minerals and vitamins, such as fruit and vegetables, but low in saturated fats) appears to promote better mood and wellbeing in stressful circumstances such as a lockdown during a global pandemic. Our research result offers a novel perspective of dietary and lifestyle recommendations that can be provided in times of high uncertainty, such as pandemic situation.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the Humboldt University of Berlin. The patients/participants provided their written informed consent to participate in this study.

Author contributions

A-KM and SP: conceptualization and project administration. A-KM: investigation, visualization, and writing—original draft preparation. A-KM, AL, and SP: methodology and formal analysis. A-KM, AL, DT, and SP: writing—review and editing. AL and SP: supervision. SP: funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.993180/full#supplementary-material

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Parent, child, and environmental predictors of vegetable consumption in Italian, Polish, and British preschoolers

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This study compared the vegetable intake of preschool children from three European countries [Italy, Poland, and the United Kingdom (UK)] and explored the parent, child, and environmental factors that predicted intake in each country. A total of 408 parents of preschoolers (Italy: $N = 61$, Poland: $N = 124$, and UK: $N = 225$; child mean age = 32.2 months, $SD = 9.47$) completed an online survey comprising a set of standardised questionnaires. For all three countries, the questionnaires included measures of children's vegetable intake (VegFFQ), child eating behaviour (CEBQ-FF), parents' mealtime goals (FMGs), and sociodemographic questions about family background and environment. In the UK and Italy, additional questionnaires were used to assess child temperament (EAS-T) and parents' feeding practices (CFPQ). The results showed that the number of child-sized portions of vegetables consumed per day varied significantly across countries; Polish children consumed the most (∼3 portions) and Italian children the least (∼1.5 portions). Between-country differences were seen in parents' goals for family mealtimes; compared to Italian parents, Polish and UK parents were more motivated to minimise mealtime stress, increase family involvement in meal preparation, and share the same foods with family members. British and Italian parents also adopted different feeding practices; parents in the UK reported more use of healthy modelling behaviours and more use of foods to support their child's emotion regulation. In terms of child factors, Italian children were reported to be more emotional and more sociable than British children. Analyses of the relationships between the parent, child, and environmental factors and children's vegetable intake revealed both similarities and differences between countries. Negative predictors of vegetable intake included child food fussiness in the UK and Poland, child temperament (especially, shyness) in Italy, and the use of food as a reward and child emotionality in the UK. Positive predictors included the parental mealtime goal of 'family involvement' in the UK. These results highlight differences in the extent to which European preschoolers achieve recommended levels of vegetable intake, and in the factors that influence whether they do. The results suggest a need to develop healthy eating interventions that are adopted to meet the specific needs of the countries in which they are implemented.

KEYWORDS

vegetable intake, cross-cultural, family environment, eating behaviour, parenting style, child temperament

Introduction

Consumption of a varied and vegetable-rich diet in early childhood predicts lifelong dietary variety and good health (1–3). Although evidence for a direct link between fruit and vegetable intake and obesity is more mixed for children than for adults (4, 5), examination of children's diets highlights that low fruit and vegetable consumption tends to be coupled with high fat and sugar consumption (6), which increases the risk of obesity and overweight (7, 8). Reports on steadily increasing rates of overweight and obesity in young children (9) highlight the need for obesity prevention initiatives that are evidence-based and informed by the latest understanding of factors that support healthy food choices, including greater vegetable intake.

This global health landscape is mirrored in the quality of children's diets in Europe, where many countries report a high prevalence of overweight or obese children. However, the picture is not uniform. One assessment conducted between 2011 and 2016 (10) compared the proportion of 2- to 7-year-olds who were overweight or obese in different regions of Europe to comparable statistics captured between 1999 and 2006. While Central Europe (including Poland) saw a decline in the proportion of overweight or obese children during this period (from 16 to 13%), Mediterranean regions (including Italy) saw a small increase in prevalence (from 19 to 20%). Although data were not collected in the Atlantic region (including the UK) between 2011 and 2016, this region showed a relatively stable prevalence of around 12% between 1999 and 2010 (10). These figures show that overweight and obesity are significant issues for children across Europe, and that prevalence patterns are not uniform and may not align with commonly held stereotypes of dietary quality in different countries.

Further evidence that children across Europe are failing to achieve healthy diets is seen in reported levels of fruit and vegetable consumption (11, 12). Recommended levels of fruit and vegetables intake are highly consistent across countries; the WHO recommends that individuals eat at least 400 g of fruit or vegetable per day to support good health (13), and public health guidelines across Europe promote the consumption of a standard five portions per day, roughly equivalent to the WHO guidance [the UK (14), Italy (15), and Poland (16)]. Between 2015 and 2017, the WHO Childhood Obesity Surveillance Initiative (COSI) (11) collected data in 23 countries (including Italy and Poland) about the fruit, vegetable, and snack intake of 6- to 9-year-old children. The results revealed that only 23% of the children sampled ate vegetables every day and that rates varied widely between countries (54% in Italy and 23% in Poland). Other assessments of children's diets in Poland (17) and Mediterranean regions (18) provide a less pessimistic view. In the UK, the Health Survey England data show that only 18% of children aged 5–15 years eat the recommended five portions of fruit and vegetables per day, while a similar proportion typically eats none at all (12). While there are inconsistencies in the literature about the precise level of children's fruit and vegetable intake, these reports suggest that there are considerable differences in these levels across European countries.

The causes of these differences, in both overweight and obesity rates and in levels of fruit and vegetable consumption, are complex and likely to include environmental, family, parent, and individual child factors. Given that food preferences and eating behaviours become established in early childhood (19) and track from childhood to adulthood (20), a better understanding of how these factors are involved in the formation of food preferences and dietary outcomes is essential to efforts to develop effective public health initiatives. This article is the first to investigate how environmental, parent, and individual child factors contribute to children's vegetable intake and whether these relationships are stable across countries or specific to particular populations.

In terms of the influence of the eating environment, European countries show a broad diversity in a range of cultural, demographic, and socioeconomic factors likely to impact public health. Cultural differences include the extent to which different populations have adopted the widespread shift from a traditional Mediterranean diet, which relies heavily on fruits and vegetables, to a more Western diet that includes more foods high in sugar, salt, and fat (10, 18). The socioeconomic status of different populations is also an important consideration given the links between economic hardship and the ability to achieve a healthy balanced diet, and we note in particular the increased prevalence of poverty, health inequality, and unemployment in Southern Europe (including Italy) following the financial crisis of 2007 (10, 21, 22). Research suggests that some socioeconomic and demographic factors such as maternal level of education and socioeconomic status are associated with children's fruit and vegetable consumption, but that other demographic factors including ethnicity are not (23).

Within the home environment, parents (and other caregivers) play a key role in shaping children's food preferences and eating behaviours (19, 24–26). Parents are the primary gatekeepers to the foods children eat, controlling the availability and accessibility of vegetables at home, which are strong predictors of preschool children's willingness to eat vegetables (27, 28). Parents also shape the environment in which foods are eaten. Mealtimes provide the opportunity to expose children to a variety of foods and for children to eat these with parents and caregivers who model positive feeding practices (29–31). Parental modelling of food acceptance plays a powerful role in how children learn about and engage with food (32–35), such that parents' dietary preferences very often predict those of their children (36–39). Parents' feeding styles, practices, and emotional responses are also known to influence a child's relationship with food (24, 40, 41). Positive feeding practices such as reasoning, praise, and encouragement are associated with greater vegetable consumption by children (42, 43), while negative feeding practices such as pressure to eat, negative comments, and food restriction are linked to lower vegetable intake (44). Parental feeding practices are related to their broader parenting style but can be modified by appropriate education and support; tailored public health initiatives that target parent feeding styles have met with some success (45). Finally, children's eating behaviour is also linked to the extent to which parents hold positive mealtime goals (31); those known to support healthy eating include the goal to reduce stress and conflict around mealtimes, the goal to provide positive modelling opportunities by sharing the same foods, and the goal to involve children in mealtime preparation.

While the home environment is often the primary eating environment for children, especially during infancy (19), children are also exposed to eating environments outside the home. Children who attend day-care settings are frequently exposed to new foods and to the eating behaviour of peers and other adults. Experimental studies involving live trained peers (46) or orchestrated video recordings of peers (47–49) have shown that peer modelling can be conducted to increase vegetable consumption in preschool and school settings. The potential for teachers and early years educators to function as effective role models to support healthy eating is more mixed (50–52) and may depend on the adult engaging in highly enthusiastic modelling (53). Nevertheless, it is clearly important not to ignore out-of-home environments as potential influencers of children's vegetable consumption and as settings for healthy eating interventions (54).

Children's eating behaviours and food preferences are not only a product of their environment but are also subject to individual differences between children themselves. During toddlerhood, as children start to show autonomy over their food choices, individual differences become apparent in children's willingness to try new foods and in their selectivity over the foods they will eat. Between18 and 58 months of age, children differ in the extent to which they might be classed as 'fussy' eaters (55), with fussiness defined as eating selectively, being picky about what is eaten, and refusing to eat both familiar and unfamiliar foods. Food fussiness is thought to particularly impact vegetable acceptance because the bitter flavours and softer textures of vegetables render these less palatable than other foods (56). Food fussiness can occur in conjunction with food neophobia, the more common tendency to avoid new foods; both peak between 2 and 6 years of age (56–59). There is some evidence that fussy eating is associated with gender. While some studies have found no gender differences in eating behaviours in early childhood (60, 61), others report more picky and selective eating among boys (62–64). Boys have also been reported to consume fewer vegetables than girls in early childhood (23), a trend that is seen to strengthen as children get older (65).

Child temperament is also related to eating behaviour (40, 55). Children with shy or more emotional temperaments display more food avoidant behaviours (60, 66, 67) and are more neophobic (68), and children who are considered anxious or dependent are less likely to consume a healthy diet (69). Negative temperament traits have also been found to be associated with higher BMI in infants, preschoolers, and older children (40, 70). More challenging infant temperaments have been linked to negative mealtime experiences, and negative traits that track into adulthood have been linked to maladaptive eating behaviours (71), suggesting a pathway from early temperament to negative health outcomes (72).

It is important to note that parent and child factors are not independent of one another. Child temperament is, to some extent, a consequence of parenting style, while parents' feeding practices are, in part, a response to the child's temperament and willingness to accept the foods offered (66). Children who are considered to be difficult or to have a negative temperament are more likely to be soothed and calmed with food by their parents (73, 74), while more indulgent feeding styles are used by parents of children with higher levels of negative affect (75). Similarly, parents of children who are considered to be fussy or picky eaters often report mealtimes to be challenging (72, 76) and that they avoid offering foods likely to be rejected by their child as a result (76). Evidence shows that the familiarity brought about by repeated exposure to a vegetable is a powerful mechanism for supporting willingness to try vegetables and acceptance of these into the child's diet (77–79). Parents' avoidance of rejected foods is therefore likely to exacerbate the problem both by limiting the opportunities for a food to become familiar and by reinforcing the child's behaviour in rejecting it. In other cases, food fussiness can cause parents to adopt more authoritarian feeding practices (45), which may be maladaptive in achieving the goals they are aiming for at mealtimes (80). Thus, children's eating behaviour in general, and their vegetable intake in particular, may depend on a complex interplay between factors that are individual to the child and to the parent, including the parent's motivations around family mealtimes.

While previous studies have established differences in the quality of children's diets (11) and in rates of childhood overweight and obesity (10) in different parts of Europe, there has been no investigation to date of whether the environmental, parental, and individual child factors that predict vegetable intake differ in different populations of preschool children. Furthermore, previous cross-country comparisons have focussed on the early infancy (41) and adolescent periods (81) when, as discussed above, the preschool years are a critical period in the development and formation of food preferences and a prime target for interventions to support healthy eating behaviour.

This study draws together several previously distinct lines of enquiry from cognitive and health psychology, epidemiology, and nutrition science to establish the environmental, parent, and child factors associated with children's vegetable intake and the extent to which these vary across populations. Data were collected in three countries (Italy, Poland, and the UK) in distinct regions of Europe, selected to represent a cross-section of the geographical and cultural landscapes of children's dietary quality, as discussed above (10–12). Parents of preschool children aged between 18 and 48 months were invited to complete a range of questionnaire measures about the family's demographics, the parent's feeding practices, the family's mealtime goals, the child's temperament, and the child's food fussiness, allowing us to explore how these factors combine to predict levels of vegetable consumption. Our research questions were as follows:

(1) Do preschool children in Italy, Poland, and the UK differ in the extent to which they meet WHO guidelines on recommended levels of vegetable intake?
(2) Do the environmental, parental, and individual child factors previously implicated in children's eating behaviour differ between countries and in their association with vegetable intake in each country?
(3) Are the environmental, parent, and child factors that combine to predict preschooler's vegetable intake stable across populations?

Materials and methods

Design

The participating parents of preschoolers completed a set of online questionnaires that asked about the child's and family's demographic characteristics including child's age, gender, ethnicity, attendance at day care, parents' education (as a proxy for socioeconomic status), relationship to child, number of children in the home, parents' feeding style and mealtime goals, and the child's eating behaviour, temperament, and vegetable intake. After completing the questionnaires, a subset of the participants in each country took part in an intervention to increase children's vegetable consumption; the results of which are reported elsewhere (82, 83). The study was conducted across three sites in Italy, Poland, and the UK. Data collection methods were very similar across sites but were adapted where necessary to meet local research ethics requirements or for practical reasons specific to a site. The design of the intervention study and sample size calculation were pre-registered[1].

The study received ethical approval from each country's designated ethics committee (UK: University of Reading Research Ethics Committee, approval no. 2019-018-CHP, date 19 March 2019; Italy: Ethics Committee of the University of Turin, approval no. 176852, date 2 February 2019; Poland: Research Ethics Committee at the Faculty of Psychology, University of Warsaw, date 8 April 2020).

Participants

The participants were parents of preschool children aged between 18 and 48 months. They were recruited by researchers in Italy, Poland, and the UK and their partner organisations between September 2019 and December 2020. Families were recruited *via* online channels (social media, web pages, and press sites), *via* face-to-face contact at sites where families congregate (e.g., kindergartens, sports centres, and bus stops), and *via* promotional activity through existing partner networks including *Szkołanawidelcu* (School on a Fork) in Poland, and the British Nutrition Foundation and the University of Reading's Child Development Group database in the UK.

Informed written consent was obtained from all the participants. In Italy, to adhere to local research ethics

1 https://osf.io/qjsdp

requirements, both parents provided written consent in hard copy. In Poland and the UK, consent was provided electronically prior to completing the questionnaires. Correspondence with families was by email. Communication with the participants was, in all cases, in the language of the recruiting country (Italian, Polish, or English).

A total of 410 parents consented to participate and completed the questionnaires (Italy: N = 61, Poland: N = 124, and the UK: N = 225). G*Power analyses suggested a target sample of 450 participants (150 per country), which, allowing for attrition over the course of the study, should provide 128 cases per group. Differences in final sample sizes resulted from variations in the duration of active recruitment and differences in recruitment success rates. Several families with children outside the target age range were keen to participate. To maximise the sample size, eligibility was extended to include parents of children aged between 16 and 58 months; data from two further families with children younger than 16 months were excluded. The mean age of children in the final sample (N = 408) was 32.2 months (SD = 9.5 months) (Italy: mean = 35 months, SD = 10.6; Poland, mean = 32.5 months, SD = 9.7; UK: mean = 31.3 months, SD = 8.9).

Materials

Data collection was conducted online using survey platforms available to the local research team (in Italy: Google Forms; in Poland: Qualtrics; in UK: a purpose-built study website). The survey questions comprised both validated scales used in previous eating behaviour research and questionnaires created specifically for the purposes of the study. Original measures were available only in English; members of the Italian and Polish research teams arranged for manual translation of all measures into their respective languages.

Demographic measures

The participants were asked the following about their child and family: child's date of birth (from which child age was calculated), child's gender (male/female), child's ethnicity (in UK, the categories were those used in the 2011 census (84); in Poland, the categories were White/African/Asian/I do not know/I prefer not to answer/Other; in Italy, it was not deemed appropriate to ask about ethnicity), attendance at day care (yes/no), number of children living at home, whether the child was the first born, country of residence, relationship of the responding parent to the child (mother/father/other), and educational level of both parents (categories were no formal education/school education equivalent to GCSE level in UK/vocational qualification/high school education equivalent to A-level/bachelor's degree/higher degree). As the sample was predominantly highly educated, the first three categories were combined for analysis purposes.

Child vegetable intake

Vegetable food frequency questionnaire

The parents were asked to indicate whether their child had eaten each of the vegetables on the vegetable food frequency questionnaire (VegFFQ) during the preceding 2 weeks. This measure was based on an instrument used in previous research (85) but was adapted to include vegetables common to the country in which it was being used, in consultation with professional nutritionists. The VegFFQ, therefore, differed across versions both in the number of vegetables (Italy: N = 24, Poland: N = 27, and UK: N = 24) and the specific vegetables listed (refer to **Appendix**). The parents were asked to report how frequently during the previous 2 weeks their child had eaten a child-sized portion of each of the vegetables on a five-point scale (categories were: never/once/a few times/many times/every day). A child-sized portion was defined for the parents as the amount that fits in a child's hand, in line with UK guidance (14).

To compute the average number of portions of vegetables children ate per day during the period in question, the ratings were recoded as follows: 'never' = 0, 'once' = 1, 'a few times' = 3, 'many times' = 6, and 'every day' = 14, converting fortnightly ratings of frequency to the values these implied. To adjust for the different numbers of vegetables on each country's list and the inclusion of potatoes on the Italian and Polish lists [potatoes do not count toward the recommended 5 portions of vegetables per day in the UK guidance (14)], we selected the 23 most frequently eaten vegetables in each country after excluding potatoes (refer to **Table 1**). Scores for the selected 23 vegetables were summed for each child and divided by 14 to compute the mean portions consumed per day, which was used as the measure of vegetable intake.

Variety of vegetable intake was assessed in terms of the number of different vegetables children were reported to have eaten during the 2-week period of interest, out of the same set of 23 vegetables included in computations of vegetable intake.

Parent measures

Family Mealtime Goals questionnaire

The Family Mealtime Goals [FMG (31)] questionnaire asks parents about the goals they have in mind when planning family meals and has been shown to have good psychometric properties. Items are scored on a five-point scale from 'strongly agree' (1) to 'strongly disagree' (5) and reverse-scored where appropriate. Questions related to three of the instrument's eight dimensions were used in this study to ensure that the overall length of the survey was manageable for parents; the dimensions selected were those most likely to be relevant to children's vegetable consumption and comprised Shared Family Food, Stress/Conflict Avoidance, and Family Involvement in Mealtimes. Examples of items are: "I don't want to prepare different foods for different family members"

TABLE 1 Mean child-sized portions of vegetables eaten per day by children in the UK, Italy, and Poland.

	UK	Italy	Poland
Mean (SD)	*N* = 225	*N* = 61	*N* = 124
Veg intake (child portions per day)	2.48 (1.66)	1.72 (1.06)	3.14 (2.03)
Variety of intake (number of different veg eaten)	9.96 (4.53)	8.62 (3.68)	12.52 (5.44)
Top 23 vegetables eaten by children in each country, listed from most to least frequently consumed	Cucumber, Carrots, Tomato, Peas, Sweetcorn, Broccoli, Peppers, Green Beans, Sweet Potato, Courgette, Mushroom, Cauliflower, Spinach, Lettuce, Butternut Squash, Leeks, Parsnip, Cabbage, Broad Bean, Beetroot, Aubergine, Asparagus, Brussels Sprouts.	Carrots, Courgette, Tomato, Peas, Butternut Squash, Fennel, CherryTomatoes, Green Beans, Lettuce, Spinach, Broccoli, Cauliflower, Chard, Aubergine, Leeks, Cucumber, Peppers, Cabbage, Artichoke, Brussels Sprouts, Broad Beans, Asparagus, Beetroot.	Tomato, Cucumber, Carrots, Onion, Peppers, Courgette, Parsley root, Broccoli, Sweetcorn, Green Beans, Cauliflower, Peas, Beetroot, Leeks, Spinach, Lettuce, Radish, Broad Bean, Cabbage, Mushroom, Pumpkin, Brussels Sprouts, Asparagus.

and "I want to avoid arguments at mealtimes." Scores were calculated by summing scores for questions related to each component.

Comprehensive Feeding Practices Questionnaire

The Comprehensive Feeding Practices Questionnaire [CFPQ (86)] comprises 49 items assessing parent feeding style and has been shown to have good psychometric properties. The questionnaire comprises 12 subscales: Monitoring, Emotional Regulation, Food as Reward, Child Control, Modelling, Restriction for Weight, Restriction for Health, Teaching Nutrition, Encourage Balance, Pressure to Eat, Healthy Environment, and Involvement. The items are rated on a five-point scale from 'never' (1) to 'always' (5) or from 'disagree' (1) to 'agree' (5) and reversed-scored as required. Examples of questions are: "How much do you keep track of the sweets (candy, ice cream, cake, pies, and pastries) that your child eats?" and "I allow my child to help prepare family meals." The CFPQ was provided to parents in the UK and Italy as an additional measure and was completed by 230 participants in these countries. This measure was not administered in Poland as it was considered that the additional time required to complete the instrument would impact negatively on participant engagement.

Child measures

Child Eating Behaviour Questionnaire: Food Fussiness subscale

Individual differences in children's food fussiness were assessed using the Food Fussiness subscale of the Child Eating Behaviour Questionnaire [CEBQ-FF (87)], which has been shown to have good psychometric properties. The subscale comprises six items rated on a five-point scale from 'never' (1) to 'always' (5), which are reverse-scored as required. Example questions are "My child enjoys a wide variety of foods" and "My child decides that s/he doesn't like food, even without tasting it." A mean score was calculated for each participant, with higher values indicating greater fussiness.

Emotionality Activity Sociability Scale – Temperament subscale

Child temperament was measured using the Temperament subscale of the Emotionality Activity Sociability Scale [EAS-T; (88)], which has been shown to have good psychometric properties. This questionnaire consists of 18 items rated on a 5-point scale from 'not typical of my child' (1) to 'very typical of my child' (5), which are reverse-scored as required. The questionnaire comprises four dimensions: Activity, Emotionality, Shyness, and Sociability. Examples of items are "My child cries easily" and "My child likes to be with people." This questionnaire was provided to parents in the UK and Italy as an additional measure and was completed by 230 parents. This measure was not administered in Poland for the same reasons outlined above.

Procedure

After parents had given their consent to participate, they were sent a link to the online questionnaire, which presented measures in this fixed order: demographic questions, food fussiness (CEBQ-FF), vegetable consumption (VegFFQ), and parents' mealtime goals (FMGs). Additional measures to assess child temperament (EAR-T) and parent feeding practices (CFPQ) were completed by all the participants in Italy and included as optional additional questionnaires for parents in the UK. Upon completion, the parents were thanked for their time and were invited to participate in an intervention to support vegetable intake, the results of which reported elsewhere (82, 83).

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Approach to data analysis

The data were analysed using statistical software SPSS version 26 (89). For standardised questionnaires, summary measures (mean or total scores) were calculated as described by the questionnaire's authors. For measures developed for the purposes of this study, scoring was as described in the Materials section above. As is common for questionnaire data, measures were frequently non-normally distributed. Parametric and non-parametric tests were therefore conducted in parallel to check for discrepancies in outcomes; in almost all cases, the results of these matched, and we report the results of parametric tests in the text given their easier interpretation. When discrepancies in findings were seen, we additionally report the results of the non-parametric comparisons in a footnote. Between-country comparisons of the demographic variables and parent and child measures involved analyses of variance with Bonferroni corrected *post hoc* tests, *t*-tests (and their non-parametric equivalents), and chi-squared analyses depending on the nature of the data and the number of countries contributing data. Pearson's correlations, analyses of variance, or *t*-tests (and their non-parametric equivalents) were conducted to explore the relationships between each of the demographic, parent, and child measures with children's vegetable intake, again followed up by *post hoc* tests as required. Multiple linear regression was conducted to establish the combined predictive value of factors found to be associated with vegetable intake in each country separately and in combined models that included predictor-country interactions. To assess and compare model fit, Fisher's *Z* tests were conducted.

Results

We first describe children's reported vegetable intake in each country, the dependent variable of interest in this study, and explore differences in levels of consumption across the three samples. We then report the environmental, parent, and child factor measures collected, explore differences in these between the samples, and examine whether these measures are related to and help to predict individual differences in children's intake of vegetables in each country.

Comparisons of children's vegetable intake across countries

Table 1 presents the reported vegetable consumption of children in each country in terms of mean child-sized portions consumed per day, the number of different vegetables eaten during the period of assessment, and the specific vegetables eaten in each country in order of frequency. Children in all three groups ate significantly less than five portions of vegetables per day [UK: $t(224) = -22.72$, $p < 0.001$; Italy: $t(60) = -24.1$, $p < 0.001$; Poland: $t(121) = -10.12$, $p < 0.001$]. However, vegetable intake differed significantly between groups, $F(2,405) = 14.52$, $p < 0.001$, $\eta^2 = 0.07$. The Polish children consumed more portions per day than the children in the UK [$t(345) = -3.23$, $p = 0.001$] and Italy [$t(180.6) = -6.19$, $p < 0.001$], while the children in UK ate more vegetables than those in Italy [$t(148.32) = 4.35$, $p < 0.001$]. The children in the UK and Italy both ate significantly less than three portions per day [UK: $t(224) = -4.66$, $p < 0.001$; Italy: $t(60) = -9.4$, $p < 0.001$], the level recently found to be optimal for good health (90).

We also examined the variety of vegetables consumed in each country in terms of the number of different vegetables children were reported to have eaten during the 2-week period of interest. Variety of intake also differed significantly between groups, $F(2,405) = 17.42$, $p < 0.001$, $\eta^2 = 0.08$, with a pattern very similar to that seen for vegetable intake. The Polish children consumed a greater variety of vegetables than the children in the UK [$t(212.78) = -4.41$, $p < 0.001$] and Italy [$t(165.07) = -5.71$, $p < 0.001$], and the children in the UK ate a wider variety of vegetables than the children in Italy [$t(284) = 2.13$, $p = 0.03$]. Variety of intake was highly correlated with quantity of vegetable intake (portions per day), both overall [$r(408) = 0.82$, $p < 0.001$] and in each country separately [UK: $r(225) = 0.8$, $p < 0.001$; Italy: $r(61) = 0.71$, $p < 0.001$; Poland: $r(122) = 0.83$, $p < 0.001$].

Similarities were observed between the groups in terms of the specific vegetables eaten. Carrots and tomatoes were among the most frequently eaten vegetables, and asparagus and Brussels sprouts were among the least frequently eaten vegetables in each country. There were also noteworthy differences. For example, cucumber was very commonly eaten in Poland and the UK but was rarely eaten by children in Italy.

The environmental, parent, and child characteristics of each group and their relationship with vegetable intake

Environmental/sociodemographic characteristics

The sociodemographic data for the participants from each country are shown in Table 2. There were several between-country differences in sociodemographic characteristics including child age [$F(2,405) = 3.88$, $p = 0.02$, $\eta^2 = 0.02$]. *Post hoc* comparisons showed that the children of the Italian participants were slightly older than those of the UK participants. The Italian sample had more male children than the other groups, although the distribution did not differ significantly between countries [$\chi^2(2) = 5.12$, $p = 0.08$]. There was a between-country difference in the proportion of children attending day care ($\chi^2(2) = 39.21$, $p < 0.001$]; fewer children attended day care in the Polish sample than in the samples from

TABLE 2 Participant demographic characteristics.

