Vitt, N., Vecchi, M., James, J., & Belot, M. (2022). Maternal Stress during Pregnancy and Children's Diet: Evidence from a population of low socioeconomic status. *Nutrition*, 93, [111423].
<https://doi.org/10.1016/j.nut.2021.111423>

Publisher's PDF, also known as Version of record

License (if available):
CC BY-NC-ND

Link to published version (if available):
[10.1016/j.nut.2021.111423](https://doi.org/10.1016/j.nut.2021.111423)

[Link to publication record in Explore Bristol Research](#)
PDF-document

This is the final published version of the article (version of record). It first appeared online via Elsevier at <https://doi.org/10.1016/j.nut.2021.111423> . Please refer to any applicable terms of use of the publisher.

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:
<http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/>

Applied nutritional investigation

Maternal stress during pregnancy and children's diet: Evidence from a population of low socioeconomic status

Nicolai Vitt Ph.D.^a, Martina Vecchi Ph.D.^b, Jonathan James Ph.D.^{c,*}, Michèle Belot Ph.D.^d^a University of Bristol, Bristol, United Kingdom^b Pennsylvania State University, State College, Pennsylvania^c University of Bath, Bath, United Kingdom^d Cornell University, Ithaca, New York

ARTICLE INFO

Article History:

Received 7 December 2020

Received in revised form 28 June 2021

Accepted 15 July 2021

Keywords:

Diet

Stress

In-utero

Food preferences

ABSTRACT

Objectives: This study examined the relationship between maternal exposure to stress during pregnancy and children's food preferences and diet in a population of low socioeconomic status.

Methods: Indices of exposure to stress were constructed based on retrospective self-reported experience of stressful events during pregnancy (e.g., death of close family member, relationship difficulties, legal issues, health issues, financial issues, or other potentially stressful event[s]). Data were collected for >200 mothers of a low socioeconomic status with a child age 2 to 12 y. Data on mothers' body mass index, current exposure to stress, current diet, and diet during pregnancy were collected at the same time, as well as data on children's food preferences and current diet as reported by the mothers. Indices of the healthiness of food preferences and diet were constructed and used as outcome variables.

Results: Maternal exposure to stress during pregnancy significantly predicts children's food and taste preferences, as well as their diet, in regression models controlling for maternal diet, current maternal stress, and demographic characteristics of both the child and mother. Higher average stress during pregnancy is linked with significantly less healthy food preferences and diet, as well as with weaker preferences for sour and bitter foods. This relationship is observed across different age groups.

Conclusions: Maternal exposure to stress during pregnancy could have long-term detrimental effects on dietary outcomes and thereby on health conditions related to diet. Prenatal care and preconception counseling could be critical to develop preventive strategies to improve public health.

© 2021 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

Introduction

The spread of obesity in developed nations over the past decades has disproportionately affected lower socioeconomic groups because they face a larger risk of being overweight and obesity [1–3]. Eating patterns and tastes particularly appear to be largely formed early on in life (ie, during pregnancy and early childhood) [4], and previous evidence has suggested that parental socioeconomic status (SES) has a direct impact on the probability of children being obese [5].

This study explores a specific pathway possibly linking parental SES to a child's diet: Maternal stress during pregnancy. Research in medicine and epidemiology has highlighted the role of maternal stress during pregnancy and the resulting hormonal processes in

determining children's obesity risk in later life via so-called fetal programming [6–9]. Fetal programming of the metabolic system emphasizes the importance of the intrauterine environment in determining health outcomes during childhood and even adulthood. Evidence based on animal and human studies [6] has shown that in utero stress increases the risk of obesity and related conditions. Stress-induced hormonal and immune processes have been suggested as channels for these effects on the fetus. The evidence suggests that experience of severe stress during pregnancy may, for example, lead to dysregulated glycemic control or energy homeostatic balance. Whether these processes increase the risk of obesity only by affecting the development of the child's metabolic system or whether they also change the child's food preferences is unclear.

A second possible channel linking in utero exposure to stress and children's diet is through the neurologic development or programming of neurologic functions in utero. One hypothesis is that in utero exposure to stress could result in the persistent

*Corresponding author. Tel.: +44 (0) 1225 385557
E-mail address: j.james@bath.ac.uk (J. James).

programming of the hypothalamic–pituitary–adrenal (HPA) axis hyperresponsiveness, which in turn affects preferences for comfort foods later in life [10]. Chronic stress is well known to be related to the chronic stimulation of the HPA axis and the glucocorticoid secretion from the adrenal gland [11,12]. Intake of high energy foods (ie, comfort eating) suppresses the hyperactivity of the HPA axis. Also, there is a body of evidence showing that if a mother is stressed while pregnant, her child is substantially more likely to have emotional or cognitive problems, including an increased risk of attention deficit/hyperactivity, anxiety, and language delay [13]. Plausibly, emotional and cognitive problems could increase the risk of emotional eating and thereby contribute to unhealthy eating patterns in the child [14].

In addition to these neurologic, hormonal, and immune processes described, stress may affect a mother's dietary choices during pregnancy and early childhood, which in turn are primary influences on the formation of children's food preferences [15]. Empirical evidence supports a link between stress and nutrition during pregnancy. In animals, stress and nutrition during pregnancy have also been linked with adverse metabolic outcomes of offspring [16]. In humans, gustatory and olfactory systems emerge in utero and are functionally mature before birth [17], providing opportunities for early sensory learning and shaping early preferences, as supported by animal studies [18,19].

