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The daily experience of hunger in UK females with and without food insecurity

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ABSTRACT

Food insecurity (FI) is associated with increased mortality risk, depression, and obesity in females in high-income countries, but causal mechanisms remain unclear. FI is often assumed to lead to increased levels of hunger. However, quantitative evidence describing daily experiences of hunger in FI is lacking. Our pre-registered study used ecological momentary assessment to capture experiences of hunger in two groups of UK-based females: those experiencing FI ($N = 143$) and those experiencing food security (FS; $N = 149$). Participants self-reported hunger hourly (0900–2100) for one week (Monday–Sunday). There was no difference between groups in mean hunger ($t(290) = 0.17, p = .866, d = 0.02$) nor within-day standard deviation in hunger ($t(290) = 1.31, p = .193, d = 0.15$). However, both quantities fluctuated more from day to day in the FI group. Compared to the FS group, participants in the FI group had a larger day-to-day variation in mean hunger ($t(284) = 2.43, p = .016, d = 0.29$) and a larger day-to-day variation in the within-day standard deviation of hunger ($t(284) = 2.90, p = .004, d = 0.34$). In exploratory analyses, we found that the hunger of the two groups patterned differently across the day. Our findings suggest that experiences of hunger are less stable in those experiencing FI, which may reflect associations between FI and greater uncertainty in food access, higher variability in meal timings or the increased likelihood of chaotic home and work lives.

1. Introduction

Food insecurity (FI) can be defined as “limited or uncertain availability of nutritionally adequate and safe food or limited or uncertain ability to acquire acceptable foods in socially acceptable ways” (USDA Economic Research Services, 2023a) and is often described using a continuum from mild to severe (Piperata et al., 2023). In recent years, there has been a global increase in the prevalence of moderate to severe FI (Communications Affordability Tracker, 2024). While this has predominantly impacted low- and middle-income countries, FI has also risen in the world’s wealthiest countries. In the UK, 14.8% of all adults and 20% of all households with children are experiencing moderate to severe FI (The Food Foundation, 2024).

In the UK, there are regional inequalities in the risk of FI, with the North East having one of the highest rates of FI in England (Department for Work & Pensions, 2023). The increasing prevalence of FI is likely a driver of widening health inequality in the UK (Office for Health Improvement & Disparities, 2023) as FI is associated with a range of

negative health outcomes, including increased risk of mortality (Banerjee et al., 2021), developing chronic disease (Laraia, 2013) and poorer mental health outcomes (Fang et al., 2021; Reeder et al., 2022). Furthermore, there may be sex differences in vulnerability to FI-associated health risks. Females experience greater psychological distress in response to FI than males, and females experiencing FI in high-income countries have higher odds of overweight and obesity than females who have food security (FS; Laraia, 2013; Nettle et al., 2017). To develop targeted interventions that tackle this growing public health challenge in affluent countries, it is imperative that we better describe the psychological and physiological experiences of those living with FI in this context.

One such experience is hunger. Hunger is an important consideration for health outcomes as it is closely associated with food consumption and overconsumption (Emilien & Hollis, 2017). Hunger caused by FI has been described as a physiological condition occurring due to resource constraints, leading to “discomfort, illness, weakness, or pain that goes beyond the usual uneasy sensation” (USDA Economic Research Services,

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2023a). While FI is often assumed to be associated with increased levels of hunger, to our knowledge, this hypothesis has not been tested. FI may also be associated with greater variation in hunger, as FI is associated with more variable patterns of eating and longer gaps between eating (Nettle & Bateson, 2019; Shinwell et al., 2022). Therefore, we may expect higher average hunger and higher hunger variation in individuals with FI than FS. Furthermore, variation in hunger could operate on two scales: within a day, with hunger peaks being more extreme with FI, and between days, with days being more different from one another with FI.

To understand daily hunger patterns in individuals with FS, we can draw upon a wealth of literature concerning the fluctuations of self-reported hunger throughout the day. Hunger usually peaks twice daily, at approximately midday and 6 p.m. (Mattes, 1990; McKiernan et al., 2008). The timing and magnitude of these peaks are associated with physiological factors such as blood glucose levels (Ciampolini & Bianchi, 2006), circadian rhythm (Scheer et al., 2013), and energetic demands (Blundell et al., 2012). Peaks are also linked to key psychological drivers, such as memory and learning (for reviews, see: Stevenson, 2023; Stevenson et al., 2023). However, to our knowledge, descriptive daily hunger data are not available in the context of FI. Therefore, little is known about differences in daily hunger patterns between those experiencing FI or FS and, if there are any, how these impact individuals' behaviour and health outcomes. Thus, describing the experience of hunger in FI is a critical step to untangling potential drivers of its associated negative health outcomes. For such data to be meaningful, they should be collected as individuals go about their day-to-day lives. Ecological momentary assessment (EMA) is designed for such scenarios, allowing repeated, frequent data collection remotely across a given timeframe. This has several benefits, including reduced reporting errors due to less reliance on retrospective memory (Lucas et al., 2021; Monk et al., 2015).