	UK	Italy	Poland
N	225	61	122
Child age (months), *M* (*SD*)	31.3 (8.9)	35.0 (10.6)	32.5 (9.7)
Child gender, % male	49.3	65.6	51.6
N children in home, %			
1	43.6	44.3	46.7
2	47.6	41.0	42.6
3+	6.7	14.8	10.6
Child is first born, % yes	60.9	54.1	68.9
Attends day care, % yes	80.0	88.5	52.5
Relationship to child, %			
Mother	96.0	93.4	98.4
Father	3.6	6.6	0.8
Other	0.4	0	0.8
Education of Parent 1, %			
No formal education/GCSE-level/vocational qualifications	5.3	1.6	3.3
High-school education	10.7	23.0	0.0
Bachelor's education	39.4	18.0	11.5
Higher degree education	44.4	55.7	85.2
Education of Parent 2, %			
No formal education/GCSE-level/vocational qualifications	17.3	6.6	26.2
High-school education	16.9	31.1	0.0
Bachelor's education	34.7	9.8	18.9
Higher degree education	29.3	45.9	54.9
Ethnicity of child, %			
White	–	–	97.5
White British	81.8	–	–
White and Asian	3.1	–	–
White and Black African	1.3	–	–
Bangladeshi	0.4	–	–
Pakistani	0.4[3]	–	–
Indian	0.4	–	–
Irish	0.9	–	–
Chinese	0.4	–	–
Arab	0.4	–	–
White –other[a]	6.7	–	–
Mixed –other[b]	2.2	–	–
Prefer not to say	1.8	–	0.8
Other[c]	–	–	1.6
Country of Residence, %			
Italy	–	96.7	–
UK	95.5	1.6	0.8
Poland	0.4	–	93.4
Australia	1.8	–	–
South Africa	–	1.6	–
Holland	–	–	1.6
Germany	0.9	–	1.6
Ireland	0.9	–	–
Norway	–	–	0.8
Netherlands	–	–	0.8
Jordan	–	–	0.8
Mauritius	0.4	–	–

[a]White-Other included Hungarian/Irish/English, European, Australian, French, Russian/Scottish, Slavic, Russian, Polish/English, Latino of European descent, Italian/Turkish Cypriot, German, New Zealand, and European.
[b]Mixed-Other included White/Fijian, English/Colombian, Indian/Chinese, White/African Arab, Portuguese Black, Caribbean, and Asian.
[c]"Other" included White and Asian.

Italy and the UK. There were no significant differences between the groups in the number of children in the family or in whether participating children were the first born. Educational levels differed between countries for both parents [parent 1: Fisher's exact test $p < 0.001$; parent 2: $\chi^2(6) = 69.31$, $p < 0.001$]; the Polish parents were the most highly educated, followed by the Italian parents, followed by the British parents. Ethnicity was measured differently at each site and was not collected in Italy, preventing direct comparison. However, the large majority of parents identified their children as 'White' in the UK (95%) and Poland (93%). Finally, while the majority of participants in each sample resided in the country in which they were recruited to the study, in each case, a small number lived elsewhere in the world. For ease of reporting, we refer to our samples as Italian, Polish, and British, respectively.

Next, we examined whether any sociodemographic characteristics (child's gender, age, day care attendance, birth order, parents' education level, and number of children in the home) were associated with children's vegetable intake, either for the group overall or in any individual country. In the group as a whole, children who attended day care were reported to consume fewer portions of vegetables ($M = 2.42$, $SD = 1.68$) than children solely cared for at home ($M = 2.97$, $SD = 1.93$) [$t(406) = 2.84$, $p = 0.005$, Cohen's $d = 0.32$]. However, the effect of day care attendance was not significant for any individual sample. The education level of the responding parents was significantly associated with children's vegetable intake, $F(3,402) = 3.5$, $p = 0.016$, $\eta^2 = 0.03$; *post hoc* tests showed that the children of parents with higher degrees had higher intake of vegetables ($M = 2.79$, $SD = 1.86$) than the children of parents holding bachelor's degrees ($M = 2.15$, $SD = 1.62$). The same general pattern was seen in the UK sample, $F(3,220) = 3.09$, $p = 0.028$, $\eta^2 = 0.04$, although *post hoc* tests found no significant differences in the vegetable intake of children whose parents fell in different educational categories. There were no other significant associations between the demographic measures collected and children's vegetable intake, including no relationships with age ($p > 0.05$ for all the analyses).

Parent mealtime goals and feeding style

Table 3 presents the mean scores for each component of the Family Mealtime Goals (FMG) questionnaire. Significant between-country differences were found for endorsement of the 'shared family food' goal [$F(2,405) = 9.88$, $p < 0.001$, $\eta^2 = 0.05$]. The parents in the UK and Poland endorsed this goal more strongly than the parents in Italy [Italy vs. UK: $t(284) = 3.43$, $p = 0.001$; Italy vs. Poland: $t(181) = -4.51$, $p < 0.001$. There was no significant difference in the goal's endorsement in the UK and Poland: $t(345) = -1.67$, $p = 0.1$]. The same pattern was seen for the goals of 'stress and conflict avoidance' [$F(2,405) = 7.83$, $p < 0.001, \eta^2 = 0.04$]

TABLE 3 Family mealtime goals questionnaire component scores for parents in the UK, Italy, and Poland.

	Whole sample	UK	Italy	Poland
N	408	225	61	122
FMG component	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Shared family food	4.44 (0.66)	4.45 (0.66)	4.12 (0.70)	4.57 (0.61)
Stress/Conflict avoidance	4.44 (0.65)	4.50 (0.64)	4.15 (0.68)	4.50 (0.62)
Family involvement	4.04 (0.71)	4.06 (0.72)	3.72 (0.69)	4.16 (0.66)

[Italy vs. UK: $t(284) = 3.74$, $p < 0.001$; Italy vs. Poland: $t(181) = -3.53$, $p = 0.001$; UK vs. Poland: $t(345) = -0.05$, $p = 0.96$] and 'family involvement in mealtimes' [$F(2,405) = 8.62$, $p < 0.001$, $\eta^2 = 0.04$] [Italy vs. UK: $t(284) = 3.39$, $p = 0.001$; Italy vs. Poland: $t(181) = -4.25$, $p < 0.001$; UK vs. Poland: $t(345) = -1.25$, $p = 0.21$]. In each case, the UK and Polish parents endorsed the goals more strongly than the Italian parents.

Table 4 provides the scores for the British and Italian participants for each component of the Comprehensive Feeding Practices Questionnaire (CFPQ) (this measure was not collected in Poland). The two groups differed on their endorsement of the feeding behaviours of 'emotion regulation' [$t(228) = 2.94$, $p = 0.004$] and 'modelling' [$t(224) = 3.33$, $p = 0.001$]. In both cases, the British parents reported engaging in these behaviours to a greater extent than the Italian parents.

To explore whether these parenting factors were related to children's vegetable intake, correlational analyses were conducted between the component measures of the two parent measures and children's mean vegetable intake per day. When all the participants were included in analyses

TABLE 4 Comprehensive feeding practices questionnaire component scores for parents in the UK and Italy.

	UK	Italy
N	169	61
CFPQ component	*M (SD)*	*M (SD)*
Child control	2.54 (0.61)	2.69 (0.72)
Emotion regulation	2.02 (0.71)	1.70 (0.73)
Encourage balance and variety	4.28 (0.58)	4.36 (0.57)
Environment	3.91 (0.72)	3.98 (0.73)
Food as reward	2.04 (0.93)	2.21 (1.16)
Involvement	3.07 (1.05)	3.15 (0.97)
Modelling	4.24 (0.68)	3.89 (0.77)
Monitoring	4.21 (0.76)	4.35 (0.65)
Pressure	2.71 (0.94)	2.86 (0.91)
Restrictions for health	3.10 (1.04)	2.98 (1.05)
Restrictions for weight	1.82 (0.59)	1.97 (0.59)
Teaching about nutrition	3.65 (0.97)	3.61 (0.89)

(refer to Table 5), endorsement of the Family Mealtime Goals (FMG) component of 'family involvement' [$r(408) = 0.18$, $p < 0.001$] was positively associated with vegetable intake. Vegetable intake was also related to two components from the CFPQ: endorsement of the 'healthy environment' dimension was positively related to vegetable intake [$r(229) = 0.15$, $p = 0.03$], while endorsement of the use of 'food as a reward' was negatively related to vegetable intake [$r(229) = -0.2$, $p = 0.002$].

To explore whether the parent factors were associated with vegetable consumption in all three countries, analyses were conducted for each country separately (refer to Tables 6–8). For the participants in the UK, the CFPQ 'environment' [$r(168) = 0.17$, $p = 0.028$] and 'food as a reward' components [$r(168) = -0.18$, $p = 0.02$] and the FMG dimension 'family involvement' [$r(225) = 0.17$, $p = 0.01$] were associated with children's vegetable intake[2]. In the Italian sample, in addition to a significant association with 'food as a reward' [$r(61) = -0.29$, $p = 0.02$], vegetable intake was negatively associated with the CFPQ dimensions of 'emotion regulation' [$r(61) = -0.29$, $p = 0.02$] and 'food restriction on health' [$r(61) = -0.27$, $p = 0.03$][2]. In the Polish sample where only the Family Mealtime Goals questionnaire was collected, no parenting component was significantly associated with vegetable intake.

Child food fussiness and temperament

Table 9 presents the mean food fussiness scores for the children in each country. There was no significant difference in food fussiness levels across countries [$F(2,405) = 2.83$, $p = 0.06$, $\eta^2 = 0.01$].

Table 10 presents the mean scores for the components of the Temperament subscale of the Emotionality Activity Sociability questionnaire (EAS-T) for children in Italy and the UK (this measure was not collected in Poland). The Italian children were rated more highly than the British children on both 'emotionality' [$t(134.06) = -2.43$, $p = 0.02$] and 'sociability' [$t(90.17) = -5.15$, $p < 0.001$].

To explore whether the individual child factors were related to vegetable intake, correlational analyses were conducted between intake and both food fussiness and the individual dimensions of child temperament (refer to Table 5). For the group as a whole, food fussiness was negatively correlated with reported vegetable intake [$r(408) = -0.28$, $p < 0.001$]; no other relationships were found (all $ps > 0.05$).

2 The non-parametric correlation (Spearman's rho) between the CFPQ dimension 'food as a reward' and vegetable intake did not reach significance in the UK sample [$r_S(168) = -0.13$, $p = 0.09$]. The non-parametric correlations (Spearman's rho) between vegetable intake and the CFPQ dimensions 'emotion regulation' [$r_S(61) = -0.24$, $p = 0.06$] and 'food restriction for health' [$r_S(61) = -0.225$, $p = 0.08$] did not reach significance in the Italian sample. These factors were nevertheless included in the final regression model to err on the side of caution when including potential predictors of vegetable intake.

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TABLE 5 Correlations between vegetable consumption and parent and child measures, all children included ($N = 408$)†.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
(1) Portions of veg per day	–																				
(2) Child's age	−0.06	–																			
(3) Food fussiness	−0.28**	0.19**	–																		
(4) EAS-T activity	0.01	−0.09	−0.05	–																	
(5) EAS-T emotionality	0.05	0.05	0.20**	−0.10	–																
(6) EAS-T shyness	−0.10	0.01	0.19**	−0.33**	0.30**	–															
(7) EAS-T sociability	−0.03	0.08	−0.11	0.21**	0.12	−0.27**	–														
(8) CFPQ child control	−0.11	0.05	0.17*	−0.04	0.14*	0.14*	−0.03	–													
(9) CFPQ emotion regulation	0.05	−0.05	0.04	−0.15*	0.12	0.06	−0.01	0.19**	–												
(10) CFPQ encourage balance and variety	0.08	0.09	−0.06	0.11	0.02	0.02	−0.05	−0.01	−0.08	–											
(11) CFPQ environment	0.15*	−0.01	0.01	−0.01	−0.02	−0.03	0.05	−0.12	−0.14*	0.25**	–										
(12) CFPQ Food as reward	−0.20**	0.27**	0.16*	0.04	0.06	−0.06	−0.04	0.07	0.33**	0.11	−0.23**	–									
(13) CFPQ involvement	0.08	0.35**	0.03	0.05	−0.06	0.00	−0.02	0.05	−0.01	0.31**	0.21**	0.07	–								
(14) CFPQ modelling	0.05	0.02	0.12	0.00	−0.08	0.04	−0.10	−0.09	0.07	0.41**	0.34**	0.01	0.27**	–							
(15) CFPQ monitoring	0.02	−0.05	−0.09	0.05	0.03	−0.00	0.03	−0.20**	−0.13	0.22**	0.29**	−0.19**	0.11	0.25**	–						
(16) CFPQ pressure	0.03	0.07	0.04	−0.02	0.06	−0.05	−0.05	−0.11	0.09	0.20**	−0.15*	0.37**	0.03	0.06	−0.06	–					
(17) CFPQ restriction for health	−0.02	0.17*	0.09	0.03	0.12	−0.04	0.03	−0.04	0.21**	0.18**	−0.16*	0.36**	0.11	0.13*	−0.07	0.37**	–				
(18) CFPQ restriction for weight control	−0.04	0.03	−0.08	0.11	0.08	−0.12	0.06	−0.11	0.06	0.13	−0.06	0.24**	0.06	0.03	0.11	0.29**	0.41**	–			
(19) CFPQ teaching about nutrition	0.07	0.34**	0.07	0.03	0.02	−0.03	−0.04	−0.06	−0.00	0.38**	0.14*	0.10	0.52**	0.31**	0.25**	0.06	0.21**	0.17**	–		
(20) FMGQ shared family food	0.07	−0.02	−0.02	−0.06	−0.00	0.02	−0.06	−0.18**	−0.04	−0.04	−0.10	0.02	−0.15*	0.06	−0.06	0.03	−0.01	−0.02	−0.01	–	
(21) FMGQ stress/conflict avoidance	0.05	−0.02	0.06	−0.05	0.07	0.11	−0.02	−0.03	0.07	−0.07	−0.07	−0.03	−0.10	0.01	−0.04	0.07	0.06	0.04	0.02	0.42**	–
(22) FMGQ family involvement at mealtimes	0.18**	0.16**	0.01	0.01	0.03	0.03	−0.00	−0.02	0.05	0.05	0.12	0.05	0.40**	0.24**	0.06	−0.02	0.13	−0.01	0.29**	0.31**	0.33**

*$p < 0.05$, **$p < 0.01$.
EAS-T, Emotionality Activity Sociability-Temperament subscale (88); CFPQ, Comprehensive Feeding Practices Questionnaire (86); FMGQ, Family Mealtime Goals questionnaire (31).
†CFPQ and EAS-T were completed by a subset of the population ($N = 230$).

TABLE 6 Correlations between vegetable consumption and parent and child measures, UK sample (N = 225)†.

Variables	*n*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
(1) Portions of veg per day	225	–																				
(2) Child's age	225	−0.01	–																			
(3) Food fussiness	225	−0.29**	0.08	–																		
(4) EAS activity subscale	169	0.03	−0.03	−0.01	–																	
(5) EAS emotionality subscale	169	0.15	−0.05	0.16*	−0.09	–																
(6) EAS shyness subscale	169	−0.05	−0.02	0.16*	−0.36**	0.29**	–															
(7) EAS sociability subscale	169	0.05	−0.02	−0.04	0.22**	0.16*	−2.4**	–														
(8) CFPQ child control	169	−0.07	0.04	0.19*	−0.01	0.08	0.10	−0.01	–													
(9) CFPQ emotion regulation	169	0.07	−0.08	−0.07	−0.11	0.08	0.04	0.12	0.16*	–												
(10) CFPQ encourage balance and variety	169	0.12	0.12	−0.05	0.10	0.07	0.05	−0.05	0.03	−0.04	–											
(11) CFPQ environment	168	0.17*	0.04	0.03	−0.03	0.00	0.01	0.01	−0.05	−0.08	0.25**	–										
(12) CFPQ food as reward	168	−0.18*	0.29**	0.09	0.06	−0.04	−0.11	0.02	0.03	0.25**	0.13	−0.20**	–									
(13) CFPQ involvement	168	0.10	0.42**	−0.01	−0.00	−0.06	0.01	−0.05	0.13	0.02	0.32**	0.19*	0.08	–								
(14) CFPQ modelling	165	0.06	0.10	0.07	−0.06	−0.04	0.05	−0.02	0.03	0.03	0.38**	0.45**	−0.01	0.30**	–							
(15) CFPQ monitoring	169	0.06	−0.05	−0.12	0.02	0.07	0.02	−0.02	−0.18*	−0.10	0.18*	0.24**	−0.17*	0.05	0.20**	–						
(16) CFPQ pressure	168	0.10	0.08	0.05	−0.06	0.10	0.03	−0.06	−0.18*	0.05	0.17*	−0.09	0.34**	0.04	−0.01	−0.03	–					
(17) CFPQ restriction for health	168	0.02	0.16*	−0.02	0.06	0.11	−0.04	0.14	−0.02	0.16*	0.23*	−0.14	0.36**	0.04	0.09	−0.10	0.38**	–				
(18) CFPQ restriction for weight control	168	0.02	0.05	−0.08	0.08	0.11	−0.08	0.07	−0.11	0.05	0.14	−0.05	0.21**	−0.01	0.01	0.15	0.29**	0.41**	–			
(19) CFPQ teaching about nutrition	168	0.07	0.42**	−0.01	0.05	0.03	−0.01	0.01	−0.01	−0.00	0.37**	0.18*	0.11	0.54**	0.33**	0.25**	0.03	0.16*	0.15	–		
(20) FMGQ shared family food	225	0.02	0.04	−0.01	−0.03	−0.02	−0.01	0.08	−0.18*	−0.11	0.02	−0.07	0.03	−0.09	0.08	0.01	0.04	0.01	−0.03	0.02	–	
(21) FMGQ stress/conflict avoidance	225	0.03	0.00	−0.02	−0.03	0.10	0.06	0.13	−0.13	0.03	−0.03	−0.12	−0.00	−0.15*	−0.07	−0.02	0.12	0.10	0.08	0.04	0.49**	–
(22) FMGQ family involvement at mealtimes	225	0.17**	0.24**	−0.08	0.01	0.03	−0.00	0.12	0.08	−0.03	0.08	0.12	0.01	0.38**	0.19*	0.03	0.00	0.06	−0.07	0.32**	0.39**	0.30**

*$p < 0.05$, **$p < 0.01$.
EAS-T, Emotionality Activity Sociability-Temperament subscale (88); CFPQ, Comprehensive Feeding Practices Questionnaire (86); FMGQ, Family Mealtime Goals questionnaire (31).
†CFPQ and EAS-T were completed by a subset of the UK sample (N = 168).

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TABLE 7 Correlations between vegetable consumption and parent and child measures, Italian sample ($N = 61$).

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
(1) Portions of veg per day	–																				
(2) Child's age	0.13	–																			
(3) Food fussiness	−0.27**	0.40**	–																		
(4) EAS activity	−0.09	−0.29*	−0.15	–																	
(5) EAS emotionality	−0.26*	0.26*	0.42**	−0.18	–																
(6) EAS shyness	−0.36**	0.10	0.25*	−0.23	0.37**	–															
(7) EAS sociability	0.10	0.10	−0.11	0.24	−0.16	−0.41**	–														
(8) CFPQ child control	−0.19	0.20	0.17	−0.14	0.26*	0.22	−0.18	–													
(9) CFPQ emotion regulation	−0.29*	0.11	0.17	−0.28*	0.41**	0.11	−0.07	0.32	–												
(10) CFPQ encourage balance and variety	−0.02	0.01	−0.08	0.17	−0.19	−0.06	−0.12	−0.12	−0.14	–											
(11) CFPQ environment	0.15	−0.15	−0.02	0.07	−0.15	−0.12	0.08	−0.30*	−0.26*	0.25	–										
(12) CFPQ food as reward	−0.29*	0.20	0.30*	−0.02	0.30*	0.05	−0.24	0.13	0.58*	0.07	−0.30*	–									
(13) CFPQ involvement	0.00	0.17	0.12	0.24	−0.07	−0.02	−0.01	−0.16	−0.05	0.26*	0.25	0.04	–								
(14) CFPQ modelling	−0.22	−0.03	0.12	0.21	−0.08	0.01	−0.04	−0.26*	0.03	0.59**	0.15	0.11	0.23	–							
(15) CFPQ monitoring	−0.06	−0.10	0.00	0.14	−0.18	−0.07	0.05	−0.30*	−0.17	0.37**	0.44**	−0.28*	0.31*	0.47**	–						
(16) CFPQ pressure	−0.15	0.01	0.06	0.14	−0.11	−0.28*	−0.13	0.01	0.27*	0.26*	0.34**	0.45**	−0.02	0.27*	−0.19	–					
(17) CFPQ restriction for health	−0.27*	0.22	0.28*	−0.04	0.19	−0.05	−0.15	−0.07	0.35**	0.05	−0.21	0.40**	0.32*	0.21	0.03	0.37**	–				
(18) CFPQ restriction for weight control	−0.17	−0.09	−0.04	0.22	−0.10	−0.22	−0.09	−0.14	0.17	0.05	−0.12	0.29*	0.27*	0.17	−0.05	0.29*	0.46**	–			
(19) CFPQ teaching about nutrition	0.04	0.20	0.23	−0.05	0.02	−0.08	−0.15	−0.21	−0.03	0.43**	0.04	0.08	0.48**	0.27*	0.29*	0.17	0.37**	0.25	–		
(20) FMGQ shared family food	−0.05	−0.11	0.07	−0.14	0.19	0.10	−0.10	−0.14	−0.01	−0.14	−0.16	0.06	−0.33*	−0.15	−0.22	0.06	−0.10	0.10	−0.11	–	
(21) FMGQ stress/conflict avoidance	−0.01	0.01	0.23	−0.13	0.12	0.25	−0.09	0.27*	0.04	−0.13	0.10	−0.03	0.08	0.02	−0.02	−0.03	−0.08	0.04	−0.04	0.26*	–
(22) FMGQ family involvement at mealtimes	−0.16	0.15	0.31*	0.03	0.18	0.14	−0.03	−0.18	0.15	0.01	0.17	0.19	0.55**	0.26*	0.21	−0.04	0.29*	0.27*	0.18	−0.04	0.28*

*$p < 0.05$, **$p < 0.01$.

EAS-T, Emotionality Activity Sociability–Temperament subscale (88); CFPQ, Comprehensive Feeding Practices Questionnaire (86); FMGQ, Family Mealtime Goals questionnaire (31).

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TABLE 8 Correlations between vegetable consumption and parent and child measures, Polish sample (N = 122).

Variables	1	2	3	4	5	6
(1) Portions of veg per day	–					
(2) Childs age	−0.15	–				
(3) Food fussiness	−0.37**	0.29**	–			
(4) FMGQ shared family food	0.04	−0.03	−0.16	–		
(5) FMGQ stress/conflict avoidance	−0.02	0.02	0.00	0.30**	–	
(6) FMGQ family involvement at mealtimes	0.16	0.12	−0.09	0.24**	0.35**	–

*p < 0.05, **p < 0.01.
FMGQ, Family Mealtime Goals questionnaire (31).

TABLE 9 Food fussiness (CEBQ:FF) scores for the children in the UK, Italy, and Poland.

	Whole sample	UK	Italy	Poland
N	408	225	61	122
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
Food fussiness	3.07(0.86)	3.15 (0.78)	2.86 (1.09)	3.03 (0.85)

TABLE 10 Emotionality activity sociability–temperament subscale (EAS-T) component scores.

	UK	Italy
N	*169*	*61*
Temperament component	*M (SD)*	*M*
Activity	4.08 (0.80)	4.11 (0.60)
Emotionality	2.62 (0.93)	2.90 (0.73)
Shyness	2.61 (0.75)	2.61 (0.75)
Sociability	3.04 (0.46)	3.45 (0.56)

To investigate whether the individual child factors associated with children's vegetable consumption differ between countries, analyses were conducted for each country separately (refer to **Tables 6–8**). Food fussiness was negatively correlated with vegetable intake in the UK [$r(225) = -0.29$, $p < 0.001$], Italy [$r(61) = -0.27$, $p = 0.04$], and Poland [$r(122) = -0.37$, $p < 0.001$]. In addition, vegetable intake was negatively related to the 'emotionality' [$r(61) = -0.26$, $p = 0.05$] and 'shyness' [$r(61) = -0.36$, $p = 0.004$] components of the EAS-T questionnaire for the Italian sample.

Predictors of child vegetable intake and how these differed between countries

To investigate the relative and independent contributions of child, parent, and environmental measures in predicting children's vegetable intake, we conducted a separate multiple regression analysis for each country. Each of the variables identified in the previous set of analyses as significantly associated with intake ($p < 0.05$) for a given country was included in an enter method multiple linear regression for that population. The data met the required assumptions for collinearity in each case, with no multicollinearity between the included predictors.

For the UK sample, the parent feeding style measures of CFPQ 'environment,' CFPQ 'food as a reward,' and FMG 'family involvement' were entered as predictors, as were child food fussiness and the responding parent's level of education. The regression model significantly predicted vegetable intake [$R^2 = 0.13$, R^2 change = 0.13, $F(5,162) = 4.69$, $p < 0.001$], explaining 10% of the variance in consumption. Only child food fussiness ($B = -0.55$, $p = 0.002$) and FMG 'family involvement' ($B = 0.35$, $p = 0.049$) made significant unique contributions to the model.

For the Polish sample, child food fussiness was the only significant correlate of vegetable intake and the only factor to be entered into the model. The model was significant [$R^2 = 0.14$, R^2 change = 0.14, $F(1,120) = 19.43$, $p < 0.001$], explaining 13% of the variance in vegetable intake (food fussiness: $B = -0.89$, $p < 0.001$).

For the Italian sample, the parent feeding style factors of CFPQ 'emotion regulation,' CFPQ 'food as a reward,' and CFPQ 'food restriction on health' were entered into the model, as were the child factors of EAS-T 'emotionality,' EAS-T 'shyness,' and child food fussiness. The model significantly predicted vegetable intake [$R^2 = 0.26$, R^2 change = 0.26, $F(6,54) = 3.13$, $p = 0.01$], explaining 18% of the variance. However, only 'shyness' made a significant unique contribution to the model ($B = -0.48$, $p = 0.01$).

While the multiple regression findings are informative, they do not directly compare the extent to which variables predict vegetable intake between countries. To explore potential differences in the role of the predictors across countries, we adopted two different analytic approaches. First, we tested the predictor by country interactions for variables that were measured across groups. Second, we compared model fits, model structures, and beta coefficients between individual regression models that included shared predictors. Given that neither 'attendance at day care' nor 'responding parent's education' was a significant predictor in the regressions for individual populations, we report the results of models excluding these sociodemographic variables. Their inclusion did not alter the results other than rendering one model for Italy non-significant ($p > 0.05$), likely because of the small sample size relative to the number of predictors entered.