A recent review by Lamichhane et al. [20] has found that subjective prenatal stress caused by exposure to natural disasters is linked to offspring obesity, but studies with biomarkers of stress showed mixed results. Based on the existing evidence, in utero exposure to stress is a plausible pathway to obesogenic food preferences. However, to our knowledge, there have been no human studies linking in utero stress exposure to food preferences and diet during childhood.

The literature has also proposed that higher levels of stress among populations from lower socioeconomic backgrounds could be a factor behind the socioeconomic gradient in obesity [21,22]. Evidence based on observational data has shown that some individuals exposed to chronic stressors have a less balanced diet and increased calorie intake [14]. Laboratory experiments have shown that acute stress shifts individuals' food choices toward a less healthy diet with higher consumption of sugars and fat and a higher total calorie intake [23,24]. Evans et al. [25] showed that exposure to stress during childhood is associated with lower self-regulation and a higher body mass index (BMI).

In this study, we examined the relationship between maternal stress during pregnancy and children's food preferences and their diet. Indices were constructed to measure the healthiness of each. Stress during pregnancy was assessed using retrospective self-reported information on stressors experienced during pregnancy and their perceived stressfulness. Additional data on possible confounding factors, such as the mothers' current stress and diet and the mother's diet during pregnancy, were collected at the same time. These confounding factors were controlled for in our analysis.

Methods

Participants

Participants were 213 mothers of low SES living in the area of Colchester, United Kingdom, who were taking part in a larger study on the link between stress and diet. The mothers were recruited using multiple channels (eg, letters sent to homes in low-income neighborhoods, leaflets provided to participants attending another study).

To participate, mothers had to fulfil the following eligibility criteria: Age between 18 and 45 y, fluent in English, youngest child age 2 to 12 y, net annual household income <£35,000, not holding a university degree, not currently enrolled at university, not having allergies or intolerances to the foods provided

during the study, and no medical conditions that can affect diet (eg, diabetes). Those interested in participation were invited to complete an online screening questionnaire or contact the experiment team by telephone. The screening aimed to assess their eligibility for the study according to the criteria described above. The age range of the children considered was relatively large (2–12 y), allowing us to study the effects across different age groups.

Subsequently, eligible mothers were invited to one of the experimental sessions, and they were provided with an informational leaflet and consent form by mail. The participants were not made aware of the topic and research question of the study. Participants in the experiment received a monetary compensation between £60 and £75, and 1 in every 15 participants additionally received a food basket they selected during the study (worth up to £30).

The questionnaires used in the study allowed for us to check again that the participants fulfilled the eligibility criteria. Fourteen of the 227 registered participants did not fulfil all eligibility criteria and were excluded from the analysis, leaving a sample of 213 mothers of low SES for our analysis.

Procedures and measures

Data were collected on the mother and one child (youngest child age >2 y, henceforth referred to as "child"). The questionnaires used in the study can be found in Supplementary Appendix B.

Primary explanatory variable: In-utero stress exposure

The primary explanatory variable is the level of stress experienced by a mother during her latest pregnancy. The measures of stress during pregnancy used in this study were based on the self-reported exposure to a number of potential stressors and their perceived stressfulness. Specifically, we asked whether mothers experienced one or several of the following life events during the pregnancy with their child: Death of close family member or close friend, changes or difficulties in their relationship, legal issues, changes or difficulties in their family life, health issues, changes or difficulties in their or their spouse's employment, financial issues, changes in their habits, other potentially stressful event(s). For each event experienced, the mothers were asked how stressful they had perceived the event to be on a Likert scale from 1 (not stressful at all) to 10 (extremely stressful). We address the issue of measurement error due to inaccurate recall in the analysis.

Based on these individual stressfulness perceptions, two aggregate measures were constructed: Average and maximum perceived stressfulness. The average perceived stressfulness is a cumulative measure, and was computed across all nine potential stressors:

$$Stress_{Avg, i} = \frac{1}{9} \sum_{j=1}^9 PercStress[event\ j]_i$$

where the stressfulness of events that were not experienced was set to the minimum value of 1: $PercStress[event\ j]_i = 1$ if participant i did not experience event j . The maximum perceived stressfulness was computed as the highest perceived stressfulness score among all events experienced, and was set to 1 if a mother was not exposed to any of the potential stressors:

$$Stress_{Max, i} = \begin{cases} \text{Max}(PercStress[event1]_i, PercStress[event2]_i, \dots) \\ 1 \text{ if no exposure to any stressor} \end{cases}$$

Both the average and maximum perceived stress measures ranged from 1 to 10.

These measures were validated by examining their relationship with a variety of coping measures (App. D). To assess the coping style of the mothers, they were asked how they usually react to stressful situations: Problem-oriented, emotion-oriented, or avoidance. The distinction between these three different coping styles was based on Endler and Parker [26]. The use of each coping style was scored on a five-point Likert scale from 1 (never) to 5 (very often).

Outcome variables

Child's diet. One of the primary outcomes examined in this study was the healthiness of the child's current diet. We constructed an adjusted index to measure the diet quality of the child. The index was adjusted from the KIDMED index developed by Serra-Majem et al. [27], measuring the adherence to a Mediterranean-like diet (ie, diet rich in fruit and vegetables, fish, legumes, and grains, and low in processed foods). This index was adjusted to the U.K. context by including other vegetable oils in the oil item section and excluding the index item "commercially baked goods or pastries for breakfast". This index was chosen because the KIDMED questionnaire has been widely used and captures the national dietary recommendations in the United Kingdom [28]. Of note, various studies have shown an association between Mediterranean diet adherence and diet quality [29] and between adherence to the Mediterranean diet and better health [30].