In this paper, we present a pre-registered EMA study which aimed to compare the experiences of daily hunger in two UK groups of females – a group experiencing FI and a group experiencing FS – over the course of a week. We use sex and the term female(s), and not gender, in this study as sex differences in health outcomes associated with FI are of interest. The purpose of the study was to compare within-day and between-day experiences of hunger between the groups. Doing this will allow for the development of testable hypotheses to inform policy decisions. Given that the definition of FI incorporates uncertain food availability, and previous assumptions and evidence suggest that those with FI experience higher levels of hunger and greater variation in meal timing, we predicted that participants experiencing FI would have:

- P1. A higher average hunger rating,
- P2. Higher within-day variation in hunger rating,
- P3. Greater between-day variation in average hunger rating,
- P4. Greater between-day variation in within-day variation in hunger rating.

2. Methods

2.1. Study Overview

The Newcastle University Faculty of Medical Science Research Ethics Committee (reference 2287/18715) granted ethical approval for this study. We pre-registered our protocol (<https://osf.io/zx5bj>) and analysis plan (<https://osf.io/ancx9>; see Supplementary Materials 1 for a summary of deviations from our pre-registrations). This study used EMA to assess and compare daily experiences of hunger in females experiencing FI and females experiencing FS. Individuals were identified as experiencing FI or FS after completing an online expression of interest form. Both groups of participants were blind to the FI of the study and completed the same study procedure throughout.

Participants took part remotely as they went about their everyday lives. They downloaded and used a mobile app, *Ethica* (2023), on their

smartphones to respond to hourly momentary assessments between 9 a.m. and 9 p.m. each day for seven days (Monday to Sunday).

2.2. Participants

We recruited 305 participants who were female or assigned female at birth (we aimed to recruit 150 participants per group, a similar sample size to that used by Dzibur et al., 2022). After removing participants with low-quality or insufficient data (see 2.5 Data Analysis), 292 participants (143 FI, 149 FS, ages 20–64 years, $M = 38.2$, $SD = 7.2$) were included in the final analyses; 118 were recruited from parent populations of schools in the North East of England with above average percentage of pupils eligible for free school meals, 133 from social media using targeted (by geographical location) advertising to recruit parents in the same region, and 41 by word of mouth. Furthermore, of the participants included in the final analyses, 69 were classified as having “low food security” (moderate FI; mFI), and 74 as having “very low food security” (high FI; hFI; USDA Economic Research Services, 2023b).

2.3. Procedure

Recruitment and data collection took place between June 5th and November 26th 2023. Individuals completed an online form to express their interest in participating. First, we presented participants with study information and a consent form. The study title presented to participants was “How does feeling hungry impact how you feel?”. We told participants that the study aimed to explore how people experience feelings of hunger and stress throughout the day. We informed participants that, to take part, they should be over 18 years old, be female (or assigned female at birth), have a smartphone, be able to download an app and commit to regularly responding to push notifications for seven days. To minimise potential confounding effects on hunger ratings, we also informed participants that they should not be following a weight management program or engaging in excessive physical activity or overnight shift work during the seven days of the study.

Next, participants provided their contact details, age, gender, height, and weight. They then completed the Household Food Security Six-Item Short Form module (USDA Economic Research Services, 2023b). We titled the question block “Cost of Living Questions” so that participants were not encouraged to draw links between the study and FI and to reduce the potential for participants to display demand characteristics. Finally, participants answered questions about their employment status and daily eating and working routines. We then emailed participants to invite them to the study, reminded them of the study requirements, and provided instructions on downloading the mobile app. We instructed participants to set up the app on Sunday so that the notifications could begin at the appropriate time on Monday.

During the EMA period, participants received push notifications from the mobile app that prompted them to open the app and complete a survey (see Fig. 1 for a timeline). There were three types of notifications that participants received:

N1. Momentary assessments. These notifications prompted participants to complete a five-question survey (see 2.4.2 Momentary Assessments). The mobile app presented the questions in a random order within the survey. If the participant did not respond, the notification and survey disappeared after 30 min. Otherwise, the survey disappeared once the participant completed it.

N2. Daily waking time. These notifications prompted participants to complete a survey asking when they woke up that day. The mobile app delivered this at 9 a.m. each day, and it disappeared after the participant responded or at midnight. We do not report these data in the current paper.

N3. Debrief questionnaire. This notification prompted participants to complete a debrief survey. This notification and survey remained until the participant responded or the study period (as programmed

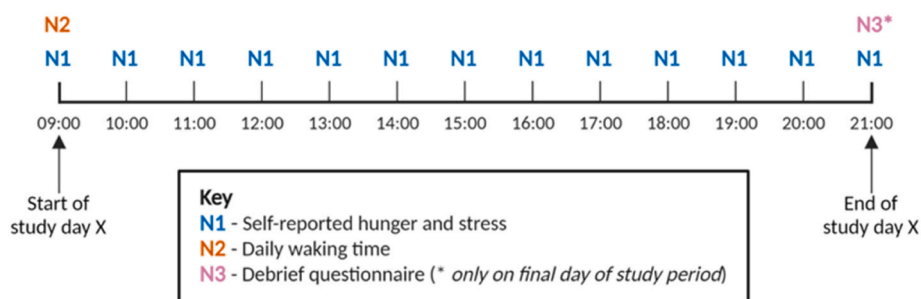


Fig. 1. Timeline of push notifications for each day of the study period.

on the app) ended the following day. We do not report these data in the current paper.

Furthermore, an “Additional Information” survey on the mobile app home screen was visible and accessible at all times. It allowed participants to submit additional information that they thought was relevant to the study or important for the researchers. We gave participants examples of how they might use this, including reporting why they had missed notifications or if they were feeling unwell.