To implement the first approach, we conducted a hierarchical regression model analysis to predict vegetable intake that included main and interaction effects. In the first block of predictors, the three countries were dummy-coded to allow for comparison between countries, with Poland as the reference group. This model significantly predicted vegetable intake [R^2 = 0.06, R^2 change = 0.07, F(2,405) = 14.52, p < 0.001]. In the second block, the shared predictors of interest were added, including age of child, food fussiness, and the FMG dimensions 'shared family mealtimes,' 'stress/conflict avoidance,' and 'family involvement.' The model was significant in predicting vegetable intake [R^2 = 0.16, R^2 change = 0.1, F(5,400) = 9.99, p < 0.001]. The third block included the interaction terms between the country variables and the shared predictors. Adding this block did not improve the model fit [R^2 = 0.16, R^2 change = 0.02, F(10,390) = 1.07, p = 0.39]. The model including the first and second blocks of predictors was therefore examined for significant beta coefficients. Vegetable intake in Poland was significantly greater than in the UK (B = –0.56, p = 0.003) and Italy (B = –1.4, p < 0.001). An alternative model with the UK as the reference group showed that vegetable intake was also higher in the UK than in Italy (B = –0.84, p = 0.001). The other significant predictors included food fussiness (B = –0.519, p < 0.001) and the FMG dimension 'family involvement' (B = 0.252, p = 0.005). Changes in the dummy-coding scheme did not change the model results or beta coefficients of non-country predictors. This hierarchical regression analysis therefore replicated the results of the ANOVA comparing vegetable intake across countries and further identified food fussiness and 'family involvement' as predictors of vegetable intake in the combined sample. However, the lack of significant interaction effects in the model suggests that this analysis was not sensitive to between-country differences in the effects of predictors.

Our second approach was to conduct separate, enter method, regression analyses for each country that included the same set of shared predictors (age, food fussiness, and FMG dimensions). Fisher's Z tests were conducted to compare the R values of the regression for each country to assess the fit of the set of predictors in each case. The regression model was significant for the UK sample [R^2 = 0.11, R^2 change = 0.11, F(5,219) = 5.24, p < 0.001] and for the Polish sample [R^2 = 0.17, R^2 change = 0.17, F(5,116) = 4.62, p = 0.001] but not for the Italian sample [R^2 = 0.16, R^2 change = 0.16, F(5,55) = 2.08, p = 0.08]. The comparisons of model fit revealed no significant difference between the fit for the UK and Poland [Z = 0.815, p = 0.42], suggesting that the same predictor set worked well for the two countries. Food fussiness was a significant negative predictor of vegetable intake in both countries (UK: B = –0.5, p < 0.001; Poland: B = –0.71, p < 0.001). FMG 'family involvement' was also a significant positive predictor for the UK sample (B = 0.29, p = 0.02). We further compared the structure of the UK and Polish models by applying the model derived from the Polish sample to the UK dataset and comparing the crossed R^2 with the direct R^2. The model structure was not significantly different [Z = *0.51*, p = 0.610]. The regression weights for food fussiness did not differ between the two countries [Z = 0.948, p = 0.343], suggesting that the magnitude of this variable's relationship with vegetable intake was similar in the two groups. Overall, these results corroborate those of the previous regression analyses. Because the model for the Italian sample was not significant, beta coefficients and model fit comparisons involving this group were not conducted.

Finally, given that a larger set of potential explanatory variables was collected in the UK and Italy, the above analysis was repeated using the common predictor set for these two countries. Separate enter method multiple regression models were used for the UK and Italy including the shared predictors of interest (age, food fussiness, FMG dimensions, CFPQ dimensions, and EAS-T dimensions). The model was significant for both the UK sample [R^2 = 0.23, R^2 change = 0.23, F(21,143) = 2.01, p = 0.009] and the Italian sample [R^2 = 0.51, R^2 change = 0.51, F(21, 39) = 1.91 p = *0.04*]. The Fisher's Z test comparing the models' fit was significant (Z = 2.424, p = 0.03); the larger R^2 value for the Italian model indicates that the predictor set worked better for the Italian sample, suggesting that some of the additional parent and child variables helped to predict vegetable intake for this group. Further testing suggested structural differences between the two models (Z = 3.399, p < 0.001), confirmed by the lack of overlap between the significant predictor variables in the models. For the Italian sample, EAS-T 'shyness' was the only variable to make a significant contribution to the prediction of vegetable intake *(*B = -0.61, p = 0.001*)*, echoing the results of the initial regression analysis. For the UK sample, food fussiness (B = –0.5, p = 0.003), EAS-T 'emotionality' (B = 0.34, p = 0.02), and CFPQ 'food as a reward' (B = –0.44, p = 0.007) all significantly contributed to the prediction of vegetable intake, presenting both consistencies and inconsistencies with the earlier regression results.

In sum, these regression analyses highlight food fussiness as a shared negative predictor of vegetable intake in the UK and Polish samples. In addition, FMG 'family involvement' was a significant positive predictor of intake for the UK sample. CFPQ 'food as a reward' and EAS-T 'emotionality' were identified as negative predictors for the UK sample in some analyses, although the results were inconsistent. No predictors were shared between the Italian sample and other countries. In Italy, EAS-T 'shyness' was the sole significant predictor of vegetable intake.

Discussion

This study sought to compare the levels of vegetable intake in children from three European countries, Italy, Poland, and the UK, to explore how these are related to parent, child, and environmental factors previously found to influence vegetable consumption and healthy eating behaviour, and to identify whether the predictive relationships between these factors and vegetable intake are the same or differ between populations.

Previous reports have highlighted that the majority of children across Europe and around the globe do not meet public health guidelines on recommended levels of vegetable intake (11). The results of the current study corroborate these claims but also confirm previous findings that levels of vegetable intake vary across countries. Consistent with some previous findings (17), the Polish children were reported to eat the most vegetables among our groups, at around three child-sized portions per day, which was significantly more than the intake of children in the UK and Italy. Furthermore, the Italian children ate significantly fewer portions of vegetables than the children in the UK, only one portion per day on average. The children in all three countries consumed significantly less than the gold standard of five portions of vegetables per day (13); however, this may not be of concern if we consider that '5 a day' guidelines typically include fruits and vegetables. A recent cohort study on adult mortality (90) concluded that good health is optimally supported by a diet consisting of three portions of vegetables and two portions of fruits per day. We therefore additionally compared children's intake levels against the advised three portions of vegetables per day and found that the children in both the UK and Italy fell significantly short of this level of intake.

The variety of different vegetables reported to be eaten by children was also explored. The children ate an average of 10 different vegetables during the 2-week assessment period, suggesting that the parents are doing their best to offer a varied diet and that the children are not restricting their intake to a limited range of foods. Variety of intake was very highly correlated with the total quantity of intake (portions per day), and we found the same pattern of between-country differences in the variety of children's diets as in the number of portions consumed. The Polish children consumed the widest range of vegetables, followed by the children in the UK, and then by the children in Italy.

It is important to consider whether methodological artefacts or third variables might be responsible for the observed differences in vegetable intake between countries. In terms of the former, might the differences be due to parents' reporting accuracy, for example? Parents may not always be aware of all the foods their child eats, particularly if the child regularly attends day care. Indeed, we found that children who attended day care were reported to have lower levels of vegetable intake than children always cared for at home, when data from all three groups were pooled. However, this relationship did not hold for any individual country, and day care attendance had no predictive value in any model of vegetable intake either for the sample overall or for any individual group. The observed between-country differences in vegetable consumption therefore cannot be straightforwardly attributed to parents' lack of awareness of the foods their child is eating at day care.

We also considered whether the questionnaires used to assess children's vegetable intake might have differed between countries in ways that could have impacted the validity of parents' responses. The original questionnaire, which was developed in English, excluded potatoes, which UK public health guidelines do not count as a vegetable because of their high carbohydrate content (14). When the UK questionnaire was adapted for use in Italy and Poland, additional vegetables that are commonly eaten in each local context were added to the list, while some rarely encountered vegetables were removed. In both adaptations, potatoes were added as a very commonly eaten vegetable; parents' responses confirmed that these were the second and third most commonly consumed vegetable in Italy and Poland, respectively. To allow consumption levels to be compared across countries, potatoes were removed from the computed vegetable intake scores. While potato is also very commonly eaten by children in the UK, we note the possibility that the between-group differences we observed might have been less stark had potato been included for all the groups. Nevertheless, this consideration does not detract from the finding of differences in children's intake of vegetables other than potatoes.

The finding that the Italian children were reported to consume the fewest portions and to have the lowest dietary variety among the three groups involved in our study corroborates other recent evaluations of preschool children's diets (41) and challenges the stereotype that this group is likely to be fed a traditional Mediterranean diet high in fruits and vegetables. This finding is clearly a cause for concern and presents a more pessimistic picture than studies conducted just a few years before the current study (11, 18). It is worth noting that in our study, the data collection took place over a shorter time frame in Italy than in the other countries and during the winter months. However, whilst this might explain the lower variety of vegetables in Italian children's diets, it does not account for the lower quantity of intake in this group. Rather, the results support the view that the rising childhood obesity rates seen in Southern European countries (10, 91) may be linked to the widespread transition from a traditional Mediterranean diet to a less vegetable-rich (i.e., more Western) diet in these populations (92). The results also suggest that the need for effective initiatives to promote vegetable intake and the potential to benefit from these varies between countries, and that Mediterranean regions may require particular support in improving the quality of children's diets.

The second key aim of this study was to identify the environmental, parenting, and individual child measures associated with children's vegetable consumption levels and to establish whether the influencing variables are the same or different across populations. To this end, we collected several questionnaire measures designed to assess factors that have previously been shown to play a role in children's healthy eating. We then conducted correlational analyses followed by linear regression to identify the variables that made a significant contribution to models of vegetable intake. Follow-up analyses allowed us to establish which predictors were common across the groups and which were unique to a specific population.

The analyses implicated individual child factors as significant drivers of the vegetable intake of the preschoolers in our study. The Food Fussiness subscale of the Child Eating Behaviour Questionnaire (87) was collected for all the participants, and food fussiness was found to be negatively correlated with both the quantity and the variety of vegetables consumed in all three countries. These findings corroborate previous reports that food fussiness is an important determinant of dietary quality during the preschool years (56–59). Food fussiness peaks between 18 and 58 months of age (57), exactly the age range of children in our study, and has been shown to impact children's willingness to consume new and familiar foods including vegetables (56–59). Despite the differing levels of vegetable intake (and variety of intake) between the children in each country, food fussiness levels were similar across the groups, corroborating the universality of fussy eating behaviour in children of this age. While food fussiness was negatively associated with vegetable intake in all three groups, it was a unique predictor of vegetable intake in the UK and Poland, where the magnitude of its impact was similar. Food fussiness was not a significant unique predictor of intake in the Italian sample, which may reflect the lack of power in the regression analysis due to the smaller size of this group; the fact that the correlation coefficient for the Italian participants was very similar to the correlation coefficient for the UK sample supports this suggestion. Failure to detect food fussiness as a significant unique predictor of vegetable intake in the Italian sample might alternatively (or additionally) reflect the important role played by other individual child factors in predicting vegetable intake (e.g., child temperament) and the variance these measures shared with food fussiness.

The Temperament subscale of the Emotional Activity Scale (EAS-T) (88) was administered in both the UK and Italy, with differences between the two groups identified on several subscales. Compared to the children in the UK, Italian children were reported to show higher emotionality, reflecting the quality and intensity of their emotional reactions, and higher sociability, indicating the extent to which children seek out and are gratified by social reward. Previous research has suggested that children with more emotional temperaments are more likely to show food avoidant behaviours (66), and that lack of sociability or 'shyness' is associated with feeding difficulties and being less willing to try new foods (40, 67). It is, therefore, possible that the low level of vegetable consumption of the Italian children was due, in part, to the higher levels of emotionality in this group (although their greater sociability should, to some extent, counteract the negative effects of their emotionality). However, the unique sole predictor of vegetable intake for the children in Italy was the 'shyness' component of the EAS-T. The role played by this factor was specific to this group; no correlation was seen between 'shyness' and vegetable consumption in the UK sample. The 'emotionality' subcomponent of EAS-T was negatively correlated with intake in the Italian sample, but did not make a significant contribution to the model for this group; rather, it emerged as a significant negative predictor of vegetable intake in some, but not all, of the analyses involving the UK sample. It is interesting to consider why child temperament, in general, and shyness, in particular, should be related to vegetable intake in children in Italy. One possibility is that Italian parents are more sensitive to their child's temperament and more responsive to this when making decisions about how they feed their child. If that is the case, parents of shy children may need particular encouragement to include a variety of vegetables in their child's diet.

Our study also explored the role of parenting factors in predicting children's vegetable intake. The assessment of parents' goals for family mealtimes [*via* the Family Mealtime Goals questionnaire (31)] revealed a number of differences between the groups. British and Polish parents endorsed the goals of sharing food as a family, avoiding stress and conflict at mealtimes, and involving family members in meal preparation to a greater extent than the Italian parents. The reasons why Italian parents are less preoccupied with these mealtime goals deserve investigation. It is possible that the differences in parents' goals reflect differing cultural expectations in each country; for example, it might be more acceptable for families to eat separately or for family members to not be involved in preparing meals in Italy. Alternatively, and perhaps more plausibly, sharing foods, involving family members in meal preparation, and lower levels of stress during mealtimes may be the norm in Italy and, as a result, less likely to be considered goals that parents are striving to achieve.

In our study, the endorsement of the Family Mealtime Goal of 'family involvement' was positively associated with children's vegetable intake and predicted unique variance in intake in the UK sample, over and above children's food fussiness. Items contributing to this component included: "I want the whole family to help out with mealtimes," "I want to choose food that my child can help prepare," and "I want to get my child involved with things like setting the table or clearing up" (31). The importance of this component suggests that in the UK, at least, interventions that encourage and support parents to involve children in the preparation of meals and in contributing to mealtime activities might prove effective in increasing children's vegetable intake.

A second parenting measure administered in the UK and Italy explored parents' feeding styles using the Comprehensive Feeding Practices Questionnaire (86). Again, differences were seen in parents' feeding practices across countries. The parents in the UK reported modelling healthy eating behaviours for their child and using food to regulate their child's emotional state to a greater extent than the Italian parents. Modelling is a powerful influence on children's early learning about the eating environment (19, 93); positive role-modelling can shape healthy eating behaviours (94) and support children in accepting new foods (34). In contrast, using food to regulate a child's emotions is thought to be maladaptive, creating a relationship between emotions and food that can lead to overeating (95), increased BMI, and obesity (96). Why British parents adopt both more positive practices (modelling healthy eating) and more maladaptive practices (using food to regulate the child's emotions) than Italian parents is unclear. One possible explanation relates to the extent to which parents feel able to influence their child's eating behaviour. British parents may take a more 'active' approach because they believe their intervention has the potential to influence their child's food preferences, causing them to attempt to manipulate their child's eating behaviour in both positive and negative ways. In contrast, Italian parents may place more weight on factors internal to the child as determinants of what their child will eat, leading them to take a less agentive role in shaping their child's eating behaviour. This hypothesis aligns with the finding that child temperament, specifically child shyness, is the key predictor of vegetable intake in Italian children. Italian parents may, quite rightly, believe that what their child eats is primarily determined by their child's disposition, and intervene less as a result.

Interestingly, the parental feeding practices that differed between groups were not among the factors that predicted children's vegetable intake. The only component of the Comprehensive Feeding Practices Questionnaire that appeared to play a role was 'use of food as a reward,' which showed a negative relationship with vegetable consumption in both groups in which it was assessed and emerged as a significant predictor in one regression analysis involving UK children. Previous studies have shown that food rewards are counter-productive, serving only to increase the desirability of the food used as a reward (the 'treat') while decreasing liking of the food that must be eaten to receive the reward (often a healthy food such as a vegetable) (97). Although we cannot be certain that the same pattern would have been true of children in Poland (where the CFPQ was not administered), the results suggest that avoidance of this parenting style may be universally important in efforts to increase children's vegetable intake.

Further investigation is clearly needed to ascertain the basis of the cross-cultural differences our study has identified in parents' mealtime goals and feeding behaviours and to better understand how child temperament interacts with parents' feeding style and mealtime goals to determine healthy eating. A mixed methods approach would be most revealing in this endeavour. Highly powered quantitative studies that allow for interactions between parent and child factors to be included in regression models would help to unpick the weighting of these in determining children's dietary quality. At the same time, qualitative approaches are more likely to provide an in-depth understanding of the differences in parents' experiences of and approaches to feeding their families in different parts of Europe (76).

Finally, we also collected information about a range of sociodemographic characteristics to explore whether the environmental variables that have previously been linked to dietary quality and vegetable consumption levels were predictive of intake in our samples. Several variables differed between countries in our study. Specifically, the children in the Italian sample were older than those in the UK and Polish samples, fewer Polish children attended day care than the British or Italian children, and the Polish parents were more educated than those in Italy and the UK. However, none of these factors, including child age, contributed significantly to models of vegetable intake. As was discussed earlier, day care attendance was negatively associated with vegetable intake for the group overall, but this factor was not significant in either overall or by country regression analyses. Parent education (a proxy for socioeconomic status) is often found to be highly predictive of vegetable consumption (23), and it would therefore be logical to attribute the higher vegetable intake of the Polish children in our study to the higher educational levels of the parents in this group. However, while the educational level of the responding parents was associated with vegetable intake in our study, this was only true for the UK sample, and educational level was not a useful addition to any model of intake. We acknowledge, however, that the socioeconomic profile of our samples (as indexed by their education level) does not mirror the distribution of income and education in the wider populations from which they were drawn. The majority of participants in each of our groups had been university-educated, and the observed effect of parent education on child vegetable consumption was driven by differences between the reports of parents with higher degrees vs. those with bachelor's degrees. In sum, while children's vegetable intake in this study was not dependent on the background demographic characteristics of their family environment, a greater influence of the family environment might be seen among a more socioeconomically diverse group.

Limitations

An obvious limitation of this study is that only a subset of the parent and child measures collected in the UK and Italy was collected in Poland and that the two measures not collected in Poland (EAS-T and CFPQ) were optional for the participants in the UK, impacting on sample sizes across our analyses. Administration of the full set of questionnaires in Poland would have allowed us to draw stronger conclusions about the predictors of vegetable intake that this group shared with the UK and/or Italy and might have revealed factors that were uniquely associated with children's vegetable intake in Poland. Given the higher level of vegetable intake in Poland, further studies to identify the predictors of vegetable intake in Polish children would be worthwhile, as they might inform efforts to increase intake in populations where children are eating less wholesome diets.

Measures of additional variables known to influence children's eating behaviour might also have been collected, such as measures of parents' own food preferences, dietary choices, and eating behaviours, along with information about the participants in family mealtimes and the nature of the meals provided, which are likely to differ between the countries in which we collected the data. As in all studies, methodological decisions had to be made to ensure that key variables were collected while ensuring that the length of the survey was acceptable to the parents. We also note that all the measurements were reported by the parents rather than directly observed by researchers. While the validity of parent reports is sometimes called into question, a recent study by our group suggests that parents' reports are reliable in the context of children's eating behaviours (98). Parents are the primary gatekeepers of the foods young children eat and are therefore likely to be the most accurate recorders of children's diets.

Other considerations to keep in mind when interpreting our findings include whether our participants were representative of the populations from which they were drawn and whether their reports can be relied upon to draw inferences about the questions of interest. Self-selecting participants in research studies tend not to be drawn equally from all demographic groups, and our sample reflects this bias; a large proportion of the parents in our study were educated to graduate or postgraduate level and identified as White. As discussed above, some questionnaires were optional, and the self-selection of those who choose to complete voluntary components of a study can introduce further bias. In this study, we considered the value of using the data contributed by the participants to outweigh concerns about potential bias given the large number of parents who completed the optional measures. The specific topic of a research study can also encourage bias in sampling. In this study, parents might have chosen to take part because they were concerned about their child's vegetable intake or because they considered their child to be a fussy eater; this is particularly likely given that a subsequent phase of the study involved an intervention to increase children's vegetable intake. We note too that the participants in each country were recruited via different channels, depending on the approach each research team considered would best achieve the target sample size. Different approaches to reaching participants might have led to differences between the participant pools. For example, the Polish sample was primarily recruited by participation in the national *Szkołanawidelcu* (School on a Fork) project, which may have biased the sample toward parents who were particularly mindful of healthy eating. The findings might therefore have been different if we had been able to recruit participants who were fully representative of the populations from which they were drawn.

Finally, we acknowledge that causal relationships between variables cannot be claimed on the basis of the correlational approach taken in this study. Indeed, while the most obvious explanation of a predictive relationship is often assumed to be the correct one, there are often alternative accounts that should be tested before they are discounted. For example, one might assume that the negative relationship between child food fussiness and vegetable intake is explained by fussy children's reluctance to eat vegetables. However, it might alternatively reflect parents' avoidance of offering vegetables to children who are perceived to be fussy, perhaps in an attempt to avoid scenes at mealtimes. In the current study, data on the quantity of vegetables offered to children were not collected separately from measures of children's intake, making it impossible to tease these accounts apart. We anticipate that further exploration of the directionality and causes of the relationships this study has identified would reveal fruitful new avenues to supporting greater vegetable intake.

Conclusion

This study has revealed both similarities and differences between the vegetable intake of preschool children in different European countries and the factors that drive these differences. The children in Poland consumed more vegetables than the children in the UK, who in turn consumed more vegetables than the children in Italy. The latter two groups fell significantly short of the guidelines on daily intake.

In terms of the predictors of vegetable consumption, child food fussiness was a negative correlate of vegetable intake in all the groups and a significant unique predictor of intake in the UK and Poland. Whilst this finding might indicate that fussy children are refusing to eat the vegetables offered to them, it might also indicate that parents of fussy children (or of children who are perceived to be fussy) are providing them with fewer vegetables at mealtimes; indeed both may be true. It is, of course, natural for parents to cease offering a food that their child has rejected several times previously (99). Many parents cannot afford food waste, while others may wish to avoid the mealtimes scenes that can occur when a disliked food is provided. However, children cannot eat foods that are not made available to them, and the literature has shown repeated exposure to a vegetable to be a powerful tool for bringing about acceptance (100, 101). Parents of fussy children may therefore need particular encouragement to be resilient in the face of food rejection.

Other predictors were found in only one or two of the populations involved in this study. Child temperament was a unique negative predictor of vegetable intake in Italy, where child shyness was associated with lower levels of consumption. Child emotionality was also negatively related to vegetable intake in some analyses involving children in the UK. The same argument applies to these groups as for children high in food fussiness; parents of shy or more emotional children (in Italy and the UK, respectively) may particularly benefit from support with encouraging healthy eating.

In terms of parents' goals and behaviours, the results revealed higher levels of vegetable consumption in the UK among the children of parents who hold the goal of family involvement in mealtime preparation, suggesting that encouraging this strategy might be beneficial in increasing vegetable intake. The results of the analyses involving children in the UK and Italy also corroborate previous claims that using food as a reward is negatively associated with vegetable intake (97), confirming that interventions should discourage parents from this feeding behaviour.

These results highlight differences in both the extent to which European preschoolers achieve recommended levels of vegetable intake and in factors that influence whether they do. These findings imply that interventions to improve the quality of children's diets require adaptation for the country in which they are implemented based on an understanding of baseline dietary quality and the specific factors that support or hinder the acceptance of healthy foods in that population.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved in the UK by the University of Reading Research Ethics Committee, approval received 19th March 2019 (2019-018-CHP); in Italy by the Ethics Committee of the University of Turin, 2nd May 2019 (approval no. 176852); and in Poland by the Research Ethics Committee at the Faculty of Psychology, University of Warsaw, 8th April 2020. The participants provided their written informed consent to participate in this study.

Author contributions

NM carried out the data analysis and wrote the first draft of the article. CH-P led the research team in developing the research questions and drafted the final version of the manuscript. NM, KD, KH, DB, MC, GC, PM, DM, and CH-P collaborated on the design of the study. NM, KD, DB, MC, GC, KW, DP, and JB were involved in the data collection and processing. KD, KH, DB, MC, GC, PM, KW, DP, JB, and DM provided feedback on the draft of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix

Vegetables listed in vegetable food frequency questionnaires in the UK, Italy, and Poland.

UK: artichoke, asparagus, aubergine, beetroot, broccoli, broad bean, Brussels sprouts, butternut squash, cabbage, carrots, cauliflower, courgette, cucumber, green beans, lettuce, leeks, mushroom, parsnip, peas, peppers, spinach, sweet potato, sweet corn, and tomato.

Italy: artichoke, asparagus, aubergine, beetroot, broccoli, broad bean, Brussels sprouts, butternut squash, cabbage, carrots, cauliflower, courgette, cucumber, green beans, lettuce, leeks, peas, peppers, spinach, tomato, potatoes, fennel, chard, and little tomato.

Poland: artichoke, asparagus, aubergine, beetroot, broccoli, broad bean, Brussels sprouts, cabbage, carrots, cauliflower, courgette, cucumber, green beans, lettuce, leeks, mushroom, peas, peppers, spinach, sweet corn, tomato, pumpkin, parsley, turnip, radish, potatoes, and onion.

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Psychotic-like experiences in the lonely predict conspiratorial beliefs and are associated with the diet during COVID-19

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The COVID-19 pandemic has increased the occurrence of conspiracy theories. It has been suggested that a greater endorsement of these theories may be associated with psychotic-like experiences (PLEs), as well as with social isolation. In this preregistered study, we investigated whether both PLEs and measures of social isolation (e.g., loneliness) can predict conspiratorial beliefs and, if so, which of these variables can mediate the association with conspiratorial beliefs. Furthermore, based on previous studies on schizophrenia, we explored whether the diet is associated with PLEs and conspiratorial beliefs. Participants (N = 142) completed online questionnaires measuring PLEs, social isolation, mental well-being, and conspiratorial beliefs. They also submitted their daily food intake for a week using a smartphone app. We found that loneliness predicted the endorsement of conspiracy theories during the COVID-19 lockdown. Strikingly, the proneness to experience subclinical psychotic symptoms played an underlying mediating role. In addition, these subclinical symptoms were associated with lower fruit, carbohydrate, and iron intakes, as well as with higher fat intake. Our results add insights into how conspiratorial beliefs can affect individuals' mental health and relationships. Moreover, these results open the avenue for potential novel intervention strategies to optimize food intake in individuals with PLEs.

KEYWORDS

conspiratorial beliefs, psychotic-like experiences, loneliness, diet, COVID-19

Introduction

The COVID-19 pandemic has affected almost all aspects of human societal daily life. A typical psychological reaction to a highly uncertain situation such as a pandemic is the increased occurrence of conspiracy theories (1, 2). These theories are alternative explanations of important events as the results of malevolent actions (or patterns of secret causal connections) involving small powerful groups, when other explanations are more plausible (3).

During the COVID-19 pandemic, the overload of COVID-19 related information, the lack of knowledge about the disease, and the more general climate of uncertainty have given rise to conspiracy theories (4). Believing in such theories may have several detrimental effects. For example, conspiracy theories linking the 5G cellular network with COVID-19 have led to episodes of violence against telecom workers in the U.K. (5). Further, conspiratorial beliefs increase vaccine refusals (6) and decrease compliance with preventive measures such as social distancing (5). Given their impact on individuals' health and safety, it is essential to identify the factors associated with beliefs in conspiracy theories.

In view of these detrimental consequences, recent studies have found that a greater endorsement of conspiracy theories is associated with psychotic-like experiences (PLEs) (7, 8). More in detail, PLEs refer to subclinical psychotic events (e.g., subthreshold forms of paranoid delusions) experienced by healthy individuals in the general population in the absence of a clear psychotic disorder (9, 10). Studies on the general adult population have found that approximately 8% of individuals who reported PLEs will become clinically psychotic after 2 years (11), suggesting that PLEs may represent a risk factor for developing psychotic disorders.