Scoring was based on questions asked to the mother about the usual food habits of her youngest child. The index items and their respective weights were at least one daily fruit or fruit juice serving (+1; all results were robust to excluding

fruit juice from the indices of diet and food preferences), a second daily fruit serving (+1), at least one daily vegetable serving (+1), a second daily vegetable serving (+1), at least 2 weekly fish portions (+1), at least 1 to 2 weekly fast-food meals (-1), at least 2 pulse/legume servings per week (+1), at least 5 weekly pasta/rice meals (+1), cereals or grains for breakfast (+1), at least 2 weekly nut servings (+1), olive or other vegetable oil used as main culinary fat at home (+1), skipping breakfast (-1), dairy products for breakfast (+1), at least 2 yoghurts/40 g cheese per day (+1) and, eating sweets/candy more than once per day (-1). The adapted KIDMED index ranged from -3 to +12.

Child's food preferences. The second primary outcome of the study was the healthiness of the child's food preferences. We constructed a novel index, Food Preference Index for Children (FPI-C), based on the children's liking of food groups listed in the Diet Quality Index described above. The index was constructed using questions asked to the mother about their child's liking of a variety of food and drink items, scored on a five-point Likert scale from 0 (dislike extremely) to 4 (like extremely). Alternatively, mothers had the option to respond "never tried" or "don't know" for each item. Of note, Pliner and Pelchat [31] validated mother-reported food preferences of children in a pretest of their questionnaires, and found strong agreement between child- and mother-reported food preferences. When comparing reports on two separate occasions, they also observed strong agreement of the reported food preferences over time.

Average liking of the following food groups was calculated and then summed using the index weights indicated in parentheses: Fruit (+2), vegetables (+2), legumes/pulses (+1), fish/shellfish (+1), pasta/rice (+1), cereal/grains (+1), dairy products (+1), commercially baked goods/pastries (-1), sweets/candies (-1), fast food (-1). Of note, we had planned to also include the food groups "nuts" and "sugar-sweetened drinks", but dropped these from the index due to large numbers (>25% of the sample) of "don't know" and "never tried" responses for all items in these two food groups.

The preference index was calculated based on the average liking of the food groups:

$$FPI_C = \sum_j weight_j \times AverageLiking_{j,c}$$

where j is a food group and c is an individual child. To simplify interpretation, the index was rescaled to run from 0 (least healthy preferences) to 10 (most healthy preferences). If information on the liking of a food item was missing due to "never tried" or "don't know" responses, the average food group liking for this child was calculated without the missing food item(s). If information on the liking of all items in a food group was missing, the observation was excluded from the analysis.

Child's tastes. Secondary outcomes in this study were the preferences of the child for the five basic tastes. We computed the average liking of sour, salty, umami, bitter, and sweet foods in a similar fashion to the average liking of food groups for the FPI-C. The resulting measures ranged from 0 (dislike extremely) to 4 (like extremely). Foods used to calculate liking of each taste were grapes, oranges, lemons, and vinegar for sour; chips/French fries and crisps for salty; mushrooms, parmesan, meat, and fish foods for umami; asparagus, Brussels sprouts, black olives for bitter; and pastries, cake, biscuits, chocolate, ice cream, cola, and Fanta for sweet.

Child's body mass index percentile. Although intended as a primary outcome, little focus was placed on the BMI percentile of the child due to data issues. Sex- and age-specific BMI percentiles were calculated based on mother-reported height and weight of the child. Seventeen percent of the sample obtained BMI percentile scores <0.05, and >45% of the sample obtained percentile scores >0.95, indicating a potential reporting bias. Hence, little faith was put into this measure, and we do not present any analysis for this outcome variable.

Control variables

Controlling for potentially confounding factors was important in our analysis, because stress during pregnancy was not a randomly assigned explanatory variable. To mitigate the influence of confounding factors in the analysis of the relationship between stress during pregnancy and the child's current diet and preferences, a number of variables capturing maternal diet (current and during pregnancy), as well as current stress levels, were included in the econometric models as control variables.

For the maternal diet, an Index of Diet Quality similar to the child's index was constructed. The index was adapted from the Index of Mediterranean Diet Adherence [32] to capture the healthiness of the mother's diet and adjusted to the U.K. context. Again, the index reflected the main U.K. dietary recommendations [28]. We used the same scores and thresholds as reported in Martínez-González et al. [32], except for the exclusion of the sofrito item and inclusion of other vegetable oils in the olive oil items to adapt to the U.K. setting. We computed this index both for the current diet and the pregnancy period. In the pregnancy context, we removed the positively weighted index item for wine consumption. Details of the index items and weights are reported in Supplementary Appendix C.

To capture maternal food preferences, a Food Preference Index was constructed based on the average liking of food groups in the Index of Diet Quality described above. The index was calculated in the same way as the FPI-C described above (Suppl. App. C). Furthermore, we used taste preference indices for children as outlined above to capture maternal liking of the five basic tastes. To capture current exposure to stress, two variables similar to the ones used for stress exposure during pregnancy were constructed (maximum and average stress), but relating to the 3-mo period before the study.

Finally, variables capturing demographic characteristics that were found to vary significantly with stress during pregnancy were also included in the analysis: Age and sex of the child, age of the mother, mother's marital status, single parenthood, net household income bracket, household benefit bracket, age at which the mother left full-time education, mother's highest level of qualification, and depression status. Of note, number of children, employment status, and dietary requirements were not found to vary significantly with stress during pregnancy, and were not included as control variables.

Statistical analysis

We analyzed the relationship between maternal stress during pregnancy and the child's food preferences and diet by estimating linear regression models using the outcomes and explanatory variables described in the previous section. First, bivariate models of the following form were estimated:

$$Y_i = \beta_0 + \beta_1 T_i + \varepsilon_i$$

where Y_i denotes a measure of the child's food preferences or diet, and T_i is a measure of maternal stress during pregnancy. β_1 is the coefficient of interest, and ε_i is an idiosyncratic error term.