At the end of the EMA period, we emailed participants debrief information and sent them a participation reward. Participants received a 10 GBP e-voucher for completing the study period and an additional 10 GBP e-voucher if they responded to over 70% of the momentary prompts. Participants with the top 10% of response rates were also entered into a lottery to win a 50 GBP e-voucher. To minimise missing data, we informed participants of these incentives during recruitment and contacted participants during the EMA period if their response rate had dropped below 70%.

2.4. Measures

2.4.1. Food insecurity status

In the online form at recruitment, participants completed the Household Food Security Survey Six-Item Short Form module (USDA Economic Research Services, 2023b). The module consists of six questions that ask participants about their experiences of hunger, meal-skipping, and consuming an imbalanced diet in the last 12 months as a result of the unaffordability of food. We assigned participants to two groups in line with the module’s scoring guidelines, as in Shinwell et al. (2022): FS (high or marginal food security, score 0–1) and FI (low/very low food security, score 2–6).

2.4.2. Momentary assessments

During the EMA period (N1), we asked participants, “How hungry are you right now?”. They responded using a visual analogue scale (VAS) anchored at 0 (“Not at all hungry”) and 100 (“Extremely hungry”). Blundell et al. (2010) recommend using this question in appetite research to assess hunger. We added “right now” at the end of the question to remind participants to report how they felt when they responded.

We also asked participants, “Do you have the desire to eat something tasty right now?”. They responded using a VAS anchored at 0 (“Not at all”) and 100 (“Very much”). Reichenberger et al. (2020) used this question to measure the intensity of the ‘desire to eat’ subcomponent of food craving (as in Cepeda-Benito et al., 2000).

We also asked participants three questions about their momentary perceived stress. We do not report these data in this paper (see Supplementary Materials 2 for details of the measures).

2.5. Data analysis

We analysed and visualised data in R (R Core Team, 2023). Our data and code are available at <https://doi.org/10.17605/OSF.IO/6BP2Z>.

We removed two momentary assessments from one participant completed before the sampling period at 8 a.m. In EMA research, a 75% response rate is often thought to be adequate, while a 90% response rate is considered excellent (Stone et al., 2023). To maintain sufficient coverage of the study period and sample in our data, we excluded days in which participants completed fewer than nine out of 13 momentary assessments (i.e., a daily response rate of less than 69.2%). This left a total of 1749 days across 292 participants. For the between-day analyses, we excluded six participants with only one day with a response rate higher than our inclusion threshold.

As the responses to the hunger and craving questions were strongly correlated with one another (Pearson’s $r = 0.80$; $t(22,177) = 197.54$, $p < .001$, 95% CI[0.79, 0.80]), we calculated the average of the two scores as our hunger measure at each assessment. For our pre-registered analyses, we reduced each participant’s momentary assessments to four summary variables. First, we calculated the mean and SD of the hunger measure for each participant on each day (we corrected the SD for the mean by using residuals from the regression of the SD on the mean). We then took the average of these two values across the week for each participant. We refer to these variables as **within-day mean (wM)** and **within-day (corrected) SD (wCSD)**. We calculated two further variables: **between-day variation in the mean (bvM)** and **between-day variation in the (corrected) standard deviation (bvCSD)**. Each participant’s bvM is the standard deviation of their wM from each day across the week, and their bvCSD is the standard deviation of their wCSD across the week.

Pilot data (described in the preregistered protocol at <https://osf.io/xntdf>) suggested that other possible descriptive measures (daily median, range, minimum, maximum and area under the curve (AUC)) were very highly correlated with the mean and SD and therefore did not add any additional information. This was true for the present dataset (see Supplementary Materials 3). Thus, we do not use these alternate descriptive measures in the present paper.

For our pre-registered analyses, we conducted a MANOVA to assess differences between FI and FS participants in the four measures of hunger defined above. These were followed with univariate models to assess which variables differed between the FI and FS groups.

In addition to pre-registered analyses, we ran exploratory analyses to investigate whether our findings differed depending on the severity of FI by rerunning the pre-registered analyses with three levels of FI rather than two (using scorings defined by (USDA Economic Research Services, 2023b): FS, moderate FI (mFI) and high FI (hFI)). Finally, we conducted exploratory analyses with the momentary assessment as the unit of analysis to investigate whether any differences in hunger between FI and FS were dependent on the time an assessment took place (i.e., time of day) or on the day type of the day an assessment occurred (i.e., weekend vs weekday). Here, our outcome variable was the momentary hunger measure, with FI group, time of day and day type as predictors. We included interactions between the predictors and added a random effect of participant to allow for repeated measures.

3. Results

3.1. Patterns of hunger

To illustrate the structure of our data, we plotted the average hunger rating at each time point for all participants (Fig. 2). On average, hunger peaked at 1200 and 1700 in our sample. The lowest hunger ratings were reported at the last assessment at 2100.