Interestingly, paranoia and conspiracy theories seem to have in common an intuitive thinking style and the so called "jumping to conclusion" bias, which is the tendency to make quick decisions based mostly on a few pieces of evidence (8). Thus, PLEs may be an indicator of the latent liability for conspiratorial beliefs. Moreover, several studies have found links between psychotic disorders and environmental factors such as a poorer diet quality (e.g., lower intake of fruit and vegetable). Some evidence has particularly identified iron deficiency as one of the most important dietary risk factor for psychosis (12, 13). Indeed, iron deficiency due to a reduced iron intake may alter prefrontal dopaminergic transmission in the brain leading to negative symptoms in schizophrenia (12, 14). Since food is a modifiable risk factor, it may be possible that nutritional interventions may prevent the occurrence also of PLEs and consequently reduce the susceptibility to believe in conspiratorial theories. However, empirical evidence is lacking.

Besides PLEs, another factor that has been linked to conspiratorial beliefs is social isolation (7). In particular, contention measures during the COVID-19 pandemic such as lockdowns and social distancing have influenced the quantity and quality of social interactions and enormously increased feelings of loneliness (15). Loneliness refers to perceived social isolation and is associated with poorer mental health including stress (16) and PLEs (17). Interestingly, some studies showed that loneliness could continue even when the lockdowns ended (15) and that the development of mental health problems can further strengthen the magnitude of loneliness (18). Previous research on ostracism, a form of social exclusion, has suggested that one of its most important consequences is indeed conspiratorial thinking (19, 20). Thus, the social exclusion experienced during the COVID-19 lockdown could have led people to endorse conspiracy theories.

Based on the above-mentioned studies, conspiratorial beliefs may be associated with several interconnected factors including PLEs, social isolation, and a more general reduced mental well-being. However, not all individuals experiencing social isolation or having PLEs may believe in conspiracy theories. Yet, it is unknown which factors may interact with each other and play a role in making people more susceptible to believing in conspiracy theories.

In this preregistered study, we first investigated whether conspiratorial beliefs during a global health crisis, such as the COVID-19 pandemic, are associated with the proneness to present PLEs. We hypothesized that during times encompassing high loneliness and uncertainty (21), individuals who report PLEs are more susceptible to believe in conspiracy theories. Second, we examined how other pandemic-related factors such as social isolation and mental well-being may relate to conspiracy theories beliefs and PLEs. We hypothesized that all these variables may be associated with each other. If so, we will then perform separate mediation analyses to determine the possible mechanisms by which PLEs, social isolation or mental well-being may relate to the endorsement of conspiracy theories. Lastly, based on previous research on schizophrenia we will explore possible associations between diet, PLEs and conspiratorial beliefs. We postulate that people reporting low average iron intake are also more prone to show PLEs as well as to believe in conspiracy theories. To test these hypotheses, participants completed questionnaires assessing PLEs, social isolation (loneliness, social support, quantity, and quality of social interactions), mental health (e.g., stress), and conspiratorial beliefs. They also submitted their daily food intake for 7 days using a smartphone app (see **Figure 1** and section "Materials and methods").

Materials and methods

Procedure

After providing instructions, participants were invited to complete a battery of online questionnaires assessing PLEs, social isolation (loneliness, social support, quantity, and quality of social interactions), mental health (e.g., stress), and conspiratorial beliefs see **Figure 1**. Written informed consent was obtained from each participant. Data were collected between 29 January and 8 February 2021) at which time there was a strict lockdown in Germany and Austria.

We also previously collected (10 November–23 December 2020) from the same participants, as a part of a larger study

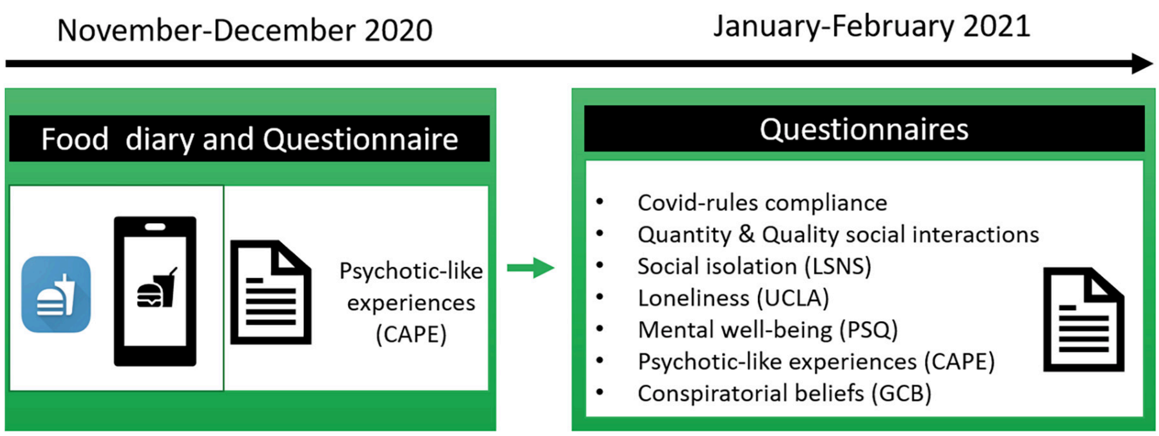

FIGURE 1
Study outline. Participants first answered a questionnaire assessing psychotic-like experiences (PLEs) and completed a daily food diary for 7 days *via* a smartphone app. Subsequently, they completed questionnaires measuring social isolation, conspiratorial beliefs, mental well-being, PLEs, demographics among others.

(preregistered under),[1] a daily diary of their food consumption. In particular, participants were asked to install a food-diary app provided by us on their smartphone, and submit their daily intake of food items and beverages in the app, from which we extracted the total calories, and the macro- and micronutrients per meal per day (22) (see **Figure 1**).

Participants

An initial sample of 147 participants took part in the study. Participants recruitment was completely online *via* Prolific,[2] including invitations and data collection. Inclusion criteria were: (1) residing in Germany or Austria, (2) being fluent in German, and (3) no personal history of psychiatric illness.

Five participants were excluded from the analyses, as they were not residing in Germany or Austria. Thus, the final sample included 142 participants (see **Table 1** for demographics). All subjects were paid £3.50 for their participation. The Humbold Ethics Committee approved the study, which was conducted in accordance with the Declaration of Helsinki.

Questionnaires

Psychotic-like experiences

The Community Assessment of Psychic Experience (CAPE) is a 42-item questionnaire that measures self-reported subclinical psychotic symptoms in the general population based on three dimensions: positive symptoms, negative symptoms, and depression (23, 24). Several studies have shown that the CAPE can be a screening tool to identify people who might be at risk for psychosis (9, 10, 25).

Conspiratorial beliefs

The Generic Conspiracist Beliefs Scale (GCB) (26) includes 15 questions relating to different conspiracy theories and asks respondent how much they agree with each given statement on a five-point scale. This scale has a total score ranging from 15 to 75, with higher scores reflecting higher levels of conspiracy beliefs. The GCB is one of the most largely used measure of beliefs in conspiracy theories (27) and comprises distinct but related factors such as Government Malfeasance, Extraterrestrial Cover-up, Malevolent Global Conspiracies, Personal Wellbeing, and Control of Information (27, 28).

Mental well-being

The Perceived Stress Questionnaire (PSQ-20) is a psychological instrument measuring subjective experiences of perceived stress (29, 30), which has been considered as a predictor of health and well-being (31).

Social isolation

We used two different questions assessing participants' quantity and quality of social interactions. The first question was: "How many social interactions, on average, did you have in the past week?." Social interactions could be face-to-face, *via* telephone or online. The second question was: "On average, how satisfied are you with the social interactions of the past week?." For both questions participants were asked to report a number from 1 (not at all) to 100 (very). Further, we used the Lubben Social Network Scale (LSNS-6) (32), a six-item self-report questionnaire assessing perceived social support received

1 https://osf.io/nqhjf
2 https://www.prolific.co/

by friends and family. Lastly, the 20-item UCLA scale was employed to measure participants' feeling of loneliness (33).

Food diary *via* FoodApp

Participants could input using a smartphone FoodApp when they had a meal (date and time), the type of meal (e.g., lunch, dinner snack), food item, and quantity (in grams or milliliters). They were asked to complete the daily food diary for 7 consecutive days (34). The output allowed us to compute two main variables: caloric content and information on micro- and macronutrients of the consumed food using the German Federal Food Key data table (Bundeslebensmittelschlüssel; Dehne et al. (35)). We calculated energy intake adjusted values (g/1,000 kcal/day) to account for an individuals' total energy intake (36). Furthermore, we extracted daily energy derived from each macronutrient. In particular, the daily intake of carbohydrates (g/day) was multiplied by 4 kcal, while fat intake by 9 kcal (22). Lastly, tyrosine and tryptophan to large neutral amino acids (LNAA) ratios were calculated by dividing the quantity of tyrosine and of tryptophan by the sum of the other LNAAs (22, 37, 38).

Statistical analyses

The analysis plan was preregistered on the public data repository Open Science Framework.[3] The data was analyzed using R statistical software (R Core Team). Mediation analyses were performed using JASP (version 0.14.1.0). The Shapiro–Wilk test was undertaken to demonstrate that data were normally distributed.

Spearman correlations were performed to test possible associations between each of the variables among social isolation (UCLA, Lubben Scale, self-report measures of quantity, and quality of social interactions), PLEs (CAPE), mental well-being (PSQ-20), and beliefs in conspiracy theories (GCB). Correlations were corrected for multiple comparisons separately for each results section using the Bonferroni method. A mediation analysis was performed to assess if the variable social isolation was mediating the relationship between PLEs and the dependent variable beliefs in conspiracy beliefs. A further mediation analysis was performed using PLEs as a mediator in the relationship between social isolation and conspiracy beliefs. Bootstrapping (1,000 samples) was performed as implemented in the "lavaan" package (39) in JASP.

A Wilcoxon signed-rank test was performed to examine within-group differences in CAPE scores between two different time-points (10 November–23 December 2020 vs. 29 January–8 February 2021). Spearman correlations were performed to test associations between participants' CAPE scores and GCB scores with their daily food intake ratings.

3 https://osf.io/y36q9

TABLE 1 Sociodemographic variables and questionnaires data.

	***N* = 142**
Demographics	
Age	29.04 (8.74); 18.00–68.00
Gender (female)	57
Education (years)	14.79 (2.14); 11.00–17.00
BMI	23.86 (4.35); 14.69–41.97
Living situation	
COVID-rules compliance (0–100)	82.47 (22.07); 0.00–100.00
Psychotic-like Experiences	
CAPE-positive	2.60 (0.53); 2.05–5.65
CAPE-negative	3.93 (0.94); 2.14–6.64
CAPE-depressive	3.87 (0.91); 2.00–6.25
CAPE-total score	10.40 (2.00); 6.64–17.70
Mental well-being	
PSQ	42.60 (1.48); 3.33–90.00
Social isolation	
Quantity social interactions (0–100)	46.23 (28.33); 0.00–100.00
Quality social interactions (0–100)	65.51 (25.37); 0.00–100.00
LSNS	13.77 (4.14); 3.00–24.00
UCLA	44.98 (14.44); 21.00–88.00
Conspiracy beliefs	
GCB	26.62 (10.78); 15.00–72.00

Mean (SD); range. CAPE, community assessment of psychic experiences; PSQ, perceived stress questionnaire; LSNS, Lubben Social Network Scale; UCLA, University of California Los Angeles loneliness scale; GCB, generic conspiracist beliefs scale.

Results

An initial sample of 147 participants signed up *via* Prolific. Five participants were excluded from the analyses, as they were not residing in Germany or Austria (see the section "Materials and methods"). Thus, analyses on questionnaire data were performed on the resulting 142 participants (see **Table 1** for descriptive statistics). Of those participants, a total of 126 completed their food intake for at least 3 days using the food-diary app. Hence, analysis including food measures was conducted on these 126 participants.

Psychotic-like experiences and conspiratorial beliefs

We first preregistered to test whether PLEs are associated with conspiratorial beliefs. To do so, we performed a Spearman correlation between the CAPE-total score and the GCB score. Results showed a significant positive correlation between the two questionnaires (rho = 0.28; $p < 0.001$). Thus, the more participants presented PLEs the more they tended to believe in conspiracy theories (see **Figure 2A**). Further, we assessed which of the three CAPE subscales (positive, negative, and depressive) was correlating with GCB scores. We found that both CAPE-positive (rho = 0.45; $p < 0.001$) and negative (rho = 0.25; p = 0.008) subscales positively correlated with GCB scores, while CAPE-depressive did not (rho = 0.15; p = 0.231). P-values are Bonferroni corrected. These results support a relationship between PLEs (and their positive and negative dimensions) and conspiratorial beliefs.

Loneliness, psychotic-like experiences, and their influence on conspiratorial beliefs

So far, we showed that PLEs are associated with conspiratorial beliefs. Next, we aimed to investigate whether perceived social isolation in a period of social restrictions is associated with conspiratorial beliefs and PLEs.

Hence, we performed different Spearman correlations between the total scores of questionnaires assessing loneliness (UCLA), social support (LSNS), and self-report measures of quantity and quality of social interactions with GCB scores. Results showed a significant positive correlation only between UCLA and GCB (rho = 0.28; p = 0.004). No other significant correlations emerged (all p's > 0.38) see **Supplementary Table 1**. Similarly, UCLA was the only measure of social isolation among others also correlating with CAPE-total scores (rho = 0.37; $p < 0.001$) (all p's > 0.69) see **Supplementary Table 1**.

Overall, these results suggest positive associations between loneliness (regardless of the amount of social interaction and/or social support the participants received), PLEs, and conspiratorial beliefs. These results persisted even when controlling for demographics such as gender and the level of education. More in details, GCB and CAPE total score are still significantly positively associated (rho = 0.272; p = 0.002), as well as UCLA and GCB (rho = 0.255; $p < 0.003$), and UCLA and CAPE total score (rho = 0.341; $p < 0.001$). To better understand how loneliness and PLEs relate to conspiratorial beliefs, we preregistered to explore different mediation analyses (see the section "Materials and methods"). More in detail, we first tested whether UCLA could mediate (mediating variable) the relationship between CAPE (predictor variable) and GCB (dependent variable). Results from this analysis showed that UCLA did not mediate the effect of CAPE on GCB [bootstrapped indirect effect ($a*b$) B = 0.26, SE = 0.20, Z = 1.31, p = 0.189]. The result of this mediation model persisted even when controlling for demographic variables such as gender and level of education [bootstrapped indirect effect ($a*b$) B = 0.24, SE = 0.20, Z = 1.21, p = 0.23]. Next, a second mediation analysis was performed using CAPE as a mediator in the relationship between UCLA (predictor variable) and GCB (dependent variable). Results showed that CAPE fully mediated the effect of UCLA on GCB [bootstrapped indirect effect ($a*b$) B = 0.08, SE = 0.03, Z = 2.57, p = 0.012; see **Figure 2B**], meaning that the more participants felt lonely, the more they believed in conspiracy theories, but this was dependent on their propensity to have PLEs. This mediation model persisted when controlling for demographics such as gender and level of education [bootstrapped indirect effect ($a*b$) B = 0.08, SE = 0.03, Z = 2.58, p = 0.010].

Perceived stress is not related to conspiratorial beliefs

Next, we examined if also another factor related to health and well-being such as perceived-stress (PSQ-20) is associated with different levels of conspiratorial beliefs. Correlations were performed using both PSQ-20 total scores and PSQ-20 subscales scores (worries, joy, tension, and demands). A Spearman correlation between PSQ-20 and GCB scores did not reveal a significant result (rho = 0.15; p = 0.380). No significant results emerged also between PSQ-20 subscales and GCB (all p's > 0.22) see **Supplementary Table 2**. These results suggest that conspiratorial beliefs are specifically associated with PLEs and loneliness but not with a more general subjective well-being or distress.

Exploratory analyses

Since a large body of literature has shown an association between dietary intake and the severity of psychotic symptoms in patients with schizophrenia (40), we preregistered to explore whether diet also relates to PLEs in healthy individuals. In particular, we focus on large amino acids such as tyrosine, tryptophan, as well as on iron intake levels since they all have been reported to be involved in the dopaminergic and serotoninergic transmission in the brain and in the pathophysiology of psychosis (12, 37, 40). Based on previous studies on schizophrenia (40), we also examined whether food intake indexed by certain nutrient compositions (e.g., carbs, fat, fruit, and vegetables) is associated with CAPE. More in details, high total intake of fruit and vegetables has been associated with better mental health (22, 41, 42). In line with this evidence, several studies reported a negative association between dietary intake of fruits and vegetables and the presence of psychosis (40, 41, 43–45). Furthermore, studies on stress in animals and humans have found that stress can modify the diet by preferring high-fat and high-carb foods (46, 47). Importantly, psychological stress is often comorbid with schizophrenia (48, 49) and correlates positively with PLEs (50). Regarding the dopaminergic precursor tyrosine and the serotoninergic precursor tryptophan, studies have reported their crucial role in motivation and mood, respectively. For example, it has been shown that acute tyrosine and tryptophan depletions can reduce motivation for reward and lower mood

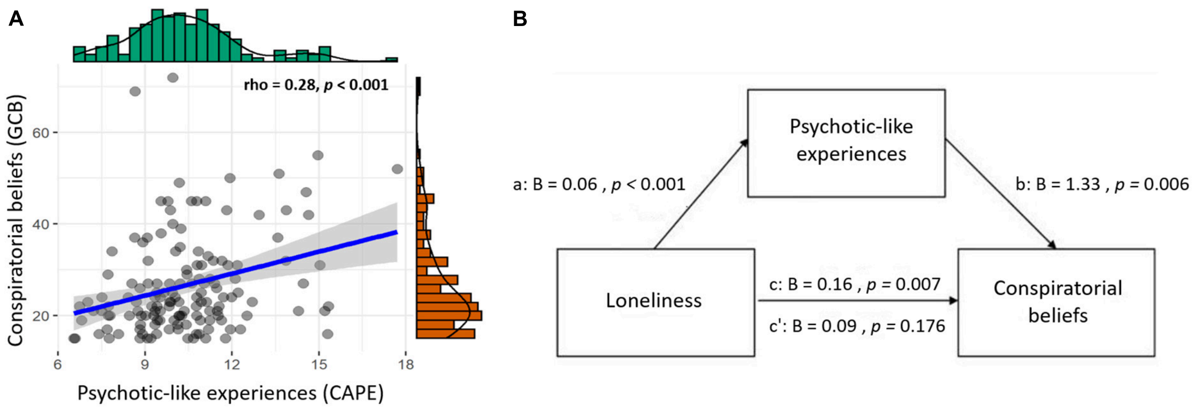

FIGURE 2
Associations between loneliness, psychotic-like experiences (PLEs) and conspiratorial beliefs. **(A)** Significant positive correlation between conspiratorial beliefs and PLEs (rho = 0.28, $p < 0.001$); **(B)** Mediation model with loneliness as predictor and PLEs as mediator predicting conspiratorial beliefs. Betas are unstandardized, total effect (c), direct path (c').

(22, 37, 51, 52). Simultaneously, dopamine and serotonin play an important role in psychosis (53, 54). Based on these results, dietary tyrosine and tryptophan intake levels may be associated with different levels of PLEs. Spearman correlations showed that CAPE scores were not associated with estimated Tyrosine/LNAA, Phenylalanine/LNAA, and Tryptophan/LNAA intakes (all p's > 0.73) see Supplementary Table 3. Interestingly, CAPE scores negatively correlated with fruit ($rho = -0.31$; $p = 0.002$) and carbohydrate ($rho = -0.26$; $p = 0.013$) intakes, and positively correlated with fat intake ($rho = 0.22$; $p = 0.045$) see Figure 3. No significant associations were found between CAPE scores and vegetable intake ($rho = 0.00$; $p = 1$) see Supplementary Table 4. Lastly, CAPE scores negatively correlated with iron intake ($rho = -0.25$; $p = 0.004$) (see Figure 3). Further decomposing this correlation, by performing separate correlations between the different CAPE subscales (positive, negative, and depressive) and iron intake, showed that lower CAPE-negative symptoms were associated with reduced iron intake ($rho = -0.28$; $p = 0.005$) (see Figure 3D). No significant correlations emerged with the CAPE-positive ($rho = -0.17$; $p = 0.171$) and the CAPE-depressive ($rho = -0.14$; $p = 0.374$) subscales (see Supplementary Table 5). These results suggest that the negative dimension of PLEs in healthy individuals is associated with lower iron intake. Strikingly, these results are in line with studies on patients with chronic psychotic disorders (12, 40). Lastly, no significant associations emerged between GCB and food intake (all p's > 0.38) see Supplementary Tables 6–8.

Note that food intake measures and CAPE scores used in these analyses were collected during time-point one (10 November–23 December 2020), while all the other questionnaire measures were collected during time-point two (29 January–8 February 2021) (see Figure 1). Since the same participants were asked to fill out the CAPE questionnaire during both time-points, a Wilcoxon signed-rank test was performed to assess whether their levels of PLEs changed over time. Results showed no differences in CAPE scores between the two time-points (time-point one $M = 10.51$, $SD = \pm 1.84$; timepoint two $M = 10.40$, $SD = \pm 0.91$; $V_{Wilcoxon} = 4490$, $p = 0.306$). Since we did not exclude participants outside of the normal BMI range, we tested through correlations and mediation analyses whether this variability may (or may not) impact our results. These analyses seem to suggest that the variability of participants' BMI did not impact our results (see Supplementary materials).

Discussion

This preregistered study investigated whether PLEs are associated with conspiratorial beliefs during the lockdown in a global health crisis. As an emerging field of research (3), only a few studies have investigated the possible relationship between conspiratorial beliefs and PLEs (7, 55, 56). We were also interested in other pandemic-related factors such as social isolation as a possible contributor to conspiratorial beliefs since social restriction measures were so prominent during lockdowns. Therefore, we assessed whether both PLEs and social isolation can predict conspiratorial beliefs and, if so, which of these variables can mediate the association with conspiratorial beliefs. Furthermore, based on previous studies on schizophrenia, we explored whether the diet is associated with PLEs and conspiratorial beliefs.

We hypothesized that PLEs are associated with conspiratorial beliefs. Similarly, we hypothesized that also other pandemic-related factors such as social isolation and mental well-being are associated with conspiratorial beliefs. Lastly, we hypothesized that PLEs, social isolation and mental

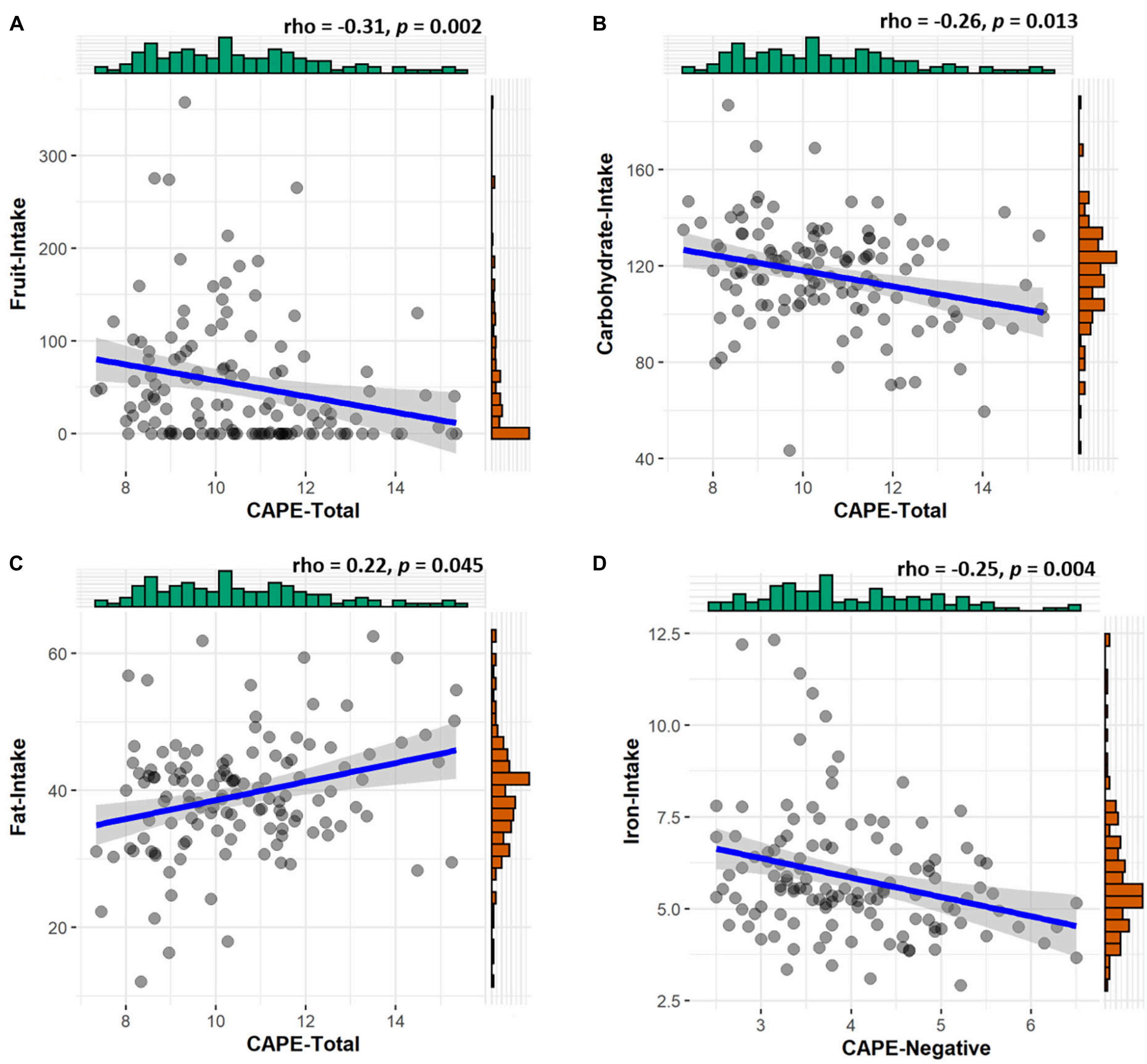

FIGURE 3
Associations between psychotic-like experiences (PLEs) and food intake. PLEs negatively correlate with **(A)** fruit (rho = −0.31, *p* = 0.002), **(B)** carbohydrate (rho = −0.26, *p* = 0.013), and **(D)** iron (rho = −0.25, *p* = 0.004) intakes. They also positively correlate with **(C)** fat intake (rho = 0.22, *p* = 0.045).

well-being could all be associated with each other and predict conspiratorial beliefs. If so, we tested through different mediation analyses whether one of these variables can mediate the contribution of the other in predicting the endorsement of conspiracy beliefs.