More augmented specifications included a vector of control variables X_i :

$$Y_i = \beta_0 + \beta_1 T_i + X_i' \gamma + \varepsilon_i$$

To account for potential error correlation among individuals in the same experimental session, standard errors were clustered at the session level. Furthermore, due to the relatively small number of clusters, the wild cluster bootstrap approach proposed by Cameron et al. [33] was used to estimate clustered P values.

Results

Descriptive statistics

The demographic characteristics of the sample can be found in Table 1. The age of the mothers ranged from 21 to 45 y, with a mean of almost 36 y. In line with the eligibility criteria, the age of the child ranged from 2 to 12 y, with a mean age of approximately 6.5 y. The descriptive statistics of stress and dietary measures used in our analysis are displayed in Table 2. The distribution of the stress measures and a discussion of its reliability can be found in Supplementary Appendix D.

Regression analysis

We focused on the results for one of two measures of stress (average perceived stress during pregnancy), because the results were very similar for both variables capturing stress (average and maximum). The results for maximum perceived stress during pregnancy are briefly discussed herein and can be found in Supplementary Appendix D.

Table 3 presents the estimation results of bivariate and augmented regression models for the primary outcomes. Columns 1 and 2 report the bivariate and augmented estimations of the link between maternal stress during pregnancy and children's food preferences. Higher average perceived stress during pregnancy was linked with significantly less healthy food preferences of the child. Controlling for a number of potentially confounding factors in column 2 (current maternal diet and food preferences, maternal diet during pregnancy, current stress, as well as demographic characteristics of child, mother, and household) gave a stronger and more statistically significant link between stress during pregnancy and the child's food preferences. The observed changes in coefficient size and significance between bivariate and augmented models in Tables 3 and 4 were not driven by the small differences in

Table 1
Demographic characteristics

	Mean	Standard deviation	Minimum	Maximum
Age mother, y	35.72	5.91	21.00	45.00
Age youngest child, y	6.44	2.93	2.00	12.75
Children, n	2.06	1.00	1.00	7.00
Single parent	0.29	0.45	0.00	1.00
Marital status:				
Single	0.23	0.42	0.00	1.00
Married	0.41	0.49	0.00	1.00
Cohabiting	0.20	0.40	0.00	1.00
Other	0.16	0.37	0.00	1.00
Monthly household net income:				
<1000 GBP	0.11	0.31	0.00	1.00
1000–2000 GBP	0.48	0.50	0.00	1.00
>2000 GBP	0.41	0.49	0.00	1.00
Monthly benefits:				
None	0.14	0.35	0.00	1.00
1–650 GBP	0.60	0.49	0.00	1.00
>650 GBP	0.26	0.44	0.00	1.00
Highest qualification:				
None	0.08	0.28	0.00	1.00
Low GCSE	0.15	0.36	0.00	1.00
High GCSE	0.30	0.46	0.00	1.00
A levels	0.37	0.48	0.00	1.00
Professional	0.10	0.30	0.00	1.00
Employment status:				
Full-time	0.12	0.32	0.00	1.00
Part-time	0.57	0.50	0.00	1.00
Self-employed	0.07	0.25	0.00	1.00
Not employed	0.24	0.43	0.00	1.00
N	213			

GBP, British pound sterling; GCSE, General Certificate of Secondary Education

sample size. The results for the bivariate models were robust to limit the samples to those of the augmented models. Furthermore, the results are robust to control for maternal BMI (Suppl. App. D; Tables D.12 and D.13). The coefficients in columns 1 and 2 corresponded to a drop in healthiness of a child's food preferences by

Table 3
Relationship between maternal stress during pregnancy and children's food preferences and diet

	Food preferences		Diet	
	(1)	(2)	(3)	(4)
Average stress–pregnancy	−0.078* (0.033) [0.066]	−0.135 [†] (0.004) [0.010]	−0.123 (0.119) [0.134]	−0.161 [†] (0.038) [0.029]
Mother's diet–current		0.015 (0.737)		0.328 [†] (0.001)
Mother's diet–pregnancy		0.046 (0.208)		0.193* (0.054)
Average stress–last 3 months		0.062 (0.338)		0.049 (0.746)
Maximum stress–last 3 months		−0.003 (0.912)		−0.016 (0.756)
Mother's food preferences		0.158* (0.075)		
Constant	6.041 [†] (0.000)	6.379 [†] (0.000)	7.363 [†] (0.000)	5.746 [†] (0.000)
Controls for:				
Child demographics	No	Yes	No	Yes
Mother/household demographics	No	Yes	No	Yes
N	210	202	213	210

The dependent variable in (1) and (2) is the Food Preference Index for Children, running from 0 (least healthy) to 10 (most healthy). The dependent variable in (3) and (4) is the adapted KIDMED index, running from −3 (least healthy) to +12 (most healthy). Controls for child demographics are age and sex of the child. Controls for mother and household demographics are age she left full-time education, level of highest qualification, household net income bracket, household benefit bracket, age, marital status, single parenthood, and depression. *P*-values based on standard errors clustered at the session level are shown in parentheses. *P*-values based on a wild bootstrap clustered at the session level are shown in brackets. Significance levels correspond to the largest *P*-value obtained from both methods.

**P* < 0.1.

[†]*P* < 0.05.

[‡]*P* < 0.01.