3.2. Pre-registered analyses

A one-way MANOVA revealed a significant effect of FI on our within- and between-day hunger variables ($F(4, 281) = 2.84, p = .025, \eta^2 = 0.039$; Table 1). Follow-up univariate analyses showed that, between the FI and FS groups, there was no difference in within-day mean hunger (wM ; $t(290) = 0.17, p = .866, d = 0.02$; Table 1) or within-in-day standard deviation of hunger ($wCSD$; $t(290) = 1.31, p = .193, d = 0.15$; Table 1). However, the FI group had higher variation in between-day mean hunger (bvM ; $t(284) = 2.43, p = .016, d = 0.29$; Table 1) and between-day SD of hunger ($bvCSD$; $t(284) = 2.90, p = .004, d = 0.34$; Table 1) than the FS group.

To visualise the finding that the FI group had greater variation in the experience of hunger between days than the FS group, we plotted the SD

of hunger at each momentary assessment. Fig. 3 shows that the FI group had higher variation than the FS group in their hunger ratings at most of the assessment times.

Independent samples *t*-tests showed that, on average, the FI group were younger than the FS group (Table 1; $t(290) = -3.86, p < .001, d = -0.45$), but the results of the MANOVA did not change when we controlled for age (no effect of age on dependent variables, $F(4, 280) = 1.30, p = .270, \eta^2 = 0.018$; significant effect of FI on dependent variables, $F(4, 280) = 2.83, p = .025, \eta^2 = 0.039$). The FI group also had a higher BMI (Table 1; $t(290) = 4.07, p < .001, d = 0.48$) than the FS group, but the results of the MANOVA did not change when we controlled for BMI (no effect of BMI on dependent variables, $F(4, 280) = 1.96, p = .100, \eta^2 = 0.027$; significant effect of FI on dependent variables, $F(4, 280) = 2.83, p = .025, \eta^2 = 0.042$; though, this analysis is arguably inadvisable due to the risk of collider bias if BMI is causally affected by hunger and FI (Elwert and Winship (2014)). Furthermore, there was no significant difference between the groups in the percentage of momentary assessments participants responded to across the week (Table 1; $t(290) = -0.72, p = .475, d = 0.08$), nor in how many days were included for analysis in the MANOVA ($t(290) = -1.02, p = .310, d = 0.12$).

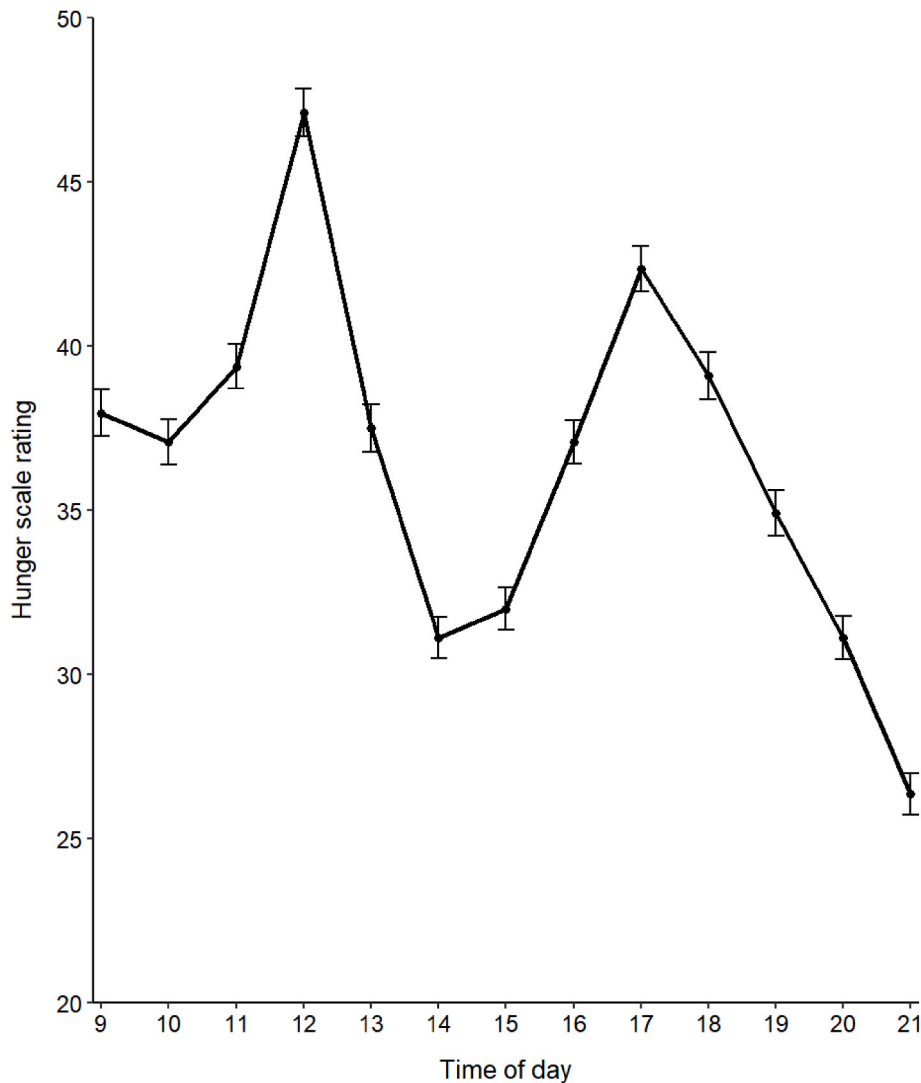


Fig. 2. Mean hunger scale rating at each time point across all days for each participant.

Note. Error bars indicate one standard error of the mean for momentary assessments. $N = 22,179$.