In line with our hypothesis, results show that PLEs are positively associated with conspiratorial beliefs, meaning that the higher the participants' levels of PLEs the more they reported to endorse conspiratorial beliefs. This result provides an extension of previous research, showing an association between a subcomponent of PLEs such as paranoia and the endorsement of conspiracy theories (2, 7). It has been argued that similar to individuals with high levels of PLEs, those supporting conspiratorial beliefs tend to collect less information to make decisions (jumping to conclusion bias). Therefore, both PLEs and conspiratorial thinking may have in common a more intuitive thinking style (2). In line with this observation, studies have found negative associations between analytic thinking and the endorsement of conspiratorial beliefs (57, 58). Interestingly, we found that not only the positive dimension of PLEs (e.g., paranoia) but also its negative dimension (e.g., avolition or lack of motivation) is associated with conspiratorial beliefs. This association was not found with the depression dimension (e.g., affective component) of PLEs. Overall, these findings suggest that not all subdimensions of PLEs are associated with conspiratorial beliefs and that both the positive (possibly through cognitive processes such as the jump to conclusion bias) and negative (reduced motivation) dimensions of PLEs may contribute to believing in conspiracy theories. In line with these findings, a study by Ståhl and colleagues (59) proposed that skepticism toward conspiratorial beliefs requires sufficient cognitive and motivational abilities, which are both altered in individuals with high levels of PLEs (9, 59, 60).

Another important result that emerged from our study is the role of loneliness in the endorsement of conspiracy theories. During the COVID-19-pandemic, social distancing restrictions led some people to experience greater social isolation and mental health illnesses (61). It is currently unknown what role social isolation plays in the dynamic between PLEs and conspiratorial beliefs in the context of the pandemic. Interestingly, loneliness positively predicted both PLEs and conspiratorial beliefs. However, this association was not found with other measures of social isolation such as social support and measures of quantity and quality of social interactions. Therefore, although studies showed that these measures of social isolation are highly correlated (62), our results suggest that only the subjective feeling of a lack of satisfactory interpersonal relationships (and not the objective amount of social support) is related to PLEs and conspiratorial beliefs during difficult times such as the COVID-19 pandemic. Similar associations between loneliness, PLEs, and conspiratorial beliefs were found in a previous study (7). The authors argued that the increased feelings of loneliness may have led people more susceptible to hear voices or perceive humanlike agency also in non-human stimuli (63), eventually influencing their association with conspiratorial beliefs (7). Our mediation analysis could confirm this hypothesis by showing that the proneness to show PLEs fully mediated the relationship between loneliness and conspiratorial beliefs. That is, the experience of loneliness during the COVID-19 pandemic enhances the proneness to experience psychotic events that increases the endorsement of conspiracy theories.

Besides social isolation and PLEs, the lockdown also resulted in diet changes (64). Research shows that a healthy diet helps to protect mental health (65). However, no studies have investigated the link between diet, PLEs and conspiratorial beliefs during challenging, and stressful times. We explored whether food intake, and in particular iron intake levels, may be associated with PLEs and conspiratorial beliefs. We found that food intake was not associated with conspiratorial beliefs. However, in line with studies on patients with schizophrenia, we found a significant association between food intake and PLEs levels. More in detail, PLEs were negatively associated with fruit, carbohydrate, and iron intakes, and positively with fat intake. In line with our findings, some studies have reported improved symptoms or decreased incidence/risk of schizophrenia with higher dietary fruit intake (40), possibly due to the antioxidant and anti-inflammatory activity of a diet rich in fruits (66). Differently, the association between psychosis and total dietary carbohydrates and fat intakes is unclear, with some studies showing a positive association (67, 68), while others a negative association or no association (40). In addition, it has been reported that altered iron homeostasis is implicated in neuropsychiatric disorders (69). In particular, iron reductions can result in changes in dopamine neurotransmission and altered neurodevelopment (70). Indeed, prospective studies have shown a significant relationship between maternal iron deficiency and the risk of schizophrenia in offspring (71, 72). Interestingly, first-episode schizophrenia individuals with high levels of negative symptoms showed lower levels of blood iron compared to healthy controls (12). Similarly, a magnetic resonance imaging (MRI) study found a decreased iron concentration in gray matter nuclei including the bilateral substantia nigra in first-episode schizophrenia individuals compared to healthy controls (14). In line with these results, we found that higher levels of PLEs (in particular, the negative domain of PLEs) are associated with a reduced average daily iron intake. Overall, our findings suggest a possible link between reduced iron intake and PLEs, possibly influencing dopaminergic neurotransmission in the brain and therefore accounting for these subclinical symptoms in the general population.

Some limitations of the current study should be addressed. First, loneliness, conspiratorial beliefs and food intake were only measured once, therefore we cannot assess within-person changes over time. Second, conspiratorial beliefs and food intake were not time-locked. Third, our findings are correlational, and we cannot make causal arguments. Fourth, our measures were based on self-reports, which may have lower reliability and validity.

Conclusion

In conclusion, loneliness predicted the endorsement of conspiracy theories during the COVID-19 lockdown. Strikingly, the proneness to experience subclinical psychotic symptoms played an underlying mediating role. In addition, these subclinical symptoms were associated with lower fruit, carbohydrate, and iron intakes, as well as with higher fat intake. Our results contribute to the study of beliefs in conspiracy theory and add insights into how they can affect individuals' mental health and relationships. Moreover, these results open the avenue for potential novel intervention strategies to manage and optimize food intake in individuals with PLEs. In future research, experimental designs should be used to test the possible causal effects shown in this study.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by The Humbold Ethics Committee approved the study. The patients/participants provided their written informed consent to participate in this study.

Author contributions

DT and SP: conceptualization and project administration. DT: investigation, writing – original draft preparation, and visualization. DT, AL, and SP: methodology. DT, A-KM, and AL: formal analysis. A-KM, AL, DT, and SP: writing – review and editing. SP: supervision and funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.1006043/full#supplementary-material

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Hedonic response sensitivity to variations in the evaluation task and culinary preparation in a natural consumption context

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Hedonic measurements in the frame of consumer tests of foods are prone to many different biases and the validity of test designs has been subject to much research with special emphasis on the role of context. While bringing elements of natural consumption context to the testing conditions is generally seen as an improvement, other aspects of the test design such as the task format have received little attention. In particular, the influence of analytical questions on hedonic responses has been studied in standardized contexts only. This study aimed to assess whether synthetic and analytical evaluation tasks result in different hedonic responses when the test is conducted in a natural consumption context. Bread and pizzas with different degrees of culinary preparation (homemade, readymade, and a combination of the two) were tested on three separate days in a university cafeteria. Overall liking scores of the bread and the three different pizzas were obtained either with a synthetic (hedonic question only) or with an analytical task (hedonic question plus intensity attributes). Care was taken to avoid any other changes to normal eating conditions, notably by recruiting on the spot only those customers who had spontaneously chosen pizza as part of their lunch. Liking scores of the homemade pizza were lower with the analytical task while the scores of the other two pizzas did not change significantly. Moreover, different rankings of the pizzas were obtained when the data were analyzed separately for each evaluation task format. The synthetic evaluation task would have led to the conclusion that the homemade pizza was the best liked and the readymade being the least liked, while the analytical evaluation task would have led to the conclusion that the "mixed" pizza would be liked significantly more than the other two. The effect of the task format (i.e., lower scores with the analytical task) was more pronounced when participants reported they had spent more time in the queue. These results strengthen the view that the task is part of the evaluation context and must be carefully considered when one wishes to design ecologically valid consumer tests.

KEYWORDS
hedonic response, consumer evaluation, food testing, synthetic task, analytical task, multicomponent food, culinary preparation

Introduction

Consumers' hedonic responses to foods and to other goods are commonly measured with rating scales in fields as diverse as sensory and consumer science, nutrition, and marketing. However, the context in which a study is conducted has been shown to potentially affect its outcome (1–4). Factors like physical location, social facilitation or availability of food options are suggested to explain why context may lead to different results (5).

In addition to these factors, test procedures and evaluation tasks may also contribute to differences in the outcome of hedonic tests. This type of context effects is referred to as *framing effects*, defined as the fact that the response to a question is linked to the way it is formulated (6). Framing effects have been attributed to the duality of cognitive processes that lead to judgment formation (7): an individual will rely either only on intuition (or, in the words of Kahneman: *system 1*) or on both intuition and reasoning (*system 2*) depending on the way the task involved in that judgment is framed.

Regarding food-related judgments, Köster (8, 9)suggested that differences in the way the evaluation task is formulated could induce varying levels of cognitive access to the attributes of the evaluated product. Indeed, the simple act of asking "Do you like this product?" or "Rate the flavor intensity of this product" is likely to induce reasoning, leading test participants to adopt a more analytical mindset than in a regular and more natural consumption situation where consumers may not explicitly ask themselves such questions (8–10). This issue has sparked interest, and several studies have investigated task-related variations in hedonic responses and found differences depending on the number of questions (11), the order in which they are asked (12), or the way they are formulated (13). In other studies, however, the question format did not appear to alter hedonic responses (14–16).

Common tasks for hedonic evaluation procedures typically require consumers either to make global judgments (*synthetic* evaluation task) or to rate successively several sensory attributes in addition to the overall liking score (*analytical* evaluation task). The choice of one task rather than another may impact the judgment-making processes involved in the hedonic evaluation. For example, Prescott et al. (17) compared the hedonic responses obtained either with synthetic or analytical evaluation of a tea drink. They found that mean liking scores were significantly higher when using a synthetic evaluation task than when using an analytical evaluation task. The authors argued that asking several questions to consumers such as rating sensory attributes may induce an analytical mind-set that undermines consumers' ability to engage the synthetic attentional approach that underlies hedonic responding. Consumers are thereby forced to resort to reasoning and to focus their attention on specific product characteristics, hence modulating their hedonic responses, while synthetic tasks may principally trigger intuitive judgment.

It is worth noting that Prescott et al. (17) results were observed in controlled testing conditions, where consumers' attention may be more focused on the task. It is not known whether such effects would be similar in natural consumption situations, where the attentional focus on both the task and on products' characteristics may differ due to the multitude of sensory stimuli surrounded the individual and the conditions involved [high cognitive load (18), level of hunger (19) or time constraints (20)]. In fact, most studies on the effect of the task format on hedonic responses were conducted in standardized environments, such as sensory labs or central testing rooms.

Yet, a recent study conducted by Zandstra et al. (21) investigated those effects on liking and Just-About-Right scores for four tomato soups in controlled, immersive and natural consumption situations. It showed no differences between the three contexts. However, despite efforts to make the physical context natural, participants in the dining out situation could not choose their food and sat with other participants that they did not know. Thus, the evaluation task could still be deemed somewhat artificial. In addition to this, the study was conducted according to a within-subject design (meaning that participants repeated the task in the three contexts), which may have also entailed the ecological validity of the natural consumption setting. Therefore, from that study, it seems difficult to draw conclusions on the role of evaluation tasks on hedonic responses in natural consumption situations.

As an attempt to shed light on this issue, we conducted a field study involving either a synthetic or an analytical evaluation task in a university restaurant in France. In order to keep the eating situation as natural as possible, we designed the study to survey regular customers without pre-recruitment. They paid for their meal; they were left completely free to choose their food, and to interact with others as they normally do when dining in the restaurant.

Following a protocol similar to that of Prescott et al. (17), we examined consumers' hedonic responses for food products using either a synthetic (overall liking) or an analytical questionnaire (overall liking plus attributes intensity scale). Secondly, previous studies having shown that context effects could depend on the product category (22), we studied the potential effect of the evaluation task on two product types (pizza and bread). These two products are normally served in that restaurant and are thus expected to be very familiar to customers. In order to assess how the evaluation task would possibly affect the differentiation between variants of the same product, we chose to test three variants of the pizza that is normally served and that was thus considered as a reference product. These variants underwent different culinary preparation and were served on separate days to simplify our logistics and avoid any confusion. However, knowing that contextual fluctuations are inevitable when conducting a field study, both versions of the questionnaire were tested each day according to a between-subject design. Besides, we monitored how consumers perceived their overall lunch experience to account for potential differences from 1 day to another. By contrast, to serve as a control point, we tested only one type of bread throughout the study.

Following Prescott et al. (17) findings, we hypothesized that the synthetic task would lead to higher hedonic scores than the analytical task. Furthermore, other studies having shown that more natural evaluation conditions could lead to higher hedonic discrimination between evaluated products (22, 23), we expected the synthetic evaluation task–deemed more natural–to potentially lead to larger differences in hedonic scores between the pizza variants.

TABLE 1 Description of the main differences among the three versions of pizza.

Versions of pizza	Homemade	Mixed	Readymade
Dough	Homemade (Prepared by the chef)	Readymade	Readymade
Tomato sauce	Homemade (Prepared by the chef)	Homemade (Prepared by the chef)	Readymade

Materials and methods

Participants

The research was conducted at the staff and student cafeteria of the Ecole Centrale of Lyon, France (a higher education institute with no major related to food science nor to consumer science). Four hundred and seventy three participants (24 ± 8 years old, 74% men) took part in the study. Participants were randomly assigned to different type of task questionnaire at their lunchtime. Participants were informed that their responses would be confidential, and voluntarily agreed to take part.

Products

Two different products were evaluated: *Margherita* pizza and bread. *Margherita* pizza was selected because it is a standard dish usually well appreciated by the cafeteria customers. It is a multicomponent food that can undergo multiple modifications in terms of culinary preparation without altering its visual appearance. Moreover, the food service company running the cafeteria was also interested in their customers' opinion on pizzas in the view of improving their offer.

Three versions of pizzas, with varying degrees of culinary preparation, were served, respectively, on 3 separate days, 1 week apart, to avoid any confusion in the preparation and potential comparison bias. The *Margherita* pizza normally served at the university restaurant is made with ready-made dough, while the tomato sauce and toppings are prepared by the chef. It is thus referred to as the "mixed" pizza. The two other variants were either entirely prepared by the chef (and referred to as "homemade"), or entirely readymade. These changes to the culinary preparation were not communicated to the customers and the denominations (homemade, readymade, and mixed) are only used here for clarity. Table 1 summarizes the differences between the three versions of pizza.

Individual pizzas were of 300 ± 5 g (individual portion size). Each type of pizza was prepared and served in different days but following the same procedure. The homemade dough and tomato sauce were prepared a day before the service. From the homemade dough (flour, yeast, water, salt), balls of 160 g were cut to follow the same size of the readymade dough (*Mademoiselle Desserts St Renan, France*) and they were kept at 4°C in the fridge. For the tomato sauce, ingredients were mixed the day before (tomato, oregano, basil, pepper, olive oil) and they were also kept at storage at 4°C. The day of the study, all preparations started at 6.30 am. The oven was turned on at 350°C and set at speed of 2.5. Both types of dough (a homemade dough for the homemade pizza and a readymade dough for the mixed pizza) were kneaded by using a pizza dough "paver" and then placed on dishes where the tomato sauce, cheese and olives were added. The readymade pizza (*Marie surgelés*, France) followed the same last step of the protocol where the cheese and olives were added. The pizzas were cooked in the oven and stored in a refrigerator (4°C) until the cafeteria was opened. Once the service started (11.30 am), the pizzas were re-heated in the oven at 350°C and at speed 2 on demand.

Bread is a popular and familiar staple food which is served every day at the cafeteria and consumed by a majority of customers. Contrary to the pizza, the type, recipe, and quality of bread was kept constant all along the study. It was served in 30 g individual portions ("mini-baguettes"). It was thus selected to serve as a reference product for evaluation across study days.

Pizza and bread were available as part of the menu during the 3 days of study. However, the bread was only evaluated during the first 2 days.

Procedure

Evaluations took place at the staff and student cafeteria of the Ecole Central of Lyon, France. Each evaluation was performed with a week apart and both versions of the questionnaire (synthetic or analytic) were handed out each testing day in a counterbalanced number. No information was given about the different versions of the pizza nor about the products concerned by the study and the cafeteria operated as usual without any change introduced. Participants arrived for lunch at the cafeteria from 11:30 to 14:00. Customers create their own fixed-price meal by choosing among three or four starters, four main dishes (pizza being one of them) and several desserts. Food items are presented on separate stands where customers help themselves (Figure 1). Once at the checkout counter, we spotted participants who had added to their trays the products that we were interested in, and we asked them whether they wanted to participate in the study, and if they could fill out a questionnaire. They were randomly given either a synthetic or an analytical version of the questionnaire. We told them to fill it while eating and to return it before leaving the cafeteria. Table 2 shows the design of the experiment regarding the tested products and their respective culinary modification and the evaluation task.

Following the protocol of Prescott et al. (17), we first asked participants about their liking on a 11-point hedonic scale with end-point labels (0 = dislike very much; 10 = like very much). This type of scale is more common to French consumers than the 9-point hedonic scale. For the analytical group, we also asked to evaluate a series of attributes related to the pizza or bread on a 11-point category scale with end-point labels (0 = very weak; 10 = very strong). The rated attributes were:

- Pizza: tomato flavor, saltiness, fattiness, cheese flavor, soft texture;
- Bread: saltiness, yeast flavor, soft crumb texture, crispiness of the crust, crunchy dough.

In addition to this, and on a separate page, the questionnaire included a short satisfaction survey, with two questions related to the main course [overall satisfaction; quality of the food (value-for-money)], and questions about participant's overall experience in the restaurant that day (time spent in the queue, ambiance, hunger before lunch, ate alone or with friends).

Data analysis

Liking data were analyzed using a Student's independent *t* test for bread and using a two-way ANOVA with interaction for pizzas, where the type of culinary preparation and the type of task were included as main effects. When the ANOVA showed a significant effect ($p < 0.05$), a *post-hoc* Tukey HSD test was applied. In the case of bread, the effect of the evaluation task on overall liking was tested using an independent sample Student's *t*-test.

Data from the second part of the questionnaire (satisfaction survey) were analyzed using one-way ANOVA to check for potential differences between testing days. Special attention was paid to the possible effect of perceived time spent queueing on satisfaction and liking using simple linear regressions. Thereupon, an analysis of covariance (ANCOVA) with second order interaction was also performed to account for the effect of queueing (as a quantitative covariable) and of culinary preparation and evaluation task (as qualitative variables) on the liking scores. The resulting model was used to estimate corrected mean liking scores (LS Means) for each product in each condition.

All analyses were performed using XLSTAT 2022.2 (Addinsoft, statistical and data analysis solution. Paris, France).

Nota bene

We selected different participants each week. However, as the study was conducted in a natural consumption context, we cannot exclude that some participants took part of the study twice (e.g., on week 1 and 2). Should this have occurred, it would had been marginal. We thus treated the data from each day as independent groups.

Results

Pizza sensory description

Owing to our design, half of the participants rated their perception of the food for five sensory attributes. Data show that the three pizza variants clearly differed on the flavor of the tomato sauce, on the cheese flavor and on the texture of the crust (Table 3). The readymade pizza had a more intense tomato flavor and cheese flavor as well as a softer texture. There were no significant differences in terms of fattiness and saltiness.

Overall liking

Regardless of the evaluation task, pizzas were overall well liked with a mean score of 6.45 (±1.81), whereas bread was not so much appreciated [mean liking score: 4.51 (±1.90)]. On average, the pizza variants were differently liked ($F_{(2,267)} = 5.32$, $p = 0.005$), with the homemade pizza and the mixed pizza receiving higher scores than the readymade pizza (Figure 2). The readymade pizza was less liked, possibly as a result of its softer texture, but its more intense cheese and tomato flavor could also have contributed to this outcome. However, analysis of the exit questionnaire revealed that time spent in the queue was perceived to be longer on the day the readymade pizza was served ($F_{(2,267)} = 10.42$, $p < 0.0001$). On average, this seems to have reflected in overall satisfaction ($F_{(1,267)} = 6.36$, $p = 0.012$, $R^2 = 0.02$) and liking ($F_{(1,267)} = 6.94$, $p = 0.009$, $R^2 = 0.02$) even if interindividual differences were important, as indicated by the low coefficients of determination.

Influence of the task format

Overall, the task format did not influence the average liking score for the bread ($t_{(176)} = 1.97$, $p = 0.114$), nor for the

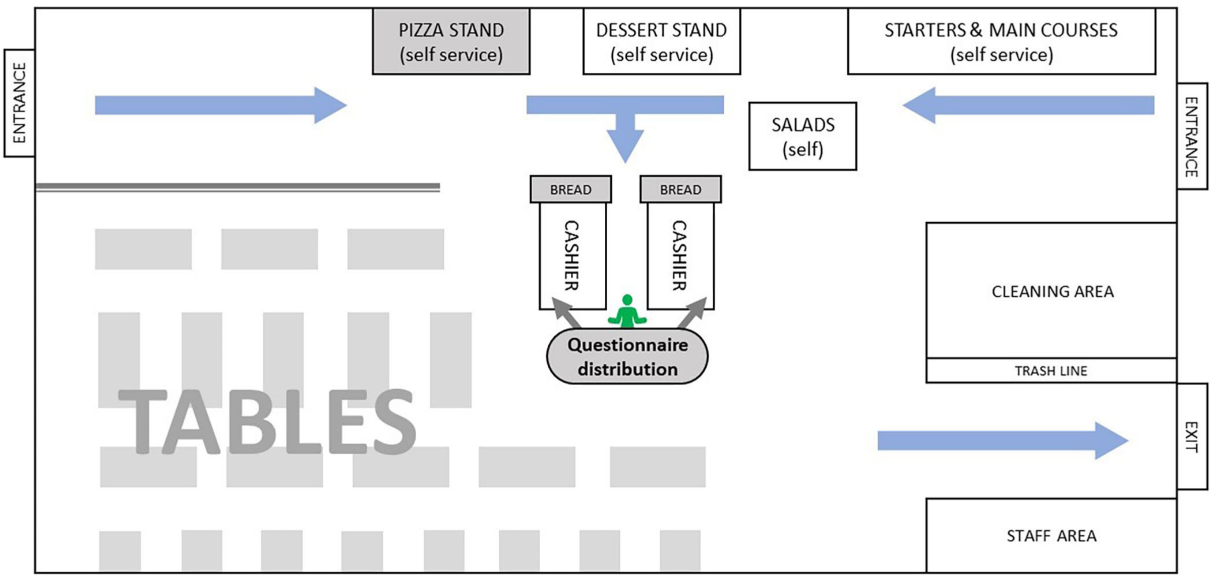


FIGURE 1
Plan of the staff and student cafeteria of the Ecole Central of Lyon, France.

TABLE 2 Experimental design.

	Week 1		Week 2		Week 3	
	Homemade		Mixed		Readymade	
Pizza	Synthetic task $n = 39$	Analytical task $n = 48$	Synthetic task $n = 43$	Analytical task $n = 43$	Synthetic task $n = 55$	Analytical task $n = 45$
	Standard and unchanged recipe				No evaluation	
Bread	Synthetic task $n = 45$	Analytical task $n = 50$	Synthetic task $n = 50$	Analytical task $n = 55$		

TABLE 3 Analyses of variance of the sensory attributes of the different types of pizza preparations.

	Tomato flavor	Salty flavor	Fatty	Cheese flavor	Soft texture
$F_{(2,134)}$	8.51	1.64	1.99	6.65	4.89
p-value	<0.001	0.197	0.141	0.002	0.009
Homemade	5.96 a	5.51 a	6.39 a	6.02 b	5.98 b
Mix	4.53 b	5.56 a	6.28 a	6.42 b	6.3 ab
Readymade	6.31 a	4.87 a	7.04 a	7.40 a	7.13 a

Letter indices indicate Tukey post-hoc groupings at $p < 0.05$ for each attribute.

pizzas ($F_{(1,267)} = 0.19$, $p = 0.66$). However, there was a significant interaction between the pizza preparation and the task format ($F_{(2,267)} = 3.51$, $p = 0.031$), indicating that the pizza variants were scored differently depending on the questionnaire used (Figure 3A). In particular, the average liking score for the homemade version was significantly lower when participants performed the analytical evaluation task ($t_{(85)} = 2.86$, $p = 0.005$).