Table 2
Descriptive statistics

	Mean	Standard deviation	Minimum	Maximum	N
Average stress–pregnancy	2.22	1.51	1.00	10.00	213
Maximum stress–pregnancy	5.68	3.66	1.00	10.00	213
Average stress–last 3 months	2.63	1.39	1.00	9.00	213
Maximum stress–last 3 months	7.05	3.04	1.00	10.00	213
Child's diet (adapted KIDMED)	7.09	1.82	2.00	11.00	213
Child food preferences (FPI-C)	5.87	0.76	3.31	7.65	210
Child – taste preferences:					
Sour	2.78	0.72	1.00	4.00	212
Salty	3.48	0.62	1.00	4.00	213
Umami	2.67	0.53	1.11	4.00	213
Bitter	1.61	0.95	0.00	4.00	196
Sweet	3.32	0.54	1.71	4.00	213
Child BMI percentile	0.67	0.40	0.00	1.00	210
Mother's diet–current	6.39	1.78	2.00	11.00	213
Mother's diet–pregnancy	6.42	1.77	1.00	11.00	213
Mother's food preferences (FPI)	5.44	0.84	3.03	7.49	207
Mother – taste preferences:					
Sour	2.88	0.54	1.50	4.00	213
Salty	3.23	0.73	0.00	4.00	213
Umami	2.76	0.69	0.33	4.00	213
Bitter	2.17	1.05	0.00	4.00	211
Sweet	2.92	0.60	1.14	4.00	213

BMI, body mass index; FPI, Food Preference Index; FPI-C, Food Preference Index for Children

Stress during pregnancy and during the last 3 months was measured using the average/maximum perceived stressfulness of nine potential stressors on a Likert scale from 1 (not stressful at all) to 10 (extremely stressful). The child's diet was measured using the adapted KIDMED index running from −3 (least healthy) to +12 (most healthy). Child food preferences were measured using the FPI-C index running from 0 (least healthy) to 10 (most healthy). The child's and mother's taste preferences were measured using the average liking of foods with a sour/salty/umami/bitter/sweet taste running from 0 (dislike extremely) to 4 (like extremely). The child's BMI percentile is based on self-reported height and weight, and refers to the sex- and age-specific BMI distribution. The mother's diet, current and during pregnancy, was measured using an index running from 0 (least healthy) to 13 and 12, respectively (most healthy). The mother's food preferences were measured using the FPI index running from 0 (least healthy) to 10 (most healthy).

Table 4

Relationship between maternal stress during pregnancy and children's taste preferences

	Taste preference					
	Sour		Salty		Umami	
	(1)	(2)	(3)	(4)	(5)	(6)
Average stress—pregnancy	−0.027 (0.401) [0.419]	−0.066 [†] (0.026) [0.019]	−0.045 (0.198) [0.203]	−0.008 (0.816) [0.818]	−0.024 (0.486) [0.499]	−0.048 (0.186) [0.252]
Mother's diet—current		−0.021 (0.553)		−0.025 (0.526)		0.027 (0.165)
Mother's diet—pregnancy		0.016 (0.692)		0.046 (0.133)		0.020 (0.266)
Average stress—last 3 months		0.024 (0.651)		−0.036 (0.464)		0.027 (0.441)
Maximum stress—last 3 months		−0.015 (0.536)		0.006 (0.649)		0.012 (0.527)
Mother's taste—sour		0.451 [‡] (0.000)				
Mother's taste—salty				0.241 [‡] (0.001)		
Mother's taste—umami						0.270 [‡] (0.002)
Constant	2.844 [‡] (0.000)	2.549 [‡] (0.000)	3.577 [‡] (0.000)	2.396 [‡] (0.001)	2.720 [‡] (0.000)	2.038 [‡] (0.001)
Controls for:						
Child demographics	No	Yes	No	Yes	No	Yes
Mother/household demographics	No	Yes	No	Yes	No	Yes
N	212	209	213	210	213	210
	Taste preference: bitter		Taste preference: sweet			
	(7)	(8)	(9)	(10)		
Average stress—pregnancy	−0.128* (0.039) [0.076]	−0.160* (0.029) [0.085]	0.029 (0.201) [0.197]	0.023 (0.500) [0.519]		
Mother's diet—current		−0.037 (0.630)		0.005 (0.813)		
Mother's diet—pregnancy		−0.026 (0.696)		0.013 (0.651)		
Average stress—last 3 months		0.140* (0.095)		0.030 (0.631)		
Maximum stress—last 3 months		−0.070 [†] (0.020)		−0.002 (0.928)		
Mother's taste—bitter		0.222* (0.056)				
Mother's taste—sweet				0.370 [‡] (0.000)		
Constant	1.890 [‡] (0.000)	2.773 [‡] (0.001)	3.255 [‡] (0.000)	1.780 [‡] (0.001)		
Controls for:						
Child demographics	No	Yes	No	Yes		
Mother/household demographics	No	Yes	No	Yes		
N	196	193	213	210		

The dependent variables are the child's average liking of foods with a sour/salty/umami/bitter/sweet taste running from 0 (dislike extremely) to 4 (like extremely). Controls for child demographics are age and sex of the child. Controls for mother and household demographics are age she left full-time education, level of highest qualification, household net income bracket, household benefit bracket, age, marital status, single parenthood, and depression. *P*-values based on standard errors clustered at the session level are shown in parentheses. *P*-values based on a wild bootstrap clustered at the session level are shown in brackets. Significance levels correspond to the largest *P*-value obtained from both methods.

**P* < 0.1.

[†]*P* < 0.05.

[‡]*P* < 0.01.

0.15 and 0.27 standard deviations, respectively, for an increase in average stress during pregnancy by 1 standard deviation.