Table 1

Descriptive statistics of hunger measures, participants' age, BMI, total compliance (across the study period) and number of days included for analysis in the MANOVA in FI and FS groups.

		FS			FI		
		Mean	SD	Range	Mean	SD	Range
Hunger measures	Within-day mean (wM)	36.6	13.7	5.9–82.1	36.9	14.12	2.62–74.9
	Within-day (corrected) SD (wCSD)	−0.48	5.82	−16.40–17.12	0.55	7.46	−16.81–19.56
	Between-day variation in the mean (bvM)	7.95	3.10	1.84–17.12	9.10	4.78	0.73–33.17
	Between-day variation in the (corrected) standard deviation (bvCSD)	4.52	2.07	0.34–15.25	5.32	2.57	0.53–13.52
	Age	39.7	1.2	20–64	36.5	6.7	20–57
	BMI	27.4	6.0	18.3–47.6	31.0	8.9	16.4–71.0
	Total compliance (%)	83.8	14.2	14.3–100.0	82.6	14.7	28.6–100.0
	Number of days included in MANOVA	6.1	1.5	1–7	5.9	1.6	1–7

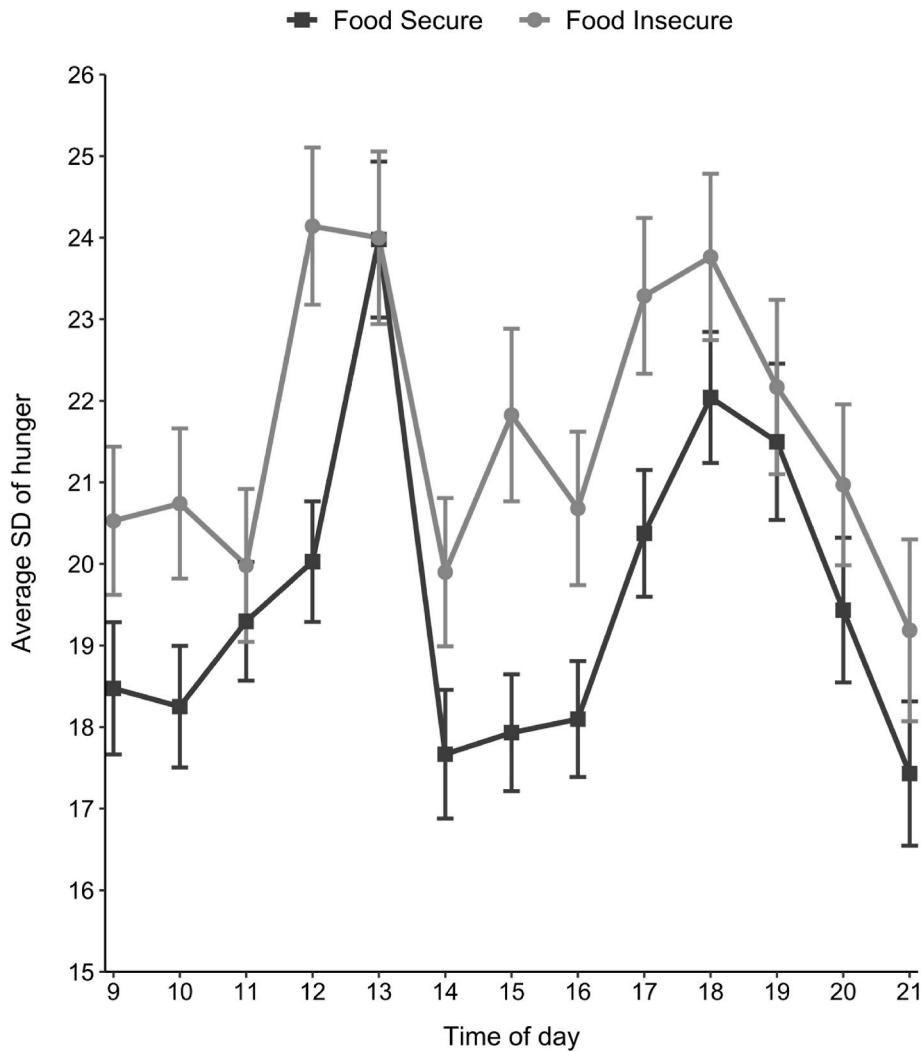


Fig. 3. Average SD at each assessment across the week for FI and FS groups.

Note. For each participant, we calculated the SD of their hunger ratings for each assessment in the study period. We then averaged the SDs for each assessment for each group. Error bars indicate one standard error of the mean.

3.3. Exploratory analyses

Of the participants included in the analyses, 69 participants could be classified as having “low food security” (scores of 2–4) according to the USDA Household Food Security Survey Six-Item Short Form module (USDA Economic Research Services, 2023b) and 74 participants could be classified as having “very low food security” (scores of 5–6). Here, we will refer to these groups of participants as moderate FI (mFI) and high

FI (hFI), respectively. There was no significant difference in age between the mFI ($M = 36.2, SD = 6.0$) and hFI groups ($M = 36.9, SD = 7.3; t(138) = 0.61, p = .544, d = 0.30$). However, there were differences in BMI. The average BMI of the hFI group ($M = 32.6, SD = 9.9$) was higher than the mFI group ($M = 29.3, SD = 7.2; t(133) = 2.25, p = .026, d = 0.37$), but the average BMI of the mFI group was not significantly higher than the FS group ($t(113) = 1.91, p = .059, d = 0.30$).