What is more, different rankings of the pizzas were obtained when the data were analyzed separately for each evaluation task format (Figure 3B). With the synthetic task, the homemade was the best liked pizza, followed by the mixed (although not statistically different) and the readymade being the least liked. In contrast, the "mixed" pizza was significantly better liked than the other two when the analytical task was used. These rankings do not reflect individual preferences since

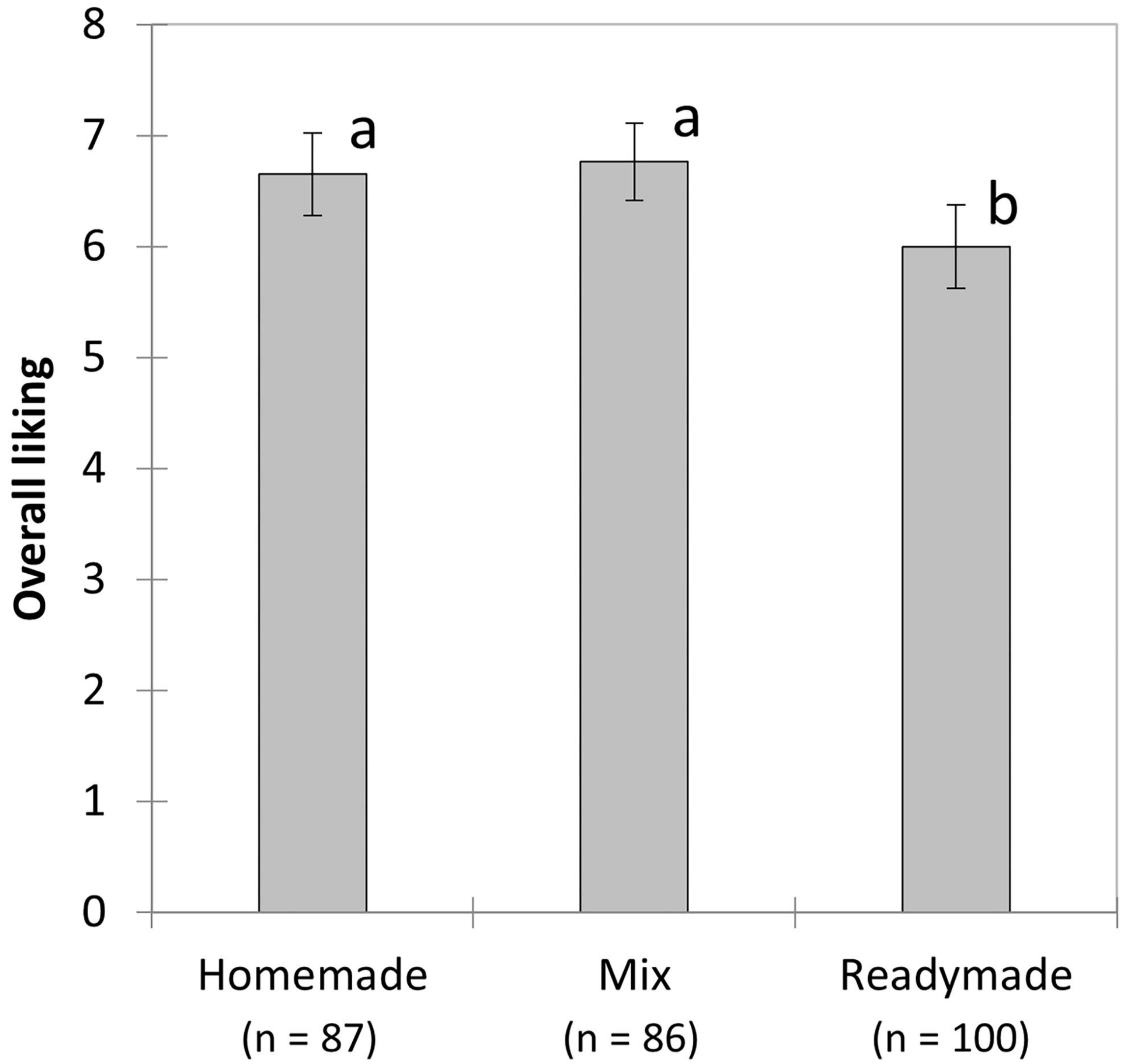


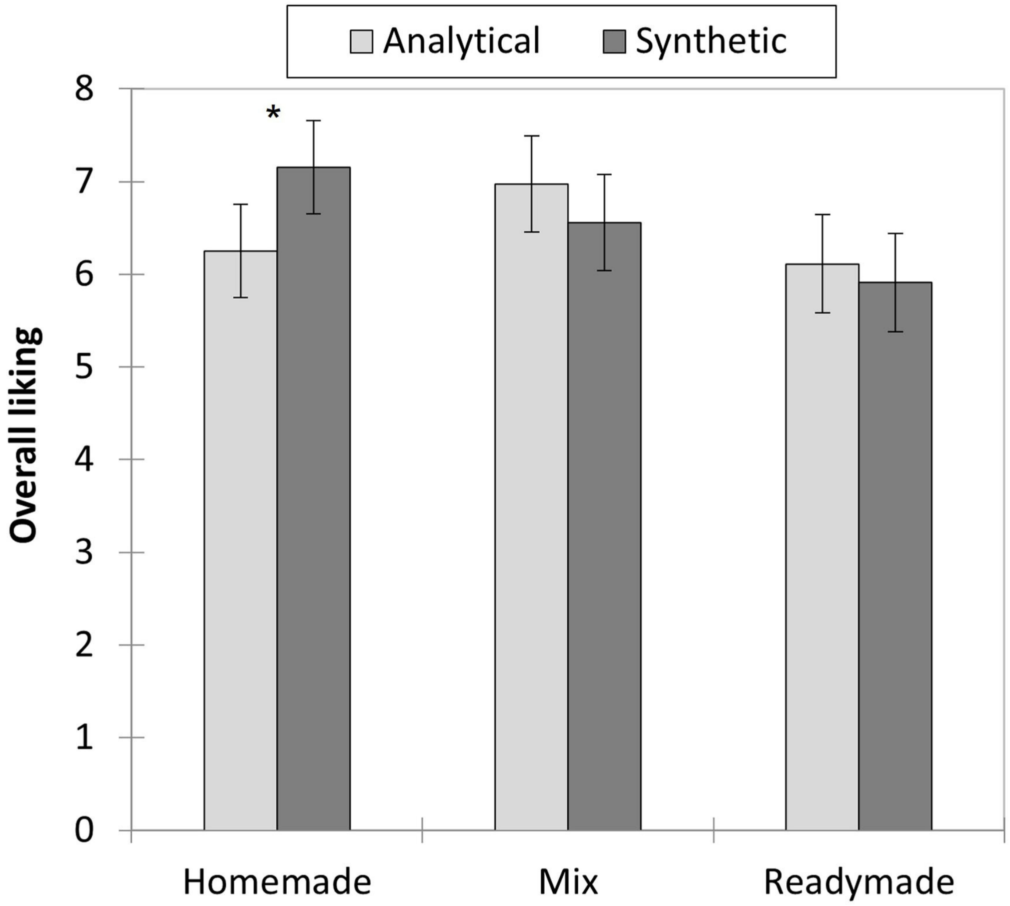
FIGURE 2
Mean scores (and SEM) for overall liking of the three pizza preparations. a and b indicate Tukey *post-hoc* groupings at $p < 0.05$.

the test was conducted in a pure monadic way. However, if a food service company had tested their products in such conditions, they would have reached different conclusions depending on the questionnaire format, and possibly different decision on which preparation or which recipe to select. Note that the synthetic evaluation task was slightly more discriminant than the analytic task, although effect sizes were very similar (Synthetic task: $F_{(2,134)} = 5.29$, $p = 0.006$, $\eta^2 = 0.07$; Analytic task: $F_{(2,135)} = 3.34$, $p = 0.039$, $\eta^2 = 0.05$).

In order to account for the effect of queueing on liking, we performed an ANCOVA (Table 4), which revealed that, in fact, the task format had a significant effect on the liking scores for the pizza. According to this model, the synthetic task indeed led to slightly higher adjusted mean scores (LS mean $_{synthetic} = 6.55 \pm 0.15$ SE) than the analytical task (LS mean $_{analytic} = 6.45 \pm 0.17$ SE). This analysis confirms the significant interaction between the task format and the pizza preparation that was previously observed. The adjusted mean score for the homemade pizza is now clearly higher when evaluated with the synthetic task (LS mean $_{synthetic} = 6.97 \pm 0.29$ SE) than with the analytic task (LS mean $_{analytic} = 5.82 \pm 0.28$ SE).

Interestingly, we identified a significant interaction between the queueing and the task format, indicating that the effect of the task format (i.e., lower scores with the analytical task) was more pronounced when participants spent more time in the queue ($t_{slopes} = 2.605$, $p = 0.010$).

A



B

Analytical task:	A 7.0 MIX	AB 6.2 HOMEMADE	B 6.1 READYMADE
Synthetic task:	A 7.2 HOMEMADE	B 6.6 MIX	B 5.9 READYMADE

FIGURE 3
(A) Mean scores and standard errors for overall liking of the three pizza preparations for each task format, * indicates a significant difference at $p < 0.05$. **(B)** Rank order of the different pizza versions for the most liked to least liked according to each evaluation task. Letters above products denote significant differences ($p < 0.05$) found between each culinary preparation using *post-hoc* LSD test.

Discussion

The format of the evaluation task significantly impacted consumer hedonic responses for one of the tested products. The analytical task indeed resulted in lower hedonic scores than the synthetic task for the homemade pizza, hence echoing Prescott et al. (17) observation for iced tea. However, this effect did not affect all pizza preparations, and in parallel, bread, whose recipe did not change across the experimental campaign, received consistent scores with both types of tasks. Thus, contrary to our first hypothesis, we cannot conclude on a systematic effect of the evaluation task on the level of liking for all tested products.

The fact that the sensitivity to the task format apparently depends on the tested product could be highly consequential in

TABLE 4 Detailed ANCOVA model for the analysis of pizza liking scores ($F_{(9,259)} = 3.77$, $p < 0.001$).

Source	df	Sum of squares	Mean squares	*F*	*p*-value
Queueing	**1**	**27.34**	**27.34**	**9.16**	**0.003**
Task format	**1**	**18.28**	**18.28**	**6.12**	**0.014**
Preparation method	2	5.84	2.92	0.98	0.378
Queueing*Task format	**1**	**20.26**	**20.26**	**6.78**	**0.010**
Queueing*Preparation method	2	9.67	4.83	1.62	0.200
Task format*Preparation method	**2**	**32.18**	**16.09**	**5.39**	**0.005**

Significant sources of variation are highlighted in bold.

a business context. For example, in foodservice, such test results would typically be used to evaluate liking for new products or new recipes and to decide which product to serve to customers, or to launch on the market. Here, in the case of pizzas, the two tasks would have been conducive to a different outcome in terms of order of preference and thus different decisions been made about which variant to offer. The synthetic evaluation task led to the conclusion that the homemade pizza was the best liked and the readymade the least liked, while the analytical evaluation task (which is more often used in satisfaction surveys in cafeterias) led to the conclusion that the "mixed" pizza was liked significantly better than the other two.

It should be noted that the mixed pizza was the regular product usually served in this cafeteria. Familiarity may thus have contributed to the observed differences in the relative impacts of analytical and synthetic tasks on evaluations outcomes (24–26). Previous research in behavioral economics suggests the existence of a link between the level of expertise, or familiarity, with a task and the use of judgment heuristics. For instance, in a market experiment, participants that were more familiar with the experimental task (an auction mechanism) were less subjected to the influences of the task context, in particular to endowment effects (27). No work has, to our knowledge, examined this relationship between the level of familiarity and the reliance on contextual cues within the context of food products evaluation tasks. However, it may be hypothesized that for more familiar products, evaluators would rely less on task-related cues, such as the criteria provided by analytical tasks. In our experiment, the mixed pizza was regularly served in this cafeteria and arguably the most familiar to customers. For this product, the liking scores were not significantly different between analytical and synthetic tasks, suggesting a low influence of the additional contextual cues (specific attributes) provided in the analytical task. A similar behavior was observed in the case of the readymade pizza, which is a familiar product in the population studied (students), and for bread, which is also a familiar and frequently consumed product. Conversely, the least familiar homemade pizza scored higher with the synthetic task than when participants' attention was focused on specific sensory attributes.

Interestingly, the task format did not influence the liking for bread, which received much lower liking scores overall than pizzas. The reasons are unclear why some products were affected while others were not. However, the result for bread is consistent with previous observations that liking scores are more sensitive to the task format for highly liked products than for disliked products (12, 13). This might also explain why, in our study, the task format did not affect the scores of the less liked pizzas. It can also be stressed that, contrary to bread, pizza is a main course and is a multicomponent food composed of multiple easily distinguishable subparts such as toppings (meat, cheese, etc.), tomato sauce, and crust, which could have been evaluated separately. The analytical task, which focuses on a selected set of sensory attributes, may have modulated the participants' overall liking scores by directing their attention on distinctive subparts (28). It would be interesting to test this hypothesis with other types of "homogeneous" (e.g., fruit juices, yogurts, cakes, etc.) and multicomponent (e.g., fruit bowls, salads, sushi, sandwiches, etc.) foods.

We can only speculate about which factors may have contributed to the observed differences in the relative impacts of analytical and synthetic tasks on evaluations outcomes. However, our results are in line with behavioral research that stresses the importance of contextual cues and reference points on judgment and decision-making, underlining that some judgments are led by intuition and rely more heavily on contextual cues, while others mobilize a more analytical and reflexive evaluation process (7, 29, 30).

In addition to the changes in the evaluation task induced by the use of different questionnaires, we measured the effect of variables that couldn't be controlled such as the perception of the time spent in the queue, the general ambiance, or whether participants ate alone or with friends / colleagues. As it happened, the time spent queuing was perceived to be significantly longer on the day the readymade pizza was served, which seemed to have negatively affected the liking scores for that pizza. Unfortunately, we did not collect data for bread on that day and cannot use this "control" product to back this hypothesis. However, this observation is consistent with previous studies that showed that queueing could influence liking and food choices in a cafeteria context (31, 32). Our model shows that when accounting for the perceived waiting time, the task format significantly affects liking scores for all pizzas, with lower liking scores when the analytical task was used. What is more striking, we found that the analytical task led to even lower liking scores when participants reported to having spent more time in the queue. This could be seen as a halo effect of the negative attitude induced by the waiting time. Should this be the case, it would suggest that longer and more analytical questionnaires would be more sensitive to such negative contextual events. This draws attention to the interaction of the task format and the evaluation context, and the potential associated biases. Rather, we would claim that the task is part of the evaluation context and must be carefully considered when one wishes to design ecologically valid consumer tests. Conversely, our results show that it would be hazardous to generalize conclusions on task effects drawn from tests conducted in one specific context, especially if this context (e.g., a sensory booth) remotely compares with real consumption situations.

Eventually, we would like to stress that this study was a field experiment, which involved a wide range of food options and possible selection biases as participants were recruited after they had selected their food and paid for their lunch. Although such an approach is seen to best represent the context in which consumers naturally behave and make decisions, the downside is the lack of control over some evaluation conditions (33). A crowdy day and longer queue is a typical example of such undesirable effects. Besides, we could only reach relatively small sample size in each condition, to be compared with the large number of participants overall (because we only recruited those consumers who spontaneously picked pizza for their meal among a much wider assortment). Despite these limitations, field experiments have high ecological validity (i.e., realistic representation of the studied stimuli in an natural environment). In this realistic environment, we find that the outcomes of satisfaction surveys for new recipes may be sensitive to the task design. Consistently with most studies on context, it was clear that many intrinsic and extrinsic variables could come into play (9). Accordingly, our results highlight the need to replicate this study, ideally with foods varying in the way they are eaten and in the type of expectations they convey.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

Author contributions

AG designed the study, collected data, analyzed and interpreted data, and drafted and revised the manuscript. LS designed the study, interpreted data, and revised the manuscript. JD designed the study, analyzed and interpreted data, and drafted and revised the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The role of reinforcement learning and value-based decision-making frameworks in understanding food choice and eating behaviors

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The obesogenic food environment includes easy access to highly-palatable, energy-dense, "ultra-processed" foods that are heavily marketed to consumers; therefore, it is critical to understand the neurocognitive processes the underlie overeating in response to environmental food-cues (e.g., food images, food branding/advertisements). Eating habits are learned through reinforcement, which is the process through which environmental food cues become valued and influence behavior. This process is supported by multiple behavioral control systems (e.g., Pavlovian, Habitual, Goal-Directed). Therefore, using neurocognitive frameworks for reinforcement learning and value-based decision-making can improve our understanding of food-choice and eating behaviors. Specifically, the role of reinforcement learning in eating behaviors was considered using the frameworks of (1) Sign-versus Goal-Tracking Phenotypes; (2) Model-Free versus Model-Based; and (3) the Utility or Value-Based Model. The sign-and goal-tracking phenotypes may contribute a mechanistic insight on the role of food-cue incentive salience in two prevailing models of overconsumption–the Extended Behavioral Susceptibility Theory and the Reactivity to Embedded Food Cues in Advertising Model. Similarly, the model-free versus model-based framework may contribute insight to the Extended Behavioral Susceptibility Theory and the Healthy Food Promotion Model. Finally, the value-based model provides a framework for understanding how all three learning systems are integrated to influence food choice. Together, these frameworks can provide mechanistic insight to existing models of food choice and overconsumption and may contribute to the development of future prevention and treatment efforts.

KEYWORDS

food choice, obesity, value-based decision-making, reinforcement learning, model-free vs. model-based learning, sign-and goal-tracking

Introduction

Each day we make hundreds of choices about what to eat, many of which occur automatically with little conscious thought (1). While in lay terms, the phrase "food choice" is often limited to the decisions about the composition of a meal (e.g., *What's for dinner?*), the current review uses a broader definition that encompasses the behavioral and environmental factors that influence meal initiation, amount consumed, and quality of the food choices (2–4). Food choices are extremely complex because they evolve over varying time scales, have multiple determinants, and occur within various contexts (e.g., celebratory, meals, and snacks) (2, 3, 5). Adding to the complexity is the overwhelming influence of the obesogenic food environment, which makes highly palatable, energy-dense (i.e., "ultra-processed") foods more affordable and accessible (6). Food choice in the context of an obesogenic environment requires the integration of multiple, often conflicting pieces of information (3). For example, presence of food cues such as McDonald's "Golden Arches" may trigger wanting for energy-dense foods (e.g., Big Mac and French fries) that are not compatible with goals to maintain a healthy diet (7). With 1 in 5 deaths linked to a poor diet (8, 9) and obesity rates among children continuing to rise (10), it is critically important to understand how food choices are made in response to environmental food cues (e.g., food images, advertising/branding). Understanding the neurocognitive processes those underly food choices in this context is crucial for the development of effective, tailored health interventions.

Environmental food cues influence food choice through three behavioral controllers or systems: Pavlovian, instrumental/habit, and goal-directed (1, 11, 12). The Pavlovian system regulates automatic behavioral responses to cues that are associated with evolutionarily relevant outcomes. The classical example is of Pavlov's dogs salivating at the sight of food (13). While these responses can be present without learning (i.e., "hard-wired"), the association between a stimulus or cue (e.g., bell sounding) and an evolutionarily significant outcome (e.g., food delivery) can be learned and presumably confers selective advantages to human and non-human animals in their search for edible and nutritious foods (11, 13, 14). For example, approaching a cue that predicts food delivery (1, 11) or consuming all the food available on a plate regardless of hunger would be considered Pavlovian behaviors (11). In contrast to the Pavlovian system where the outcome or reward is delivered regardless of behavior, in instrumental learning, reward delivery is contingent upon the behavior performed in response to the cue (11, 14, 15). Thus, while the Pavlovian system supports stimulus-outcome (S-O) learning the instrumental system supports stimulus-response (S-R) learning. The instrumental system has also been termed the "habit" system because learned actions can occur even when the outcome is not desired, which can lead to habitual behaviors (15). For example, the instrumental system would drive habitual coffee intake at a specific time of day regardless of whether the stimulating effect of caffeine is needed or desired (1, 11, 15). While a habitual behavior may occur regardless of state as in the prior example, the value of food-related actions is also influenced by internal states like hunger (16–18). In contrast to the instrumental system which is driven by previously learned S-R associations, the goal-directed system prospectively evaluates response-outcome (R-O) associations based on the anticipated or predicted outcome for each action (1, 11, 15). For example, the goal-directed behavior of choosing where to eat in a novel city would be driven by the anticipated value for the food at each restaurant. Together, these three systems drive eating behavior and food choice in response to environmental food cues.

While the instrumental and goal-directed systems contribute to value-based decision-making in general, food choice is a unique because it can also be influenced by the Pavlovian system (1). Therefore, applying neurocognitive frameworks to understanding the factors that motivate food choice may elucidate novel behaviors to target in dietary interventions. The current review is intended to provide an overview of three frameworks that encompass these learning systems: (1) sign-and goal-tracking phenotypes; (2) model-based and model-free reinforcement learning; and (3) the utility or value-based model. For each framework we will provide a brief translational review of the theory and its supporting neurobiological substrates, followed by a summary of possible applications to understanding food choice and eating behaviors. Finally, we will consider how these frameworks can be utilized to improve understanding of food-choice and applied to the development of more effective prevention/treatment programs for disordered or dysregulated eating.

Sign-and goal-tracking

The sign-and goal-tracking phenotype is an animal model for motivational control of behavior in response to environmental cues (19–23). These phenotypes are characterized in animals using the Pavlovian Conditioned Approach (PCA) test (24, 25). Pavlovian conditioning occurs when a neutral cue (e.g., lever) becomes a conditioned stimulus (CS) after being repeatedly paired with an unconditioned stimulus (US) like food. In the PCA test (**Figure 1A**), a lever (neutral) is repeatedly presented prior to food delivery (US) allowing the animal to learn the lever-food (S-O) association (**Figure 1A**). Once the lever becomes a CS, it is able to elicit conditioned responses (CR) (22, 24, 25). Animals display three patterns of CRs: (1) goal-tracking: approaching the location of food delivery (US); (2) sign-tracking: approaching the lever (CS) itself; and (3) intermediate: switching between the two CRs (20–22, 25). Importantly, all animals are equally able to learn the

S-O association regardless of CR displayed (26). The differing patterns of CRs occur due to differences in the attribution of incentive salience or motivational value to the CS (20–22, 25). For sign-trackers, the CS becomes an incentivized stimulus, which has three defining properties: (1) it biases attention; (2) it is desired and the animal will work for it (i.e., is "wanted"); and (3) it can increase motivation to seek reward (20–22, 25, 27). Once the CS becomes desired, sign-trackers will approach and interact with the CS even if it means losing access to the primary reward (e.g., food) (25). Therefore, a key behavioral distinction between these phenotypes is the propensity for environmental cues to take on rewarding properties and motivate wanting.

Neural pathways that support sign-and goal-tracking phenotypes

The sign-and goal-tracking phenotypes have well-characterized differences in neural engagement during stimulus-reward learning and attribution of incentive salience. Sign-trackers show greater phasic dopaminergic (DA) signaling in ventral striatum, a region integral in stimulus-reward learning, which has been linked to the attribution of incentive salience to the CS (21, 22, 26, 28, 29). Sign-trackers also show a higher firing rate for excitatory signals in response to the CS in ventral pallidum (30), a subcortical region that is important for motivated behaviors and incentive salience (31). While both ventral striatum and pallidum have "hedonic hotspots" that enhance hedonic influence of the CS (31–33), incentive motivation or wanting of the CS (i.e., sign-tracking) seems to be driven by projections from ventral striatum to ventral pallidum (34). Although sign-tracking seems to be driven by these subcortical DA-related signaling differences, there are also important differences in cortical signaling. In particular, sign-trackers show cortical differences in acetylcholine (ACh), a neuromodulator that is important for attentional control and learning. In response to attentional demands, sign-trackers are less able to upregulate ACh which leads to stimulus-driven or bottom-up attention control [for review see (24)]. Therefore, sign-trackers show a pattern of greater signaling in subcortical "hedonic hotspots" in conjunction with a reduced cortical ACh signaling, which limits engagement top-down attentional control.

The pattern of greater bottom-up reward signaling and reduced top-down control signaling in sign-compared to goal-trackers is paralleled by circuit-level differences. Cue-motivated behaviors driven by incentive salience involve widespread circuits including cortical, thalamic pallidum, and striatal loops that converge in the ventral striatum (21, 33, 35). Sign-trackers have greater engagement of ventral and dorsal striatum (i.e., caudate-putamen) during stimulus-reward learning while goal-trackers show greater engagement of prefrontal cortical regions [for review see (21)]. Therefore, it has been hypothesized that cue-motivated behaviors are subserved by subcortical circuits while top-down cortical circuits inhibit the attribution of incentive salience to cues (21). Reduced engagement of cortical regions associated with top-down control may also contribute to greater impulsivity (36, 37) and reduced behavioral flexibility (38) observed in sign-trackers compared to goal-trackers. Together, this suggests neural differences between phenotypes contribute to differences in attribution of incentive salience and may also be related to differences in attentional control and impulsivity (21, 24).

Translation of sign-and goal-tracking phenotypes to humans

In humans, sign-and goal-tracking have been characterized using Pavlovian conditioning tasks (often as part of the Pavlovian instrumental transfer paradigm) and the Value-Drive Attentional Capture (VDAC) task. Using eye-tracking, incentive salience can be measured in Pavlovian conditioning tasks by examining the amount of time looking at the location of the CS compared to the location where reward is delivered (**Figure 1B**). Much like sign-tracking animals that fixate on the lever rather than location of food delivery, adult humans who spend more time looking at the location of the CS compared to the reward have also been classified as sign-trackers (39, 40). In line with the animal phenotype of sign-tracking, adults classified as sign-trackers during Pavlovian conditioning show greater impulsivity than those classified as goal-trackers (39). Similarly, VDAC tasks (**Figure 1C**) measure attentional bias toward high-value stimuli, however, these tasks assess this bias when the stimuli are no longer relevant to the task goal and are no longer rewarded (41–43). Continued attentional bias toward previous high-value stimuli–termed attentional capture–reflects the attribution of incentive salience to these stimuli (27, 43–45) and sign-tracking (27, 45). Greater attentional capture on the VDAC has been associated with greater compulsivity (45, 46) and impulsivity (41) as well as risk for substance use disorder (45). Together, this shows that behavioral profiles associated with sign-tracking have similarities in human and non-human animals (e.g., impulsivity, poor attentional control).

Relevance to food choice and eating behaviors

The sign-and goal-tracking phenotype model has high translational potential to inform our understanding of food choice and overconsumption. This is supported by animal studies which have shown that obesity-prone rats display greater attribution of incentive salience compared to obesity-resistant models (47). There is initial evidence that obesity is associated with cue-outcome behavioral responses that are indicative of

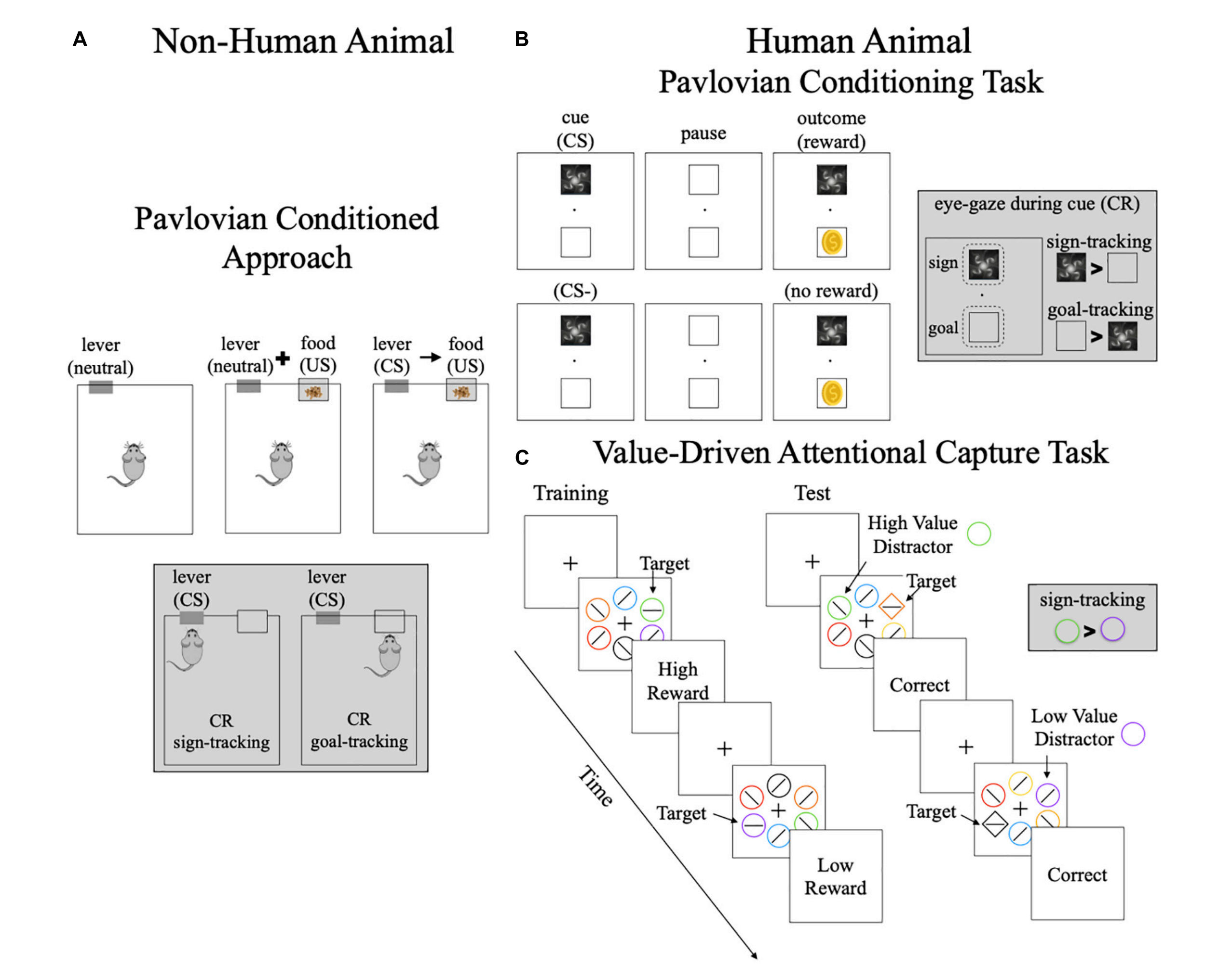

FIGURE 1
Methods of assessing sign-and goal-tracking phenotypes. **(A)** Pavlovian conditioned approach task–this task is used in non-human animal models. Animals learn the stimulus-outcome (S–O) association between the lever and food delivery. The conditioned responses are: (1) sign-trackers–approach the lever; (2) goal-trackers–approach the location of food delivery. **(B)** Pavlovian conditioning task–this is a simplified schematic of a Pavlovian conditioning task where a conditioned stimulus either predicts reward receipt or no reward. The conditioned stimulus and reward are presented in different locations so the conditioned response of eye-gaze can be measured. The conditioned responses are: (1) sign-trackers–look at the conditioned stimulus more than reward location; (2) goal-trackers–look more at the reward location than conditioned response. **(C)** Value-Driven Attentional Capture Task–this task includes a training and a test phase. Both phases include a visual search task where participants must locate the location of the horizontal line. During training, one color is associated with high reward (e.g., green) and one color is associated with low reward (e.g., purple). During the test phase, the target is the unique shape and the previously rewarded colors are used as high or low value distractors. No reward is given for correct responses in the test phase. The conditioned responses are: (1) sign-trackers–looking at the previously rewarded cue, resulting in slower reaction times; (2) goal-trackers–not distracted by previously rewarded cues. CS, conditioned stimuli; CR, conditioned response; US, unconditioned stimuli. Gray boxes highlight the definition of sign-and goal-tracking for each task.

sign-tracking. In a Pavlovian conditioning task that paired visual cues with receipt of chocolate milkshake, water, or nothing, adults with overweight showed the CR of increased swallowing in response to cues that predicted chocolate milkshake delivery while adults with healthy weight did not (48). This suggests that adults with overweight were more likely to attribute incentive salience to the cues that predicted chocolate milkshake receipt (i.e., sign-track) than those with healthy weight. Additionally, in adolescents, greater caudate and ventral pallidum activity is seen during Pavlovian cue-outcome learning for milkshake compared to water (49, 50) with greater ventral pallidum activity predicting greater increases in BMI 2 years later (49). This finding parallels greater ventral pallidum activity in animal models of sign-tracking (30), suggesting that this may be a common neural pathway for sign-tracking and may be associated with tendency to develop obesity.