Columns 3 and 4 report the bivariate and augmented estimations of the link between maternal stress during pregnancy and children's diet. Column 3 shows a marginally significant association between higher average stress during pregnancy and a less healthy diet of the child. Controlling for potentially confounding factors in column 4 resulted in a statistically significant and somewhat stronger negative link. The coefficients in columns 3 and 4 correspond to a decrease in healthiness of a child's diet by 0.1 and

0.13 standard deviations, respectively, for an increase in average stress during pregnancy by 1 standard deviation.

These results suggest a sizable negative association between in utero exposure to stress and the development of food preferences and dietary patterns of the child. Although our sample was limited in size to look at heterogeneous effects, the wide age range of children allowed us to study whether the effects are similar across various age cohorts. This appeared to be the case (Suppl. App. D; Table D.3). Furthermore, the results did not indicate the mother's diet during pregnancy to be a relevant channel, and no association

between the mother's stress levels and her diet during pregnancy were detected.

Next, we analyzed the relationship between maternal stress during pregnancy and the child's liking of the five basic tastes: Sour, salty, umami, bitter, and sweet. Table 4 presents the estimation results of bivariate and augmented regression models for these secondary outcomes. In utero stress was found to be negatively associated with the child's liking of sour and bitter foods, where the former was only found to be significant for models controlling for potentially confounding factors. In the bivariate (augmented) model, the liking of sour foods was estimated to be 0.06 (0.14) standard deviations lower and the liking of bitter foods 0.20 (0.25) standard deviations lower if average stress during pregnancy increased by 1 standard deviation. No significant relationships were found for the liking of salty, umami, and sweet foods, which could be due to the high average levels and low variation in liking of these tastes.

We also estimated the relationship between average perceived stress during pregnancy and the preference for the food groups in the FPI-C food preference index (fruit, vegetables, legumes/pulses, fish/shellfish, pasta/rice, cereal/grains, dairy products, commercially baked goods/pastries, sweets/candies, and fast food). The results for the bivariate and augmented regression models can be found in Supplementary Appendix D, Table D.4. Higher average perceived stress during pregnancy was linked with a significantly lower preference for fruit, legumes/pulses, fish/shellfish, and dairy products, as well as with a significantly higher preference for sweets/candies.

To assess whether our findings are robust to other methods of measuring and aggregating food preferences, we calculated children's average liking of low-fat savory, high-fat savory, low-fat sweet, and high-fat sweet foods similar to the approach in the Leeds Food Preference Questionnaire [34]. The corresponding results can be found in Supplementary Appendix D, Table D.5. Higher average perceived stress during pregnancy was associated with a lower preference for sweet low-fat and savory low-fat foods.

Finally, we estimated the relationship between maternal stress during pregnancy and the measures of consumption that underlie the Diet Quality Index for the child. The results for the bivariate and augmented regression models are shown in Supplementary Appendix D, Table D.6. Most coefficients did not show significant associations for these individual items, except for a lower probability that the child ate at least 1 daily fruit serving and 2 weekly legume servings when mothers were exposed to higher average perceived stress during pregnancy.

Due to the likely reporting bias in the mother-reported height and weight of children, little focus was put on BMI percentiles as a further outcome. Estimation results can be found in Supplementary Appendix D, Table D.7, which show a negative association between average stress during pregnancy and the child's BMI percentile (marginally significant in the bivariate model). Although this can only be speculative given the quality of the data, low birthweight due to stress during pregnancy [35] might explain the negative association. However, we did not collect information on birth weight.

We repeated the main estimations above using maximum maternal stress during pregnancy as the explanatory variable. The corresponding results are shown in Supplementary Appendix D, Tables D.8 to D.10. The direction of the estimated coefficients matched those for average maternal stress during pregnancy. However, with the exception of the food consumption and BMI percentile outcomes, the estimates were less precisely estimated. This might be an indication that extended periods of maternal stress during pregnancy have a stronger association with the development of a child's dietary preferences than short intensive stressors. An alternative explanation for the lower levels of

significance could be that average stress during pregnancy is a less noisy measure that uses more information provided by respondents.

Discussion

Child obesity is of significant interest because obesity is very likely to persist into adulthood. Previous work has documented a link between in utero stress exposure and the risk of obesity during childhood. Using data collected from 213 mothers of low SES in the United Kingdom, we examined the relationship between in utero exposure to stress and children's food preferences and diet. We found that maternal stress during pregnancy predicted children's food and taste preferences, as well as their current diet, even after controlling for maternal diet (current and during pregnancy), demographic characteristics of the child and mother, and current maternal stress. Higher average stress during pregnancy was linked with food preferences and diets that are significantly less healthy, as well as a weaker preference for sour and bitter foods. Maternal stress during pregnancy did not predict the mother's diet during pregnancy or later, but was found to be associated with the child's food preferences. These results are in line with the hypothesis of hormonal processes leading to fetal programming of the metabolic system or the neurologic development/programming of neurologic functions in utero.

To the best of our knowledge, this is the first study to examine the relationship between in utero stress exposure in humans and food preferences, as well as diet in childhood. Several animal studies, where maternal diet and stress can be experimentally manipulated, have examined the link with offspring's metabolic outcomes [16]. In humans, studies have been conducted focusing on the impact of extreme and unusual occurrences that also affect the nutritional environment, as well as proven stressfulness. Some studies focused on the effects of the Dutch famine on dietary preferences later on in life [36], or the effects of violent events on outcomes at birth [37], or the impact of being incarcerated during pregnancy [38]. In addition, there is a large body of work focusing on intrauterine growth restriction or low birthweight on food preferences [39,40].