Compared to the FS group, there was no difference in mean hunger

(wM) in the mFI group ($t(289) = -0.08, p = .934, d = 0.01$) or the hFI group ($t(289) = 0.35, p = .728, d = 0.05$; [Supplementary Fig. 1A](#)), nor was there a difference in the within-day standard deviation of hunger (wCSD) in the mFI group ($t(289) = 1.59, p = .114, d = 0.25$) or the hFI group ($t(289) = 0.56, p = .574, d = 0.08$; [Supplementary Fig. 1B](#)). The hFI group had greater variation in between-day mean hunger (bvM; $t(283) = 2.81, p = .005, d = 0.40$) than the FS group, but the mFI group did not ($t(283) = 1.12, p = .264, d = 0.20$; [Supplementary Fig. 1C](#)). Similarly, the hFI group had greater variation in between-day SD of hunger (bvCSD; $t(283) = 3.21, p = .002, d = 0.46$) than the FS group, but the mFI group did not ($t(283) = 1.49, p = .139, d = 0.23$; [Supplementary Fig. 1D](#)).

In our exploratory model using the momentary assessment as the unit of analysis, there were significant differences in hunger by time of day ($F(12, 21840) = 56.91, p < .001, \eta^2 = 0.03$) and by day type (i.e., weekend vs. weekday; $F(1, 21854) = 4.80, p = .029, \eta^2 < 0.001$). There was also a significant interaction between time of day and day type ($F(12, 21840) = 4.41, p < .001, \eta^2 = 0.002$), suggesting that hunger varies over the course of the day differently at the weekend. The main effect of FI was not significant ($F(1, 300) = 0.05, p = .830, \eta^2 < 0.001$). However, there was a significant interaction between FI and time of day ($F(12, 21840) = 1.89, p = .031, \eta^2 = 0.001$). The interaction between FI and day type was not significant ($F(1, 21854) = 0.21, p = .646, \eta^2 < 0.001$), and neither was the three-way interaction ($F(12, 21840) = 1.35, p = .181, \eta^2 < 0.001$). Thus, the exploratory analysis suggests that although members of the FI group were not more hungry overall, their hunger patterned differently over the day than that of the members of the FS group ([Supplementary Fig. 2](#)). FI participants started the study period each day with a higher hunger level than FS participants. In both groups, hunger peaked at 1200 and 1700, with the FS group reporting higher hunger levels at these times. At 1400, there was a trough in hunger rating that was greater in FS participants; FI participants reported being hungrier than FS participants at 1400. The lowest hunger rating was at 2100, with little apparent difference between the FS and FI groups.

4. Discussion

In the present study, we measured hunger throughout the day for a week in two groups of UK females, one with and one without FI. We found no differences between groups in mean hunger or within-day hunger variation. However, we found that the FI group had greater variation in mean levels of daily hunger and variation of hunger across days than the FS group. Our results suggest that, compared to FS, the experience of hunger under conditions of FI differs more from day to day than is true under FS. In exploratory analyses, we found that hunger patterns were different on weekdays compared to weekends, but the effect of day type was not impacted by FI status. Furthermore, our exploratory analyses highlighted that hunger patterned differently across the day between the FI and FS groups. To our knowledge, this is the first dataset that quantitatively describes the daily experience of hunger in conditions of FI.

Interpretation of results. Our within-day results were contrary to our predictions that the FI group would have higher average hunger (P1) and within-day variation (P2), suggesting that FI is not associated with globally higher levels of hunger and hunger variation. However, we observed higher between-day variations in daily mean hunger and hunger variation in the FI group, which supported predictions P3 and P4, respectively. We also found that the severity of FI is relevant to our findings; only the hFI group had greater variation in mean levels of daily hunger and variation of hunger across days than the FS group. There was no significant difference between mFI and FS ([Supplementary Fig. 1](#)), which suggests that the severity of FI impacts how the experience of hunger differs between days from that experienced under conditions of FS.

Greater between-day variation in daily mean hunger and hunger variation may reflect particular experiences which are known to be

associated with FI. For example, these results may reflect greater uncertainty and instability in access to food, higher variation in meal timings, or more demanding or chaotic lives at home and work ([Eicher-Miller et al., 2023](#); [Nettle & Bateson, 2019](#); [Shinwell et al., 2022](#)). These characteristics could also help to explain our exploratory results which suggested that, on average, hunger was distributed differently across the day in the FI group. It is worth noting that these features of FI could also lead to more hunger variation within an individual within a day; however, our results suggest that they do not do so overall.

Use of EMA methods. Using EMA methods in this study allowed us to repeatedly sample participants during their regular, day-to-day lives. EMA study design minimises recall bias, improves ecological validity, and allows for detailed data collection over longer timeframes than would be reasonable in a laboratory setting ([Shiffman et al., 2008](#)). Of course, collecting data outside of a controlled laboratory setting means that participant responses may not be as consistent, reliable, or considered due to distractions from their surroundings. However, in our study, potential noise in the data resulting from *in situ* data collection was largely overcome by more frequent repeated sampling, longer study periods, and increased sample sizes than what would be achievable in the laboratory. Additionally, reporting how hungry one feels is a relatively simple task, and responses are unlikely to be significantly affected by environmental distractions. Existing evidence also highlights the improvements in validity and adherence that app-based EMA may offer over traditional pen-and-paper VAS methods for free-living assessments of hunger ([Holliday et al., 2021](#)).