The sign-tracking phenotype, in particular, may also play an important role in eating behaviors. While we are not aware of studies examining Pavlovian conditioning, there is one study showing that adults with greater eating restraint were less likely to attribute incentive salience to food cues in a VDAC task (51). This indicates that adults who report a greater tendency to restrict calories are less likely to attribute salience to food cues. There is also a larger literature examining attentional bias to food cues [see reviews (52–54)], which is an indirect measure of incentive salience (27). A recent meta-analysis examining direct [e.g., electroencephalographic (EEG) recordings, eye-tracking] and indirect (e.g., reaction times) measures of food-related attentional bias showed that greater bias was associated with greater hunger, food cravings, and food intake but not body mass index (52). In particular, EEG recordings may be a promising approach for characterizing sign-tracking as late positive event-related potentials (ERPs, e.g., P300 or late positive potentials–LPP) index motivational salience associated with cues (55, 56). In support of this, a recent study used a data-driven approach to cluster adults based on emotional and food-related LLPs with those classified as "sign-trackers" showing larger food-related LLP and higher rates of obesity compared to those classified as "goal-trackers" (57). While late positive ERPs to food-cues is a promising approach for measuring incentive salience and sign-tracking, there is mixed evidence for an association with obesity and binge eating disorder (53). Together, these studies highlight initial evidence that the tendency to attribute incentive salience to food cues (i.e., sign-track) may increase susceptibility to eating behaviors associated with overconsumption [for review of food-cue reactivity beyond incentive salience see (58)].

Based on initial evidence of its role in eating behaviors related to overconsumption and obesity, the sign-tracking phenotype may provide mechanistic insight on the role of food-cue incentive salience in two prevailing models of overconsumption–the Extended Behavioral Susceptibility Theory (59) and the Reactivity to Embedded Food Cues in Advertising Model (REFCAM; **Figure 2**; 60). The importance of food-cue incentive salience across models highlights its broad potential as a behavioral target for prevention and intervention efforts. For example, cue-exposure therapy aims to reduce food-cue incentive salience by repeatedly exposing participants to a food-cue without the CR of food intake [for review see (12, 61, 62)]. Thus far, cue-exposure therapy has focused on exposures to specific foods, which has been successful in reducing the number of binge eating episodes, number of binge eating days, intake of exposed food, and body weight (63–65) in adults with binge eating disorder and obesity (61–65). While cue-exposure therapy has shown effectiveness for individuals who have already developed food-specific cravings and overconsumption, it is not clear if this approach would be effective for targeting brand or advertising related cues as proposed in the REFCAM model. Additionally, it is not clear if targeting incentive salience would be more efficacious for reducing overconsumption in individuals with sign-tracking compared to goal-tracking phenotypes. Therefore, future work is needed to determine whether targeting individuals based on sign-and goal-tracking phenotypes will contribute to more effective and sustainable weight maintenance.

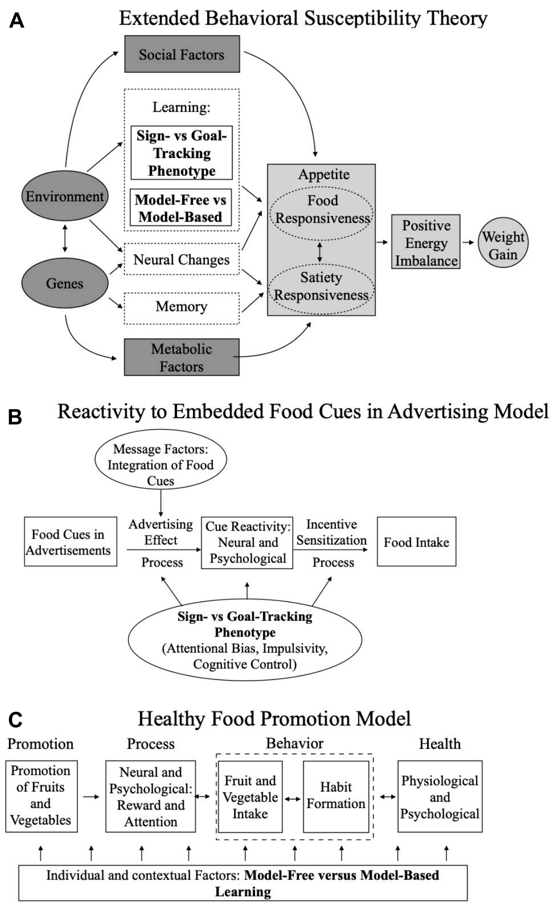

FIGURE 2
Adapted models with the sign-and goal-tracking and model-free and model-based learning frameworks incorporated. **(A)** Boutelle et al.'s (59) Extended Behavioral Susceptibility; **(B)** Folkvord et al.'s (60) Reactivity to Embedded Food Cues in Advertising Model; **(C)** Folkvord et al.'s (7) Healthy Food Promotion Model.

Model-free and model-based reinforcement learning

Reinforcement learning is the process through which environmental cues become valued and influence behavior (66). This process is driven by two competing systems–a habitual and a goal-driven system (15, 67–71). The habitual system drives model-free reinforcement learning which relies on stimulus-response (S-R) associations and is a fast, almost automatic, process that requires little cognitive effort (72). For example, stopping for coffee at the same coffee shop on the way to work every day is likely a habitual process. Model-free learning increases the probability of choosing actions that were most recently rewarded, which leads to less accurate and flexible responses. In contrast, the goal-directed system drives model-based learning because it relies on a mental model or cognitive map of the expected value of different responses (i.e., R-O associations) for different "states" or environmental situations. For example, if the coffee shop is closed for maintenance, a goal-directed process is needed to change the morning routine and make coffee at home. Model-based learning leads to more flexible responses; however, it is also more cognitively demanding. These reinforcement learning strategies operate in parallel, with optimal value-based decision-making balancing the need for accuracy with cognitive demand (67, 70, 73, 74).

Neural pathways that support model-free and model-based learning

Reinforcement learning processes rely on neural encoding of prediction errors, which are used to update outcome expectations and improve accuracy. Model-free learning depends on reward prediction errors (RPEs). A RPE is the difference between the expected outcome and the actual outcome. For example, if someone orders their morning coffee and receives a free donut, that would be a positive RPE. In contrast, if someone orders their morning coffee and receives decaffeinated coffee, that would be a negative RPE. RPEs are encoded by phasic DA signaling in the basal ganglia, which includes ventral striatum, caudate-putamen, and dorsal pallidum (29, 75). In contrast, model-based learning relies on a cognitive model of a task or environmental reward structure so learning is driven by state prediction errors (SPEs). A SPE is the difference between the expected "state" and the actual "state" (70). For example, arriving at coffee shop in the morning and finding it closed for maintenance would be a SPE. SPEs are thought to be encoded by lateral prefrontal cortex, intraparietal sulcus, and anterior cingulate (70, 76, 77). While the neural systems supporting RPEs and SPEs are partially distinct, both model-free and model-based learning include value-based signaling associated with ventral striatal activation (68, 70, 73, 78, 79). A recent meta-analysis showed that in addition to ventral striatum, model-free learning specifically engaged dorsal striatum and dorsal pallidum while model-based learning specifically engaged ventral medial prefrontal cortex and anterior cingulate cortex (79). In addition to regions supporting SPEs, model-based learning also involves dorsolateral prefrontal cortex, orbital frontal cortex, posterior parietal cortex, and hippocampus to support the mental model of different states (15, 71, 80). Given these learning strategies likely operate in parallel (67, 70, 73, 74), common neural correlates for these strategies may help to mediate switching between model-free and model-based learning (15, 69, 81).

Characterizing model-free and model-based learning

The advent of computational models for reinforcement learning has propelled our ability to distinguish model-free and model-based learning processes. In particular, the dual-system model incorporates both model-free and model-based algorithms (68, 73) which allows for individual differences in the balance of these systems to be examined. A task structure that leverages the dual-system model is the two-step or serial decision-making task (73, 82). This task involves a series of decisions between two stages. Actions in the first stage lead probabilistically to one of two second-stage states (i.e., high versus low transition probability; **Figure 3A**). Decisions made in the second-stage then lead to different probabilities of reward, which change or drift slowly throughout the task to encourage learning. The transition structure between stages allows for model-based and model-free strategies to be distinguished. In particular, model-free learners are more likely to repeat an action after a rare or low probability reward due to positive RPE. In contrast, model-based learners will experience a SPE and will be less likely to repeat the action due to the overall low probability of reward. This task has also been adapted to enhance the accuracy-demand tradeoff such that model-based strategies will lead to greater reward (82). In the adapted version, the transitions between the stages are deterministic rather than probabilistic (**Figure 3B**). Overall, greater use of model-free learning has also been associated with poorer working memory (83, 84), cognitive control (85), and processing speed (86). Therefore, greater reliance on model-free learning during this task is thought to reflect less adaptive reinforcement learning.

While two-step tasks were first developed for human studies, translational applications of the task to rodent models [e.g., (76, 80, 87; **Figures 3C,D**)] has shown similar patterns of behavior as seen in humans [for reviews on other animal models of habit see (88, 89)]. Animals show evidence of both model-free and model-based learning and evidence for switching between strategies (76, 87, 90, 91). An advantage to animal models is that ability to measure reinforcement learning before and after drug exposure. Drug-naïve animals with less model-free learning exhibited greater subsequent drug administration in animals, while use of model-based learning did not predict subsequent drug administration (92). However, after drug self-administration, rodents showed a reduction in both model-free and model-based learning (92). While this study used a computational model that quantified use of model-free and model-based strategies independently, studies in humans tend to look at the relative use of learning strategies (68, 73) and have shown relatively more model-free than model-based learning in drug users (93). Together, this highlights the importance of having translational assays of decision-making frameworks to better understand behavioral and neural mechanisms of reinforcement learning.

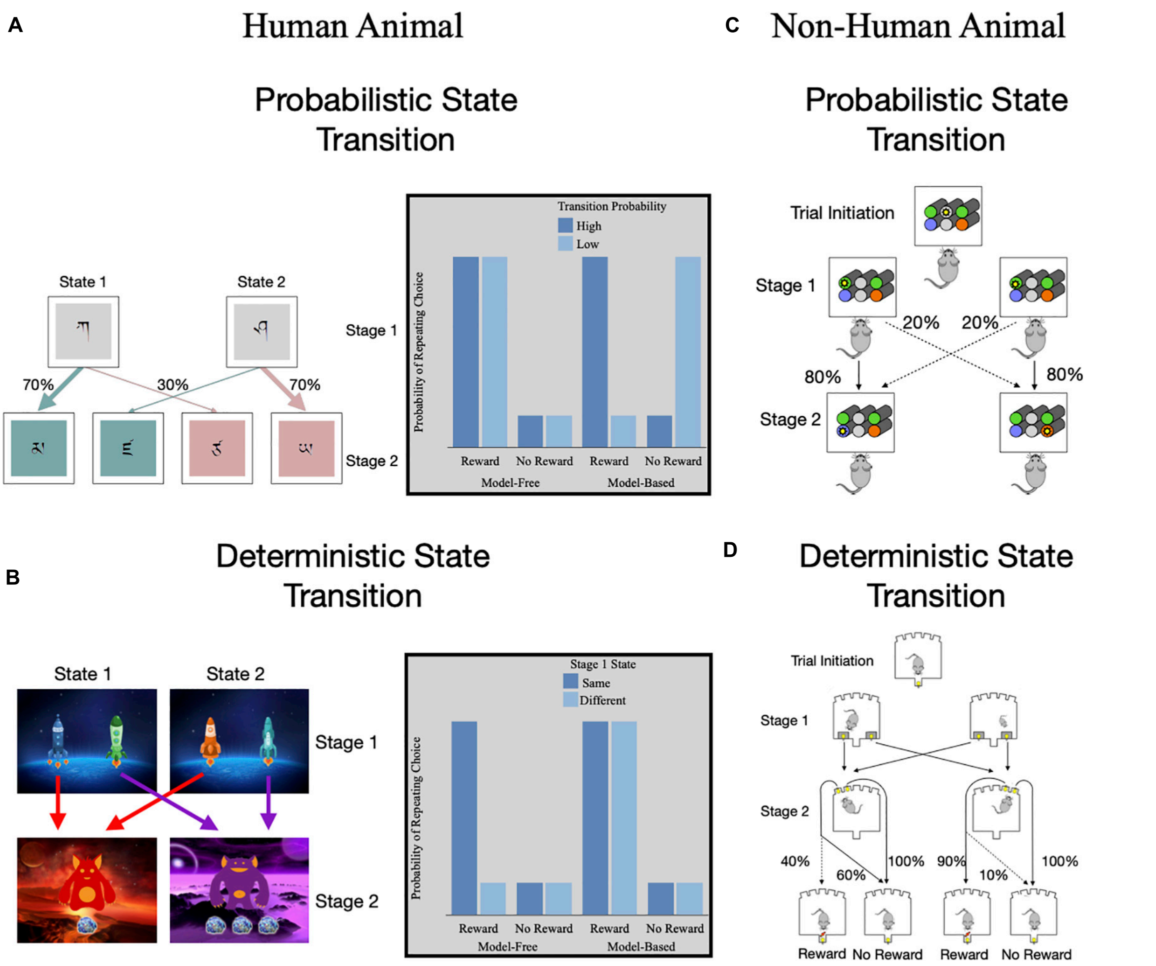

FIGURE 3
Methods of assessing model-based and model-free reinforcement learning using two-step serial decision-making tasks. Two-step tasks have two stages of decisions with the second stage state dependent upon the first stage choice. **(A)** Daw et al.'s (68) task that uses a probabilistic transition from stage 1 to 2. Gray box highlights the theoretically expected probability of repeating a stage 1 choice for model-free and model-based learning based on previous trial reward and transition probability. **(B)** Kool et al.'s (82) task that uses a deterministic transition from stage 1 to 2. Gray box highlights the theoretically expected probability of repeating a stage 1 choice for model-free and model-based learning based on previous trial reward and whether the current trial stage 1 state differs from the previous trial's stage 1 state. **(C)** Miller et al.'s (80) translation of a two-stage task for non-human animals with probabilistic state transitions. **(D)** Groman et al.'s (87) translation of a two-stage task for non-human animals with deterministic state transitions.

Relevance to food choice and eating behaviors

While the advent of the dual-system model and two-stage task has led to a swell of research on individual differences in reinforcement learning, little work has directly tested the role of reinforcement learning in food choice and obesity. Of the two studies we are aware of that have directly tested this association one showed greater reliance on model-free learning in adults with obesity compared to those without (94) and one showed no relationship between weight status and reinforcement learning (93). Additionally, model-free learning has been associated with psychological disorders marked by compulsivity including addiction, gambling disorder, obsessive compulsive disorder, and binge eating disorder (93, 95, 96). Model-free learning has been indirectly implicated in overconsumption (97) due to the contribution of compulsivity in habitual overeating (98, 99). Model-free learning may also contribute insight into the Extended Behavioral Susceptibility model, which proposes that "habitual" or instrumental systems contribute to overconsumption (**Figures 2A,B**; 59). While the majority of the literature and prevailing theories have focused on overconsumption, the Healthy Food Promotion Model proposes that habit learning can be leveraged to bolster intake of fruit and vegetables (**Figure 2C**; 100). Together, this suggests that interventions that leverage habit learning strategies may be able to increase healthy eating behaviors, but future studies are needed to test this empirically.

Utility model

Value-based decision-making often involves choosing between multiple actions that could lead to different advantageous outcomes. In utility or value-based decision-making models, every action has an expected value or utility (i.e., action-outcome association) and the action with the highest expected value will be selected. Values associated with different actions are integrated across Pavlovian, instrumental, and goal-directed systems (11) for different consequences of that action, termed attributes. For example, choosing to eat at a restaurant rather than at home could occur because the cumulative value of convenience and taste of food at the restaurant is greater than the value of cost saving and alignment with health goals for eating at home. Thus, the cumulative value of an action integrates both positive and negative value signals across learning systems and attributes. Additionally, the weight of the value signals from different learning systems can be influenced by individual characteristics, such as delay discounting (101, 102). Individuals who value smaller, immediate rewards more than larger, delayed rewards may be more influenced by value signals from the Pavlovian or instrumental systems than the goal-directed system. Further, environmental cues can modulate the weight given to different attributes (e.g., taste, health) (103). For example, an advertisement that draws attention to the palatable aspects of food may increase the value of taste when choosing what to eat. Therefore, value-based decisions are influenced by the subjective value of relevant attributes in addition to self-regulation and environmental contexts.

Neural pathways that support value-based decision-making

Value-based decision-making relies on the integration of multiple value signals across different learning systems. To compare value signals across dissimilar actions (e.g., take a lunch break or continue reading this paper), a "common currency" or value is encoded in the brain (104, 105). Neuroimaging research suggests that this common value signal is encoded in ventromedial prefrontal cortex and medial orbitofrontal cortex, while value signals for distinct attributes are encoded throughout the brain (106, 107). A meta-analysis showed that when executing reward-based decisions, valuations of different types of reward (e.g., food, money) were associated with activation in ventromedial prefrontal cortex, ventral striatum, posterior cingulate cortex, and superior frontal gyrus; however, only ventromedial prefrontal cortex activity was related to valuations for each reward modality separately (108). This suggests ventromedial prefrontal cortex is a key region for encoding subjective value of both primary rewards like food and secondary rewards like money during decisions. Dorsolateral prefrontal cortex has also been shown to modulate ventromedial prefrontal cortex value signaling during self-control (109, 110) and during context-dependent valuation (111) indicating the importance of both regions in goal-directed decisions. In sum, attribute-specific value signals across the brain are integrated in ventromedial prefrontal cortex, which can be modulated by dorsolateral prefrontal cortex when self-control is engaged or environmental context is important.

Characterizing value-based decision-making

Characterizing value-based decision-making can involve assessing overall value of an action or stimuli, assessing how different attributes impact overall value, or assessing how psychological and environmental characteristics impact value-based decisions. To estimate the overall expected value of an action, participants can rate how much they want (e.g., strong yes, yes, no, strong no) or how much they are willing to pay for an item (112). Direct ratings of the value of different attributes (e.g., health or taste) have been shown to relate to real world behaviors such as fruit and vegetable intake (113) and smoking initiation (114). These ratings can also be used to examine how attributes influence value-based decision-making by asking participants to make choices between the items. For example, after rating the health and taste of foods, the influence of these attributes on food choice can be examined by having participants choose between food items that differ in taste and health attributes (109, 115–118). Assessing mouse-tracking during these decisions can provide insight into how attributes impact value-based decisions. For example, mouse-tracking trajectories have been used to measure the cognitive effort required to make healthy choices in children (117) and determine when different attributes impact the decision-making process (115, 118). Computational models of decision-making can also be used to examine individual differences in decision-making processes when choosing among options that vary in value. For example, in the Iowa Gambling Task (119) or its adapted child version the Hungry Donkey Task (120), participants try to accumulate as many rewards as possible by repeatedly choosing between four options associated with different reward and punishment probabilities. Computational models can characterize decision-making processes such as how value is updated, consistency between valuation and choice, loss aversion, and sensitivity to the magnitude of gains and losses (121–126). Together, these approaches can be used to understand how individual differences in valuation or cognitive and psychological process relate to disordered or dysregulated eating behaviors.

Relevance to food choice and eating behaviors

Food choice and eating behaviors require the evaluation of multiple food-related attributes (e.g., taste, health) in addition to personal goals and environmental cues. Taste and health ratings are predictive of food choices in adults (127, 128), however, the impact of these attributes on decisions varies among individuals (109, 128) and can be altered following exposure to taste and health cues (103). These behavioral differences are underpinned by differences in ventromedial and dorsolateral prefrontal cortex activation during decisions (103, 109). In children, taste is more predictive of food choices than health ratings (129, 130), although the temporal dynamics of taste and health attributes on children's food choices vary by children's hunger and weight status (115). Additionally, children's food choices have been shown to be influenced by what they believe their mothers would choose for them (130). For both children and adults, food choices are impacted by many attributes including expectations about the likelihood of feeling satisfied and happy, feeling in control of one's behavior, eliminating hunger, cost, and convenience (113, 128, 131). This suggests that in addition to food-related attributes, social context, and individual characteristics (132) influence value-based food choices. Understanding the individual characteristics and environmental contexts that influence the value of certain eating behaviors could contribute to interventions that increase the value and selection of foods that optimize health.

Value-based decision-making models complement the other models discussed in this review (**Figure 2**). For example, a value-based perspective of the Extended Behavioral Susceptibility Theory would suggest that social and environmental factors, genes, and metabolic signals increase the valuation of food cues (i.e., food responsiveness) relative to satiety signals (i.e., satiety responsiveness), contributing to a positive energy balance. Similarly, a value-based perspective of REFCAM would be that food advertisements subconsciously increase the value of food through incentive sensitization, which increases the likelihood of consumption. Correspondingly, interventions that modulate value from social and environmental attributes could lead to changes in food intake. This may include techniques such as cognitive reappraisal and food cue-exposure, which could reduce the value of food cues and increase the relative influence of goal-directed values on food choice. Additionally, manipulations that increase the self-relevancy of goals or influence delay discounting for food may have the potential to influence eating behaviors through their impact on valuation (101). Future research should assess ways to modify food-related value signals across learning systems and attributes and identify who would benefit most from these interventions.

Discussion

This paper presented three neurocognitive frameworks that could help to advance our understanding of the neurocognitive processes that underly food choices, a critical step toward the development of effective, tailored health interventions. These frameworks support and may help provide mechanistic insight to prominent models for food choice and overconsumption such as the Extended Behavioral Susceptibility model, REFCAM, and the Healthy Food Promotion Model. The sign-and goal-tracking framework can help to provide insight in behavioral phenotypes that may be more susceptible to the attribution of incentive salience to food cues, which could increase craving and overconsumption. The model-free versus model-based framework provides computational models that could be used to better understand habitual intake and compulsive overeating. Finally, the utility or value-based decision-making model provides a framework for understanding how value signals from all three learning systems could be integrated to influence food choice.

The primary advantage of utilizing neurocognitive frameworks is the ability to directly probe valuation and reinforcement learning processes that drive food choice and overconsumption. As the frameworks presented here involve but distinct reward-learning processes, it is often not possible to distinguish causal mechanisms without task behavior. For example, while obesity (133–136), future weight gain (49, 137, 138), and greater food intake (139–141) have all been associated with greater food-cue reactivity in ventral striatum [see (58) for review on neural food-cue reactivity], the interpretation of these findings may differ based on which framework is referenced. Under the sign-and goal-tracking framework, this pattern of results could be interpreted as evidence that greater attribution of incentive salience to food cues drives obesity and overconsumption. In contrast, under the model-free and model-based learning framework, this pattern of results would not be sufficient to make a distinction as both strategies engage ventral striatum (79). However, when considered along with consistent evidence that greater prefrontal cortex engagement is associated with healthy weight (133–136) and lower food intake (142, 143), the combined pattern of results may be interpreted as evidence that greater reliance on model-based strategies is associated with lower weight status and food intake. Alternatively, when using the utility or value-based decision-making framework, the combined pattern of findings could be interpreted as evidence that greater relative value for goal-directed than hedonic values when viewing food cues is protective from excess consumption and adiposity. Therefore, future studies need to assess both neural food-cue reactivity and reward learning. In order to determine how these frameworks mechanistically contribute to different aspects of food choice and overconsumption, ingestive behavior needs to be characterized alongside reward learning and neuroimaging.

All three of these frameworks have utility for better understanding food choice and overconsumption; the choice of which framework(s) to reference ultimately depends on the theory of eating behavior and hypotheses being tested. The sign- and goal-tracking framework enables one to test very specific hypotheses related to the attribution of incentive salience to food cues and its role in motivated behavior such as craving. Model-free and model-based reinforcement learning provides a broader framework to examine reinforcement learning and its role in habitual or compulsive overeating. Lastly, the utility or value-based decision-making theory provides a larger framework to understand how valuation and reinforcement learning processes interact across behavioral control systems during food choice. In sum, applying these frameworks to provide mechanistic insight of prominent models of food choice and overconsumption may eventually contribute to more informed prevention and treatment efforts.

Author contributions

AP conceptualized the topic and structure and lead the writing and editing of manuscript. BF and KK helped to write and edit the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Potential mechanisms and modulators of food intake during pregnancy

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Dietary choice during pregnancy is crucial not only for fetal development, but also for long-term health outcomes of both mother and child. During pregnancy, dramatic changes in endocrine, cognitive, and reward systems have been shown to take place. Interestingly, in different contexts, many of these mechanisms play a key role in guiding food intake. Here, we review how food intake may be impacted as a function of pregnancy-induced changes across species. We first summarize changes in endocrine and metabolic signaling in the course of pregnancy. Then, we show how these may be related to cognitive function and reward processing in humans. Finally, we link these to potential drivers of change in eating behavior throughout the course of pregnancy.

KEYWORDS

nutrition, pregnancy, reward processing, cognition, hormones, metabolism, diet

Introduction

Pregnancy is a time of major hormonal, physiological, and cognitive change for the mother, and of vital development for the child. Dietary intake is particularly important during this period, as it shapes both short- and long-term health outcomes of mother and child. Diet during pregnancy influences the development of gestational disease in pregnant women (1). For example, it impacts gestational diabetes mellitus (2), which is the development of glucose intolerance during pregnancy (3), and pre-eclampsia (4, 5), which is the development of hypertension and increased protein levels in the urine during pregnancy (6). Gestational diabetes increases risk for hypertensive disorders (including pre-eclampsia) as well as preterm birth and infants born large for gestational age (7). Dietary intake during pregnancy also influences health outcomes through its impact on weight gain. Overweight and obesity, as well as excessive weight gain are associated with health complications during pregnancy (8), such as thrombosis (9) and caesarian delivery (9). In offspring, maternal food intake can impact neurobiological development. For example, maternal high fat diets influence dopaminergic (10), hypothalamic (11), and hippocampal (12) development in rodents. Maternal diet also impacts other important aspects of development, such as the infant's gut microbiome (13).