One limitation of the study is the retrospective measurements of stress, which may introduce measurement error. Although the stressful events we considered were typically events that would be unlikely to have been forgotten (eg, death of a family member), measurement error could happen due to recall bias or discomfort, and our measure of exposure to stress would not have been fully reflective of the actual stress experienced. Measurement error of this type would have led to an underestimation of the relationship between maternal stress during pregnancy and food preference or diet of the children. To further explore this issue, we examined the relationship between the age of the child and the stress the mother experienced during pregnancy. The idea is that if there was no relationship between the age of the child (and in turn the length of time since the pregnancy took place) and stress experienced during pregnancy, then this would be suggestive evidence that the retrospective nature of the data collection was not subject to recall bias. To this end, we regressed our measure of stress during pregnancy on the age of the child. As seen in Supplementary Appendix D, Table D.11, we did not find a relationship between age of the child (and therefore length of time since pregnancy) and the measure of exposure to stress during pregnancy. Thus, recall bias is unlikely to drive any of the results presented in this study.

Although we focus on a sample of mothers from a low socioeconomic background, they are not the only group of women who

suffer from daily or chronic stress. A significant proportion of women from all SES suffer from chronic stress [41] and face work related stress [42]. Future research could investigate whether these results are applicable to women from higher socioeconomic groups as well.

Conclusions

The results presented herein suggest that stress during pregnancy could have long-term detrimental effects on the next generation in terms of a less healthy diet and subsequent health implications associated with these effects, such as higher rates of obesity and obesity-related diseases. As a consequence, we advocate for more research into understanding the sources of maternal stress and the extent to which these can be altered. Prenatal care and preconception counseling could be critical to develop preventive strategies to improve public health. A recent randomized clinical trial by Esfandiari et al. [43] shows that supportive counseling during pregnancy resulted in reduced stress, reinforced health-promoting behaviors, and reduced health-impairing behaviors. Future research could focus on developing and evaluating other interventions that aim to reduce stress or help cope with stressful events during the pregnancy period and beyond.

Acknowledgments

The authors thank EssexLab and the Università degli Studi di Firenze for allowing the use of their facilities. All phases of this study were supported by the European Union's Seventh Framework Programme (grant agreement no. 607310). Nicolai Vitt further gratefully acknowledges funding from the Economic and Social Research Council (award 1651922). The study was part of a larger study preregistered in the AEA RCT registry (trial ID AEARCTR-0003410) before data collection. Details can be found at <https://www.socialscisearch.org/trials/3410/history/35937>. The study was conducted with ethical approval of the European University Institute and the University of Edinburgh. Written informed consent was given by all participants.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.nut.2021.111423.