Furthermore, because participants completed the study as they went about their day-to-day lives, we had to consider how to maximise study adherence and minimise how many momentary assessments participants missed. To encourage participants to respond as often as possible, we offered an additional voucher to participants who responded to more than 70% of the momentary assessments across the week and prompted participants during the study period if their response rate fell below this. In addition to incentives ([Wrzus & Neubauer, 2022](#)), study design can also minimise how many momentary assessments are missed in EMA studies; minimising momentary assessment length improves study compliance, but sampling frequency has no impact ([Eisele et al., 2022](#)). Therefore, we used a high-frequency sampling schedule to ensure we obtained high-fidelity data that accurately captured fluctuating hunger levels throughout the day and minimised the time it took a participant to respond to each momentary assessment. However, by only including five questions with VAS responses at each assessment, we were limited in the amount of data we could collect and consequently could not gather additional information about participants' eating episodes and dietary habits. While we recognise dietary data could have been a valuable addition to our dataset, we believe the quality of our existing dataset benefitted from limiting the scope of our study. Compliance would likely have been lower had we increased the participant burden through additional questioning. We achieved 83% compliance across the study, above the 79% average found in a recent meta-analysis of EMA research ([Wrzus & Neubauer, 2022](#)), and there was no difference in compliance between groups. Therefore, we conclude that we were justified in limiting the scope of our study, and we do not believe study compliance impacted the conclusions drawn from the between-group comparisons of the present study.

Assessing hunger. At each momentary assessment, we used two questions about different subcomponents of hunger (subjective hunger ([Blundell et al., 2010](#)) and craving ([Reichenberger et al., 2020](#))) to investigate whether the experience of different aspects of hunger differed between FI and FS. However, we did not use these two questions as independent measures of hunger as their responses were strongly correlated. Instead, we created a hunger measure that was the average of the two responses. To our knowledge, this exact measure has not been used in prior research. Nonetheless, we find similar overall patterns of daily hunger using our hunger measure as in other research (e.g.,

McKiernan et al., 2008), indicating our approach produces similar outcomes to previous work despite its differences.

Another consideration for EMA research is whether repeated sampling of the same questions influences participants' responses over time (referred to as reactivity; Shiffman et al., 2008). However, there is little evidence for reactivity in EMA designs which do not aim to change a target behaviour (Shiffman et al., 2008), as in the present study. Furthermore, the hunger questions that we used at each momentary assessment have been successfully used in other studies which do not report issues with reactivity (Dzubur et al., 2022; Reichenberger et al., 2020). We also ensured that participants in both groups were blinded to the FI component of the study (FI questions were masked in a "Cost of Living" section of the initial survey) so that knowledge of the study topic did not impact responses. In the study debrief, we informed participants about the FI aspect of the study, but they did not know which group they were in. Because we advertised the study as exploring the relationship between hunger and stress and participants were blind to the FI component of the research, it is unlikely that participants displayed demand characteristics relevant to their FI status. However, as we did not ask participants in the debrief whether they were aware of the study's FI component, we do have data to evidence the success of our blinding strategies.

Study sample. In our study, we focussed on recruiting female parents of school-aged children who were living in the North East of England. Therefore, we cannot claim that our sample broadly represented UK females. However, there was a strong rationale for our targeted sample. For example, we initially planned to recruit exclusively from parent populations of schools with above-average proportions of pupils eligible for free school meals and match FI and FS participants based on BMI, age, and school (to minimise the impact of unknown confounds of the local area). We focussed on schools with high free school meal eligibility to maximise our odds of recruiting females experiencing FI. Furthermore, we concentrated on recruiting parents of school-age children as rates of FI are higher in households with children than without (The Food Foundation, 2024), which further improved our chances of recruiting our target sample.

However, due to recruitment challenges, we could only recruit half of our sample from school parent populations and consequently had to remove our matching criteria and use targeted Facebook advertising to recruit the remainder of our sample. Before we shifted our approach, all participants joined the study via schools in the NE of England, which had some of the highest regional rates of FI in the UK when the study began (Department for Work & Pensions, 2023). Subsequently, we retained our recruitment focus on the NE, as sampling here improved our chances of recruiting enough participants to our FI group to meet our planned sample size.

In addition to removing matching participants based on school, we also removed our matching criteria for age and BMI due to challenges in recruitment. As a result, the FI group were younger than the FS group, which was expected as younger adults are typically more likely to be affected by FI (e.g., Miller et al., 2020; Office for National Statistics, 2023). The FI group also had a higher average BMI, and participants experiencing the highest severity of FI had higher BMIs than those experiencing a more moderate level of FI. Again, it is not surprising that participants experiencing FI had higher BMIs, given the link between FI and obesity in women from high-income countries, which we outlined in the introduction (Laraia, 2013; Nettle et al., 2017). However, controlling for BMI did not impact the study's results, suggesting that higher variation in mean levels of daily hunger and variation of hunger across days in the FI group are unlikely to be related to the group's higher average BMI.