Dietary choice during pregnancy continues to impact health outcomes of mother and child even after pregnancy. In offspring, nutrient exposure during pregnancy impacts disease development later in life (14) such as obesity, diabetes (15), cancer (16), and asthma (17). Higher diet quality during pregnancy has been associated with higher neurodevelopment (18) and intelligence scores (19) in childhood. Higher intake of highly processed foods in pregnancy has been associated with worse verbal functioning in childhood (20). The aforementioned impact of maternal high fat diets on neuronal circuitry development impacts eating behaviors later in life, for example, non-human primates exposed to such diets *in utero* are more likely to later choose foods high in fat and sugar, and also show suppressed dopamine signaling (21). The impact of maternal diet on the infant gut microbiome has important implications for health outcomes such as asthma (22) and the functioning of the immune system (23). In pregnant women, gestational diabetes is associated with at least a sevenfold increased risk of developing type 2 diabetes later in life (24), as well as an increased risk of cardiovascular disease (25). Preeclampsia is associated with a multitude of long-term health outcomes (26), such as roughly double the risk of early cardiac disease (27) and an increased risk of renal disease (28). Further, women who gain more weight during pregnancy retain more of this weight gain both 1 and 15 years after delivery (29). Diet during pregnancy, therefore, is important to the health of mother and child both during pregnancy and post-pregnancy.

Beyond the importance of preventing undesirable health outcomes, the magnitude of an event such as pregnancy may make it a "teachable moment." A teachable moment is a life event during which those experiencing it are especially amenable to positive lifestyle behavioral change (30). Pregnancy can be considered such an event, as it is a period in which women are more concerned about health-related behaviors, and have increased contact with healthcare providers (31). Therefore, effective nutrition interventions may be especially impactful on positive long-term health behaviors of women if they are administered during pregnancy (31).

Despite the importance of dietary intake during pregnancy, sufficient research on how to improve diet and associated health outcomes during pregnancy is lacking. According to a review by Skouteris et al. (32), diet improvement outcomes from health interventions in pregnant women have produced inconsistent results. Encouraging healthy gestational weight gain through current healthcare provider advice has also not produced consistent improvements (33). Further, interventions are still not effective at improving many critical outcomes, such as gestational diabetes (1). There is a need to move beyond simple dietary advice, and incorporate other important factors guiding food intake (32). For this, we require a better understanding of the relevant mechanisms guiding dietary choice during pregnancy (32).

Recent research on dietary choice has highlighted the importance of underlying mechanisms involving metabolic, reward, and cognitive processes (34). During pregnancy, the maternal body and brain undergo hormonally driven changes that result in alterations in these mechanisms of metabolic functioning (35), reward processing (36), and cognition (36). A better understanding of these pregnancy-related changes to important mechanisms underlying eating behavior would be helpful in understanding what shapes dietary choice during pregnancy (see **Figure 1**). This can foster the efficacy of healthcare provider advice and interventions to promote healthy dietary choice during pregnancy.

The aim of this narrative review is to better understand the physiological and cognitive mechanisms shaping dietary decision-making during pregnancy, and is structured as follows: first, we review how eating behavior changes during pregnancy. Then, we review the current understanding of pregnancy-related hormonal, metabolic, reward-related, and cognitive changes. Further, we review how these mechanisms can impact eating behaviors and food intake in general. Finally, we link these mechanisms to eating behavior during pregnancy. This review, therefore, will highlight an underexplored and important research direction involving the impact of pregnancy-induced changes on the eating behavior of pregnant women. Though the focus of this review is pregnancy, we occasionally draw upon postpartum research in areas in which research in pregnancy is limited and the postpartum findings can help us to better understand the pregnancy transition. Additionally, as described above, maternal nutrition has important consequences for offspring-related outcomes. Findings from this area of research, however, are largely beyond the scope of this review.

Food intake during pregnancy

During pregnancy, total energy consumed increases (37). Specifically, resting metabolic rate can increase by about 29%, whereas energy intake can increase by about 9%, and fat mass can increase by around 4.5 kg when comparing pregnancy to pre-pregnancy (38). Self-reported food-intake of pregnant women seems to shift toward more healthy nutrition, as significant increases are observed in the consumption of fruit and vegetables, and decreases in the consumption of eggs, fried and fast foods, and coffee and tea (37).

Such a shift in nutrition seems to partly reflect the reported motivations to adjust diet in pregnancy, including the desire to optimize health outcomes for the fetus, to optimize nutrient intake, to enhance health, to lessen illness or to help pregnancy-induced nausea, as well as to satisfy craving and for enjoyment (39). Craving, in particular, is an often reported important motivator of food intake during pregnancy, but it is not yet determined what underlies reported increases in cravings during pregnancy (40) [although higher stress and worse sleep quality during pregnancy can exacerbate them (41)]. The most frequently reported changes in diet were in line with direction received by expectant mothers, such as to reduce caffeine consumption, to be careful in terms of food preparation, and to increase intake of both dairy as well as fruits and vegetables (39). Whereas advice to increase the intake of fish, meat, and alternatives are less well-followed, the motivation to reduce intake of harmful foods was more often reported than the motivation to increase intake of foods containing important nutrients, which leaves room for improvement in terms of dietary choice during pregnancy (39).

It is important to keep in mind that the research on dietary intake during pregnancy so far has primarily relied on self-reports (37). Although self-reported motivations for dietary choice can be informative, it is essential to know that these might deviate from actual food intake, and it is also important to understand how pregnancy itself might impact dietary choice. This challenge highlights the importance of understanding objectively observable factors, such as hormonal, reward, and cognitive mechanisms, since these guide eating behaviors.

Hormonal signaling

Major hormonal changes in pregnancy and food intake

Dramatic hormonal changes orchestrate the maternal adaptations necessary to meet the demands of a successful pregnancy (42). Progesterone levels, which normally decrease during the

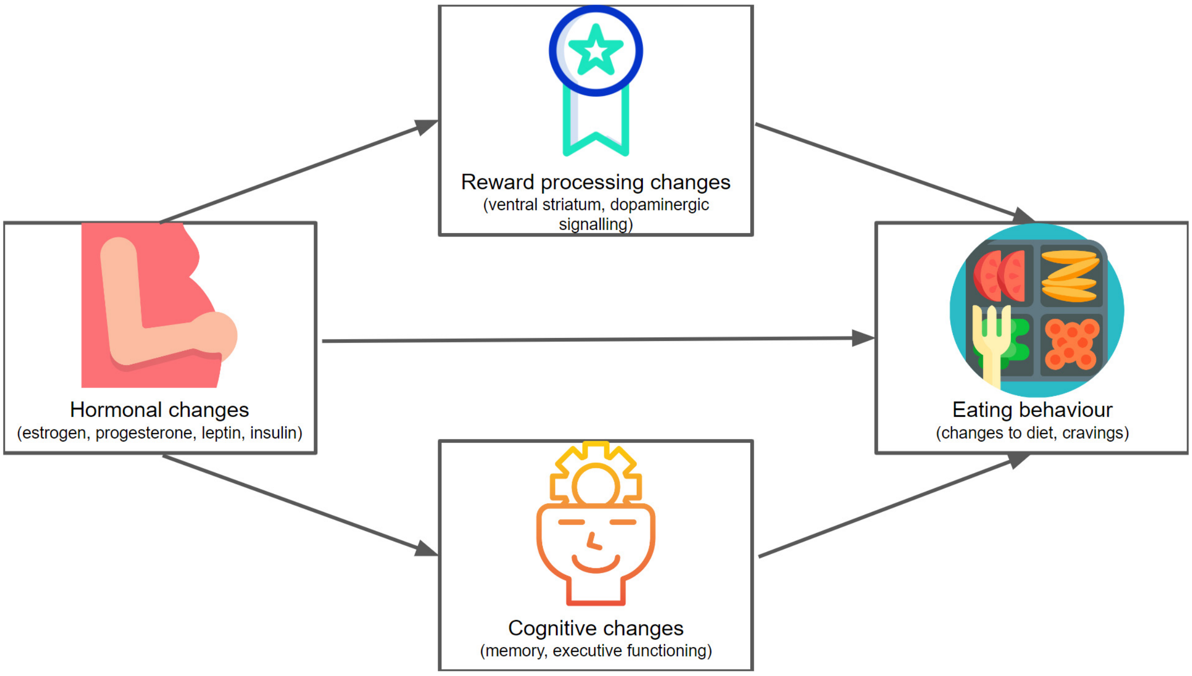

FIGURE 1
A conceptual mapping of the framework of this review. We explore hormonal (including metabolic), reward-related, and cognitive changes in pregnancy, and consider how these might affect eating behavior. Icons made by Freepik (136, 137), Icongeek26 (138) and catkuro (135) from www.flaticon.com.

menstrual cycle, remain high and increase in response to the initial pregnancy signaling hormone human chorionic gonadotropin (hCG), and estradiol (an estrogen) levels increase during the second and third trimester (42). In the course of pregnancy, both estrogen and progesterone levels reach levels many fold higher than at any point during the menstrual cycle (43). Other important hormonal changes during pregnancy include those affecting glucocorticoids [which reach levels three times higher than usual by the third trimester (44)] as well as prolactin and growth hormone (42).

Interestingly, hormones such as estrogen, progesterone, prolactin, growth hormone, and cortisol have been reported to impact eating behavior in general. In non-pregnant populations, estrogen generally reduces food intake (45), protecting against binge eating (46), and has been a candidate hormone for treating obesity (47). In non-pregnant rodent models, estradiol administration can reduce weight gain (48, 49) and restore leptin sensitivity [a satiety-signaling hormone (48)], while estrogen depletion can lead to an increase in body fat (50). However, in pregnant populations, these estrogenic effects disappear. For example, thermogenesis of brown adipose (fat) tissue resulting from estradiol administration in non-pregnant rats is absent in pregnant rats (51).

The increased food intake and weight gain occurring alongside large increases in estrogen (35) during pregnancy suggest interactions with other pregnancy-related hormonal changes, such as an estrogen-progesterone interaction. Progesterone has been shown to influence dietary intake indirectly, for example through counteracting the effects of estrogen (35, 52). In non-pregnant populations, higher progesterone levels can increase the risk for maladaptive eating behaviors by reducing the protective effects of estrogen on, for example, binge eating behavior (46). It is the interaction of high levels of both progesterone and estrogen that has been associated with increased emotional eating across the menstrual cycle, rather than the independent effects of either (53).

In pregnant rodent models, prolactin interacts with satiety signaling by contributing to leptin insensitivity to promote food consumption (54), and growth hormone affects plasma glucose regulation and fat gain in pregnancy (35). Excessive cortisol production has been linked to increased fat accumulation in non-pregnant populations, as well as to metabolic disorders such as diabetes (55), but the role of cortisol in eating behavior during pregnancy remains unknown (35). Although many of these pregnancy-related hormones, as well as their complex interactions, point to their potential role on dietary intake and metabolic dynamics, these are largely under-investigated and present an important avenue for further research, especially since they dramatically change during pregnancy.

Metabolic modulations during pregnancy and food intake

Energy homeostasis signaling is affected by the above-described hormonal changes in a manner that ensures adequate energy for fetal development and lactation (35). Here, we focus on the ingestive hormonal changes of leptin and insulin. Leptin is a hormone released from adipose tissue that maintains fat tissue levels by signaling the body's current energy state and suppressing further food intake (56), and insulin is a hormone involved in facilitating muscle and fat tissue glucose uptake (57).

Pregnant women display both increased serum leptin levels (58) and decreased leptin sensitivity (59). This increase in leptin levels may result from an increase in fat mass during pregnancy (60), additional leptin secretion from the placenta (61), and a slower clearing of leptin from the blood during pregnancy (62). The functional role of increased leptin levels (beyond being a by-product of increased fat stores) is not fully known (54), but it plays a role in fetal development (63). Since leptin signals a reduction in the need for food intake, a decrease in leptin sensitivity (possibly due to the effect of prolactin and growth hormone) counteracts this and allows for the important maternal adaptation of greater food intake and positive energy levels (54).

Like leptin, insulin functioning has been shown to be altered during pregnancy *via* higher insulin levels on the one hand and decreased insulin sensitivity on the other (64). These changes in insulin functioning are thought to play an important role in ensuring adequate energy supply to the fetus through their role in glucose regulation (42), which is to facilitate glucose uptake in fat and muscle tissue (65). Glucose is transmitted to the fetus passively; for this to be possible, the mother's glucose levels must remain higher than that of the fetus', and so the mother's tissues become less insulin sensitive (66). The fetus must also, however, be protected from excessive glucose exposure following a meal, and so higher levels of insulin are released to protect the fetus from overexposure due to the mother's insulin-insensitive tissue (54). The changes in insulin during pregnancy have been associated with pregnancy-related weight gain (67). These changes both in insulin and leptin are conducive to creating a positive energy balance, which is thought to be necessary to provide energy to the growing fetus (68). As noted by Grattan and Ladyman (42), the pregnant body is engineered for weight gain, but this increases the risk for excessive gestational weight gain in our current food environment (42).

Effects of hormonal modulations on reward processing and cognition

Receptors for hormones such as estradiol (69), progesterone (70), glucocorticoids (71), leptin (72), and insulin (73) are present throughout the brain, and have been shown to impact both reward processing and cognition (42, 74, 75). For example, the rewarding value of pup stimuli in rodents is mediated by progesterone and estradiol (76, 77). Across species, leptin and insulin have been shown to modulate reward processing *via* the dopamine system (34). Specifically, both leptin (78) and insulin (79) dampen dopaminergic signaling in (non-pregnant) rodents. Estradiol, progesterone, and glucocorticoid levels have been linked to cognitive functioning in both pregnant (80) and non-pregnant (for example, menopausal) (81) women. For instance, higher estradiol and lower cortisol levels have been associated with worse verbal recall ability in pregnant populations (82). Insulin resistance (83) and leptin resistance (84) have been associated with cognitive impairment (such as mild cognitive impairment) in non-pregnant populations, and insulin resistance in gestational diabetes mellitus may contribute to worse cognitive performance during pregnancy (85). For instance, pregnant women with gestational diabetes mellitus performed worse than non-diabetic pregnant women on the Montreal Cognitive Assessment test, which measures a range of cognitive functions (86). Although more work on these relationships in pregnancy is needed (80), initial evidence points to how these systems are interrelated. In the following sections, we will more closely explore how pregnancy-induced changes in reward processing and cognition may impact eating behavior.

Reward processing

Pregnancy and reward processing

Pregnancy alters reward processing in humans. Hoekzema et al. (87) found a reduction in gray matter volume in the right ventral striatum (a region important to reward processing) from pre- to post-pregnancy. Further, the striatum was more strongly activated when viewing images of one's own vs. other baby, and the degree of this striatal activation was also associated with the degree of gray matter reduction (87). This has been interpreted as synaptic pruning representing an adaptive specialization, such that mothers' reward processing areas are altered during pregnancy and show strong responsivity to infant cues (87). Such reward processing adaptations during pregnancy may predict responsiveness in domains other than infant-reward. Indeed, a neural reward signal in response to monetary reward during pregnancy predicts later self-reported bonding between mother and child (88). Research on reward processing in pregnancy is currently quite limited, but presents an exciting avenue for future research on dietary choice.

More research exists regarding the postpartum period, and these findings support our current understanding of the reward processing changes that occur in the transition to parenthood beginning in pregnancy. Gray matter volume change from early to later postpartum is associated with a positive perception of one's baby (89), and reward processing of infant cues in postpartum women show strong activation in response to own-infant stimuli in reward-related areas including the nucleus accumbens (74). The role of reward processing in parenthood is also supported by the finding that dopamine receptor genes in human mothers have been associated with maternal behavior, for example, orienting to one's infant (90). Pregnant and postpartum rodent models further highlight this important transition in reward processing, since rodents transition from finding pup cueing aversive to rewarding (75). Postpartum rodent mothers have greater activation in dopamine reward pathways in reaction to the suckling of their offspring than they do in reaction to cocaine exposure (91). Further, they will bar press for contact with pups (92). Additionally, agonists of D1 receptors [which are important in reward-related learning (93)] can facilitate maternal behavior in pregnancy-terminated rats (94). Much of this reward-related research has focused on the postpartum period and reward responses toward offspring, likely because this is most relevant to maternal behavior. However, it is important to remember that a substantial transition in reward-related brain areas occurs already during pregnancy in humans (87), and this carries important implications for eating behavior during pregnancy, as we will see in the following sections.

Reward processing and eating behavior

Reward processing is one of the primary drivers of food consumption (34), and motivates consumption through the rewarding properties of the food rather than due to metabolic demand (95). Reward-related eating has been associated with excess food intake and higher body mass index (96). Reward motivations for eating consist of both liking and wanting motivations (97). Liking can be described as a positive, affective reaction to a food's palatability, whereas wanting can be described as an incentive motivation to eat (97). Dopamine functioning, such as dopaminergic projections to the striatum, is especially important in wanting (98). For example, using lesions to eliminate dopamine in rats resulted in a lack of motivation to seek out or consume food, even though taste reactions remained the same (99). Further evidence for the role of dopaminergic functioning in eating behavior is that altered dopaminergic functioning has been implicated in obesity (100). Therefore, an event like pregnancy which alters such reward pathways may impact eating behavior through affecting reward-related eating.

Pregnancy, reward processing, and eating behavior

Reward processing is a key mechanism of food intake and seems to be modulated during pregnancy. One of the rare studies investigating this question in humans is the Pregnancy Eating Attributes Study (101). Here, greater reward-related eating during pregnancy was associated with lower scores on the Healthy Eating Index (102). Further analyses showed that reward-related eating was associated with higher calorie consumption after satiety (103). Interestingly, questionnaire-based food reward measures (self-reports), however, did not correlate with excessive gestational weight gain (96). Changes in the processing of food reward in pregnant rodents have been reported, with a recent association being found between changes in dopaminergic signaling and craving-like eating episodes (104). Postpartum rats, alongside an increased preference for pup cueing, show an attenuation in preference for food cueing in a conditioned-place paradigm compared to virgin rats (105), suggesting a reprioritization of reward types.

Since reward processing plays a large role in guiding dietary decision-making, these changes to reward processing during pregnancy should be considered when attempting to promote healthy eating behavior. Future research could employ neuroimaging methods to better understand how changes to the structure of the striatum and to dopaminergic signaling during pregnancy impact reward-related eating.

Cognition

Changes to cognition during pregnancy

Pregnant women experience changes in cognitive functioning. A majority of pregnant women report cognitive impairment, often termed "pregnancy brain" (80). It has often been suggested that this may demonstrate a trade-off with gestation, parturition, and maternal behaviors (82, 106). Women may undergo some "cognitive reorganization" during pregnancy, with functions such as social cognition given precedence, and others, such as memory, given a lower priority (107). It could also be that the energy demands of the fetus may impact upon cognitive function (108). Structurally, there are overall decreases in gray matter volume in pregnancy (109, 110) in areas associated with cognitive functions like memory that may be altered during pregnancy, such as the hippocampus (109).

One domain of cognition impacted by pregnancy is executive functioning. This is a collection of higher order cognitive processes that are utilized when we act in a flexible, goal-oriented manner, and include inhibition, working memory, and flexibility (111). A recent meta-analysis by Davies et al. (112) found that executive functioning (including attention, planning, cognitive flexibility, and inhibition) significantly decreases in pregnant women in the third trimester. This supports a previous review that found that working memory seemed to be particularly impaired in pregnant women (113). Conversely, Fiterman and Raz (114) found that pregnant women have better inhibition in a behavioral task, and these findings were supported by event-related potential (ERP) neural signaling (114). Pregnant women's response times were also slower (114), and these results suggest that pregnant women may be more cautious in their decision making. This finding is supported by a recent study by Chen et al. (115), in which pregnant women show higher risk aversion in the Columbia Card Sorting Task. Research so far suggests pregnancy may alter executive functioning, but work on this is limited (112). The direction of change remains unclear, but pregnancy may be associated with better inhibition.

A prevalent cognitive impairment reported during pregnancy is worsened memory (116). Overall, pregnancy appears to be associated with a decrease in memory function in both subjective reports and objective measurements. A meta-analysis by Davies et al. (112) found that memory (including working memory, long-term memory retrieval, and recognition) was broadly impacted by pregnancy, with a decrease in overall memory performance. This occurred during the third trimester in correlational studies, and the largest reduction in memory performance in longitudinal studies occurred between the first and second trimester (112). A previous meta-analysis by Henry and Rendell (113) found some measures of memory to be impacted by pregnancy, specifically free recall and delayed free recall, and the executive component of working memory. It is important to note that, while these findings are robust (112), the effects that have been found are small (113) and within normal ranges of cognitive functioning (112).

Despite small effect sizes, these memory impairments might impact the daily lives of pregnant women (117). Pregnant women report subjective memory impairment (118). Further, "naturalistic" measures of memory function, such as remembering to make a phone call or complete a time-logging task in the upcoming week found that pregnant women performed significantly worse than non-pregnant controls, even though they performed equally well on lab-based measures of memory function (113, 119), and this correlated with subjective impressions of memory function (119). Such studies shed important light on the ways in which cognitive impairment may affect the everyday lives of pregnant women, and an important domain that may be affected is eating behavior.

Cognition and eating behavior

Executive functioning has been linked with dietary choice. This relationship depends both on the facet of executive functioning as well as the facet of eating behavior being considered. For example, initiation of healthy eating behaviors, vs. inhibition of unhealthy eating behaviors, may be affected by different processes within executive functioning (120). A study by Allom and Mullan (121) found better inhibition to predict lower unhealthy food intake (saturated fat) while updating in working memory was associated with initiation of healthy food intake (fruits and vegetables). Overall, lower inhibition and greater impulsivity have been associated with a greater risk of becoming overweight or obese (101, 120).

Memory plays an important role in eating behavior [see Higgs and Spetter (122) and Seitz et al. (123) for recent reviews]. Episodic recall is important in food consumption, and this has been demonstrated by the "meal recall" effect. Cueing participants to recall a recent meal is related to less food consumption compared to being cued to recall something else, such as a meal from longer ago (124). This finding has been replicated several times, although it can also be modulated by contextual factors, such as mood (125) or dietary disinhibition (126). Initial memory encoding also guides later food consumption, and an oft-replicated finding is that distracting participants while they eat leads to greater food consumption later (122). For example, watching television while snacking has been associated with more food consumed at a later meal, along with worse recall of the amount that they had snacked (127, 128). Further, better episodic recall is associated with less uncontrolled and emotional eating, and more strategic dieting, as well as a higher likelihood of avoiding fatty food consumption (129). Interestingly, hippocampal volume (a brain area important in memory functioning) has been repeatedly associated with diet-related outcomes, such as being overweight or obese (123). Different cognitive functions play an important role in eating behavior, therefore changes in these cognitive functions during pregnancy will impact eating behavior.

Pregnancy-induced cognitive function changes and links to eating behavior

From the above-described findings, we can conclude that pregnancy-induced changes in cognitive functioning, such as in memory and executive functioning, are very likely to impact dietary choices. Though there is very limited research on executive functioning during pregnancy, some of the available evidence suggests that pregnant women may have slower response times and greater inhibition. Future research could determine if this may positively impact dietary choice, since better inhibition may limit unhealthy food intake. Conversely, worse memory in pregnancy may exacerbate excessive food intake, since memory function has been linked to the regulation of eating behavior. It would also be interesting to better understand the possible relationship between a reduction of hippocampal volume during pregnancy, and the association between reduced hippocampal volume and a higher likelihood of being overweight or obese in non-pregnant populations. A better understanding of these relationships would allow us to work toward optimizing dietary advice and interventions during this critical period, by tailoring such approaches to both counteract cognitive impairment, and harness cognitive changes that could promote healthy eating behavior.

Conclusion and future perspectives

This review has considered pregnancy-induced changes to hormonal, metabolic, reward-related, and cognitive processes guiding dietary choice. As outlined above, some changes, such as metabolic and memory changes, may make it difficult to make healthy dietary decisions during pregnancy, since the pregnant body is adaptively geared for weight gain, and impaired memory may negatively impact eating behaviors. Other changes, such as those related to reward processing and inhibition, may encourage beneficial eating behavior, since pregnant women may be more attuned to offspring-related reward (including the health of the baby), and greater inhibition could encourage healthy food choice. Future research is needed to further investigate the influence of these changing mechanisms on dietary intake.

Despite limitations in terms of research available in this area, we are already able to integrate these findings from different fields to produce tangible suggestions for the improvement of dietary behavior in pregnant women. For example, we have seen that memory impairment negatively impacts healthy food choices, and that memory is impaired in pregnancy. Therefore, practices aimed at improving memory of food consumption, such as food journaling (122), may be especially helpful during this time period. Further, since reward responsiveness to offspring develops during pregnancy, it may be helpful to increase education regarding the impact of nutrition on offspring outcomes. Currently, nutrition education for pregnant women is inadequate (130). If it were improved, pregnant women would be more aware of health information which may increase the reward value of healthy food once it has been explicitly connected to offspring wellbeing.

Effective promotion of healthy nutrition during pregnancy could be implemented both through healthcare providers as well as *via* digital devices. Healthcare providers such as physicians, midwives, and counselors could educate pregnant women on the reward-related and cognitive processes guiding dietary choice, and implement practices that target the pregnancy-induced changes in such processes. A more cost-efficient strategy could involve current technology such as mHealth (the use of mobile devices in healthcare) that have wide availability (131). Current mobile health interventions for pregnancy have shown only limited success (132), suggesting room for improvement. Mobile interventions for pregnancy could be improved by integrating practices targeted at the pregnancy-induced changes discussed in this review. For example, smartphone interventions can effectively improve memory function in the context of food consumption in non-pregnant populations, through, for example, recording meals, and this can lead to increased reported awareness of food consumption and weight loss (133). Another mobile intervention altered reward value of food through increasing awareness with mindfulness practices in a non-pregnant population (134). Such a practice could be tailored to the changes women experience in reward processing in pregnancy by promoting awareness of the health associations of their dietary choices for their offspring, as this could alter food reward value for pregnant women in a manner encouraging healthy food choices. Understanding pregnancy-induced changes to hormonal, metabolic, reward-related, and cognitive processes would provide evidence for which tasks, training, and educational materials would be most effective in promoting healthy eating behavior in pregnant women, both from healthcare providers and from digital sources.

A limitation of this review is the limited research in this domain, and therefore our use of postpartum studies. However, from what we know of the dramatic hormonal and anatomical changes occurring during pregnancy, we can assume that postpartum findings have something valuable to offer in helping us better understand changes in pregnancy. Another limitation is that much of the research currently available employs rodent models. While these are helpful in gaining an understanding of how we might expect pregnancy to affect women, it is important to verify such findings in humans.

In conclusion, a better understanding of pregnancy-induced changes to hormonal, metabolic, reward-related, and cognitive changes would provide actionable suggestions for improving important health outcomes for pregnant women. More research in this domain is essential because dietary choice during pregnancy affects both short- and long-term outcomes for mother and child, such as cardiovascular and metabolic health. The health consequences of dietary choice during this period extend throughout the lifetime, carrying significant personal and financial implications, making this an important research area to pursue.

Author contributions

TW and SP: conceptualization, investigation, methodology, formal analysis, writing, and project administration. TW: visualization. SP: supervision and funding acquisition. Both authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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