References

- [1] Zhang Q, Wang Y. Socioeconomic inequality of obesity in the United States: Do gender, age, and ethnicity matter? *Soc Sci Med* 2004;58:1171–80.
- [2] McLaren L. Socioeconomic status and obesity. *Epidemiol Rev* 2007;29:29–48.
- [3] Cutler DM, Lleras-Muney A. Understanding differences in health behaviors by education. *J Health Econ* 2010;29:1–28.
- [4] Birch LL. Development of food preferences. *Ann Rev Nutr* 1999;19:41–62.
- [5] Costa-Font J, Gil J. Intergenerational and socioeconomic gradients of child obesity. *Soc Sci Med* 2013;93:29–37.
- [6] Entringer S. Impact of stress and stress physiology during pregnancy on child metabolic function and obesity risk. *Curr Opin Clin Nutr Metab Care* 2013;16:320–7.
- [7] Entringer S, Wadhwa PD. Developmental programming of obesity and metabolic dysfunction: Role of prenatal stress and stress biology. *Nestle Nutr Inst Workshop Ser* 2013;74:107–20.
- [8] Stout SA, Espel EV, Sandman CA, Glynn LM, Davis EP. Fetal programming of children's obesity risk. *Psychoneuroendocrinology* 2015;53:29–39.
- [9] Entringer S, Buss C, Rasmussen JM, Lindsay K, Gillen DL, Cooper DM, et al. Maternal cortisol during pregnancy and infant adiposity: A prospective investigation. *J Clin Endocrinol Metab* 2017;102:1366–74.
- [10] Machado TD, Dalle Molle R, Laureano DP, Portella AK, Werlang IC, da Silva Benetti C, et al. Early life stress is associated with anxiety, increased stress responsivity and preference for "comfort foods" in adult female rats. *Stress* 2013;16:549–56.
- [11] Dallman MF, Pecoraro N, Akana SF, La Fleur SE, Gomez F, Houshyar H, et al. Chronic stress and obesity: A new view of "comfort food". *Proc Natl Acad Sci U S A* 2003;100:11696–701.
- [12] Leng G, Adan RAH, Belot M, Brunstrom JM, de Graaf K, Dickson SL, et al. The determinants of food choice. *Proc Nutr Soc* 2017;76:316–27.
- [13] Talge NM, Neal C, Glover V. Antenatal maternal stress and long-term effects on child neurodevelopment: How and why? *J Child Psychol Psychiatry* 2007;48:245–61.
- [14] Torres SJ, Nowson CA. Relationship between stress, eating behavior, and obesity. *Nutrition* 2007;23:887–94.
- [15] Nehring I, Kostka T, von Kries R, Rehfuess EA. Impacts of in utero and early infant taste experiences on later taste acceptance: A systematic review. *J Nutr* 2015;145:1271–9.
- [16] Lindsay KL, Buss C, Wadhwa PD, Entringer S. The interplay between maternal nutrition and stress during pregnancy: Issues and considerations. *Ann Nutr Metab* 2017;70:191–200.
- [17] Witt M, Reutter K. Embryonic and early fetal development of human taste buds: A transmission electron microscopical study. *Anat Rec* 1996;246:507–23.
- [18] Ventura AK, Worobey J. Early influences on the development of food preferences. *Curr Biol* 2013;23:R401–8.
- [19] Anzman-Frasca S, Ventura AK, Ehrenberg S, Myers KP. Promoting healthy food preferences from the start: A narrative review of food preference learning from the prenatal period through early childhood. *Obes Rev* 2018;19:576–604.
- [20] Lamichhane N, Olsen NJ, Mortensen EL, Obel C, Heitmann BL, Händel MN. Associations between maternal stress during pregnancy and offspring obesity risk later in life—A systematic literature review. *Obes Rev* 2020;21:e12951.
- [21] Baum A, Garofalo JP, Yali AM. Socioeconomic status and chronic stress. Does stress account for SES effects on health? *Ann N Y Acad Sci* 1999;896:131–44.
- [22] Caplan LJ, Schooler C. Socioeconomic status and financial coping strategies: The mediating role of perceived control. *Soc Psychol Quart* 2007;70:43–58.
- [23] Rutter F, Nieuwenhuizen AG, Lemmens SGT, Born JM, Westerterp-Plantenga MS. Acute stress-related changes in eating in the absence of hunger. *Obesity* 2009;17:72–7.
- [24] Zellner DA, Loaiza S, Gonzalez Z, Pita J, Morales J, Pecora D, et al. Food selection changes under stress. *Physiol Behav* 2006;87:789–93.
- [25] Evans GW, Fuller-Rowell TE, Doan SN. Childhood cumulative risk and obesity: The mediating role of self-regulatory ability. *Pediatrics* 2012;129:e68–73.
- [26] Endler NS, Parker JDA. Multidimensional assessment of coping: A critical evaluation. *J Pers Soc Psychol* 1990;58:844–54.
- [27] Serra-Majem L, Ribas L, Ngo J, Ortega RM, García A, Pérez-Rodrigo C, et al. Food, youth and the Mediterranean diet in Spain. Development of KIDMED, Mediterranean Diet Quality Index in children and adolescents. *Public Health Nutr* 2004;7:931–5.
- [28] Public Health England. The eatwell guide. Available at: <https://www.gov.uk/government/publications/the-eatwell-guide>. Accessed August 4, 2020.
- [29] Idelson PI, Scalfi L, Valerio G. Adherence to the Mediterranean diet in children and adolescents: A systematic review. *Nutr Metab Cardiovasc Dis* 2017;27:283–99.
- [30] Dinu M, Pagliai G, Casini A, Sofi F. Mediterranean diet and multiple health outcomes: An umbrella review of meta-analyses of observational studies and randomised trials. *Eur J Clin Nutr* 2018;72:30–43.
- [31] Pliner P, Pelchat ML. Similarities in food preferences between children and their siblings and parents. *Appetite* 1986;7:333–42.
- [32] Martínez-González MA, García-Arellano A, Toledo E, Salas-Salvadó J, Buil-Cosiales P, Corella D, et al. A 14-item Mediterranean diet assessment tool and obesity indexes among high-risk subjects: The PREDIMED trial. *PLoS One* 2012;7:e43134.
- [33] Cameron AC, Gelbach JB, Miller DL. Bootstrap-based improvements for inference with clustered errors. *Rev Econ Stat* 2008;90:414–27.
- [34] Finlayson G, King N, Blundell JE. Is it possible to dissociate 'liking' and 'wanting' for foods in humans? A novel experimental procedure. *Physiol Behav* 2007;90:36–42.
- [35] Camacho A. Stress and birth weight: Evidence from terrorist attacks. *Am Econ Rev* 2008;98:511–5.
- [36] Lussana F, Painter RC, Ocke MC, Buller HR, Bossuyt PM, Roseboom TJ. Prenatal exposure to the Dutch famine is associated with a preference for fatty foods and a more atherogenic lipid profile. *Am J Clin Nutr* 2008;88:1648–52.
- [37] Lee C. Intergenerational health consequences of in utero exposure to maternal stress: Evidence from the 1980 Kwangju uprising. *Soc Sci Med* 2014;119:284–91.
- [38] Testa A, Jackson DB, Vaughn MG, Bello JK. Incarceration as a unique social stressor during pregnancy: Implications for maternal and newborn health. *Soc Sci Med* 2020;246:112777.
- [39] Ayres C, Agranonik M, Portella AK, Filion F, Johnston CC, Silveira PP. Intrauterine growth restriction and the fetal programming of the hedonic response to sweet taste in newborn infants. *Int J Pediatr* 2012;2012:657379.

- [40] Silveira PP, Agranonik M, Faras H, Portella AK, Meaney MJ, Levitan RD, et al. Preliminary evidence for an impulsivity-based thrifty eating phenotype. *Pediatr Res* 2012;71:293–8.
- [41] Azevedo I. Stress and obesity. In: Monteiro R, Martins MJ, editors. *Understanding obesity: From its causes to impact on life*, Singapore: Bentham Science; 2020. p. 374–99.
- [42] Damaske S, Zawadzki MJ, Smyth JM. Stress at work: Differential experiences of high versus low SES workers. *Soc Sci Med* 2016;156:125–33.
- [43] Esfandiari M, Faramarzi M, Nasiri-Amiri F, Parsian H, Chehrizi M, Pasha H, et al. Effect of supportive counseling on pregnancy-specific stress, general stress, and prenatal health behaviors: A multicenter randomized controlled trial. *Patient Educ Couns* 2020;103:2297–304.