Future studies may further improve our sample selection by enforcing stricter inclusion and exclusion participation criteria. For example, our screening methods did not consider whether potential participants had a history of disordered eating, were currently pregnant or lactating, or were taking medication which may affect their appetite. As such, we

cannot account for these possible influences on hunger in our dataset and findings. **Barriers to participation.** The intensity of the sampling schedule and week-long time commitment likely created a barrier to study participation; during recruitment, many individuals indicated they would like to participate but could not because working arrangements meant they would be unable to respond to momentary assessments during working hours. Such limitations may have affected certain groups more than others (e.g., females working in education or health-care) and led to a less representative sample, particularly as many females in the UK work in these settings (e.g., almost 1 million women in the UK work in the NHS (NHS, 2019)). Future studies may consider how EMA methods, such as those used in the present study, may be adapted to allow for the inclusion of these participants, for instance, using wearable devices to respond to momentary assessments. Furthermore, our study relied on participants owning a smartphone and having a level of digital literacy that allowed them to download and use an unfamiliar app. While these factors may have further limited who was able to participate in our study, they are unlikely to have had a significant impact on the representativeness of our sample, as 92% of adults in the UK have a smartphone (FAO, I, 2023). Digital poverty was another potential barrier to study participation, especially given that half of our sample was likely experiencing a level of financial instability and 28% of UK households struggle to afford communications services (Ofcom, 2024). However, continuous access to mobile data or a Wi-Fi connection throughout the study period was not required as the app downloads the notification schedule to a participant's phone when they sign up and uploads recorded responses to the server when the participant's device next has an internet connection. Therefore, only those experiencing the most severe levels of digital data poverty would not have been able to participate in our study.

Future research and implications. We recognise that the sample in the present study was limited and did not include males or older females, and, as such, our findings cannot be assumed to reflect their experiences. Future research should explore whether observed between-day hunger differences are also present in males with FI, which may provide additional insights into sex differences in the association between weight status and FI exposure (Nettle et al., 2017). Furthermore, future research should consider older females. Although rates of FI in UK adults over 65 are lower than in younger adults (Department for Work & Pensions, 2024), older females may be especially vulnerable to the health-harming effects of FI because of the compounding effect of their age (Gundersen & Ziliak, 2015). Moreover, we did not collect data regarding ethnicity in the present study. Given that the North East of England has particularly low ethnic diversity relative to the rest of the UK, our sample is likely not representative of the ethnic diversity of the UK population (UK Government, 2022). Minoritised ethnic groups often have different dietary habits and higher rates of FI than the White British population in the UK (Department for Work & Pensions, 2023; UK Government, 2024), thus, future research should ensure these people are meaningfully represented in the sample to ensure results reflect their experiences.

The causal mechanisms linking FI to poorer health outcomes in females, particularly increased weight status (Bateson & Pepper, 2023), remain poorly understood. Stress is frequently discussed as a possible mediator (Bateson & Pepper, 2023; Franklin et al., 2012; Kowaleski-Jones et al., 2019; Laraia, 2013). Our next steps with this dataset are to use longitudinal analysis methods to investigate the temporal relationship between momentary hunger and perceived stress and explore differences in this relationship between the FI and FS samples. An EMA study that investigated hunger and stress in a population of vulnerable young adults (Dzubur et al., 2022) found that when participants experienced above-average hunger, they reported greater stress variation at the next assessment. Furthermore, when individuals who reported higher average stress levels became hungry, they became significantly more stressed than individuals with lower average stress. Given that FI is associated with higher levels of stress (Martin et al., 2016), greater variation in hunger across days may exacerbate already high stress

levels in the FI sample compared to FS. Research into the links between these psychological components of FI, as well as behavioural (e.g., diet and exercise measures) and physiological (e.g., energy expenditure) components, is critical to establish the causal pathways that lead to the negative health outcomes associated with FI and evidence the need for policy change to overcome the growing public health challenge that FI has become in the UK.

5. Conclusion

We have shown that females experiencing FI have greater variation in daily mean hunger and hunger variation across days than those experiencing FS. However, we did not find evidence that these groups differed in average hunger or hunger variation within a day. To our knowledge, our study is the first to gather hourly, quantitative measurements of hunger in an FI and FS group. The hourly hunger patterns in this study largely follow the trends expected from research monitoring hunger in the general population (McKiernan et al., 2008), but the FI group appear to be more variable in how hungry they feel at each assessment than the FS group. We suggest future research should measure hunger longitudinally with other psychological, behavioural and physiological factors in participants experiencing FI (with an FS comparison group) to investigate potential causal pathways of how FI negatively impacts health. Future research should also explore whether the greater variation in hunger under FI conditions that we have described can be explained by uncertainty in food access, greater variability in meal timing, and more demanding and chaotic lives in those experiencing FI.

CRedit authorship contribution statement

Courtney Neal: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Gillian V. Pepper:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Oliver M. Shannon:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Caroline Allen:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Melissa Bateson:** Writing – review & editing, Supervision, Methodology. **Daniel Nettle:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization.

Ethics declaration

The Newcastle University Faculty of Medical Science Research Ethics Committee (reference 2287/18715) granted ethical approval for both studies. Informed consent was obtained from all participants.

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Declaration of competing interest

There is no conflict of interest for any of the authors.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.appet.2024.107732>.

Data availability

All code and data are available on Open Science Framework at <https://doi.org/10.17605/OSF.IO/6BP2Z>.

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