‘Hanger’ and beyond: measuring hunger-related mood dysregulation and its links with mental health, functioning and task-based mood induction

Miranda Copps[a], Pablo Vidal-Ribas[b], Layla Sadek[c], Clare Llewellyn[d], Moritz Herle[e], Gerome Breen[e,f], Karina Allen[g,h], Anna Carnegie[e], Lu Qi[e], Rosemary Chandler-Wilde[e], Saakshi Kakar[e,f], Iona Smith[e,f], Jutta Joormann[i], Essi Viding[a]*, Argyris Stringaris[c,j]*

Corresponding author: Miranda Copps (miranda.copps.21@ucl.ac.uk)

a. Division of Psychology and Language Sciences, University College London, London, UK
b. Child and Adolescent Mental Health Research Group, Institut de Recerca Sant Joan de Déu (IRSJD), Esplugues de Llobregat, Barcelona, Spain
c. Division of Psychiatry, University College London, London, UK
d. Department of Behavioural Science & Health, University College London, London, UK
e. Social, Genetic & Developmental Psychiatry Centre, Institute of Psychiatry, Psychology & Neuroscience, King’s College London, London, UK
f. UK National Institute for Health and Social Care Research (NIHR) Biomedical Research Centre for Mental Health, South London and Maudsley Hospital, London, UK
g. Eating Disorders Service, South London and Maudsley NHS Foundation Trust, London, UK
h. Centre for Research in Eating and Weight Disorders, Institute of Psychiatry, Psychology & Neuroscience, King’s College London
i. Department of Psychology, Yale University, New Haven, CT, USA
j. First Department of Psychiatry, Aiginiteion Hospital, National and Kapodistrian University of Athens, Athens, Greece

*EV and AS share joint last author.

Abstract

Background

Some people experience mood changes when hungry. However, the relevance of this phenomenon to clinical conditions—such as depression, anxiety and eating disorders—is understudied. Therefore, we devised a questionnaire to measure hunger-related mood dysregulation.

Methods

We developed and validated the Mood, Emotions and Appetite List (MEAL) using exploratory and confirmatory factor analysis in adults and adolescents in the community, and adults with a history of mental health disorder (N = 1,119). We examined the association of MEAL scores with happiness, frustration and boredom during the frustration-inducing mood drift task, in which participants wait for six minutes and rate their mood every 30 seconds.

Results

The MEAL showed good psychometric properties, capturing three factors for hunger-related 'irritability', 'low mood' and 'somatic feelings' (RMSEA = 0.03 in community adults, 0.05 in community adolescents, 0.08 in adults with mental health disorder history). Quantitative and qualitative responses evidenced that hunger-related mood dysregulation impacts relationships, work and hobbies. MEAL scores were associated with irritability, depression, anxiety and menstrual symptoms. In the mood drift task, the irritability subscale (MEAL-i) demonstrated a significant interaction with time, such that individuals with higher MEAL-i scores reported steeper decreases in happiness (B = -0.11; 95% CI: -0.16–-0.06) and steeper increases in boredom (B = 0.06; 95% CI: 0.00–0.12) and frustration (B = 0.12; 95% CI: 0.05–0.19).

Conclusions

The MEAL measures individual differences in hunger-related mood dysregulation, is associated with mental health, self-reported functioning, and predicts faster worsening of mood during experimentally induced frustration.

Introduction

Some people experience intense irritability when hungry, colloquially termed "hanger" (Monello & Mayer, 1967; Stevenson et al., 2023a), and evidence suggests that hunger also elicits other negative feelings (Swami et al., 2022). Are such negatively valenced experiences innocuous or do they signal risk for adverse outcomes, such as mood disorders? This question remains surprisingly understudied given its potential implications both for understanding behaviour and preventing negative outcomes. In this pre-registered study, we report on how to measure inter-individual differences in hunger-related mood dysregulation, examine how these relate to mental health symptoms and impairment, and experimentally test whether these trait differences impact momentary mood. We examine these questions in adults and adolescents in the community, and in people with a history of depression, anxiety or eating disorder.

Studying the relationship between food intake and mood is critical to understanding human behaviour and informing clinical practice. Mood relates to fluctuations in the environment (Nettle & Bateson, 2012), helping motivate behaviour that increases chances of survival. Scarcity of food is a threat to survival and food has hedonic properties for humans. Therefore, it is intuitive that mood tracking of hunger would be adaptive, which would explain the link between hunger and mood dysregulation. Experimental evidence supports this theory. Women showed increased anger, tension, fatigue and confusion, and lower vigour after an overnight fast (Ackermans et al., 2022); adolescents were less alert, calm and content after missing breakfast (Defeyter & Russo, 2013); and animals displayed increased aggression after food restriction (Edmunds et al., 2021). Similarly, studies link blood glucose levels to aggressive tendencies (Bushman et al., 2014; DeWall et al., 2011).

From a clinical perspective, the question arises as to whether hunger-related mood dysregulation signals meaningful vulnerability to states of hunger in a way that indicates risk of psychopathology or whether they are transient and inconsequential. If the former, they would be expected to impact daily life and to be a marker of more general dysregulated mood in response to environmental triggers. There are several reasons why hunger-related mood dysregulation may indicate risk for psychopathology. First, many mental health disorders involve disturbances in mood and eating. For example, appetite changes are a symptom of depression (Simmons et al., 2020); eating disorders often co-occur with affective disorders (Eck & Byrd-Bredbenner, 2021)

and some people binge eat to cope with negative emotions (Evers et al., 2010). Second, hunger may be particularly relevant to children and young people's mental health as they learn how to interpret bodily cues for hunger, via interoception, and how to employ emotion regulation strategies (Harshaw, 2015; Stevenson et al., 2023b). Rates of mood and eating disorders also increase during adolescence, and children and young people may find that their eating is regulated in school or by parents.

To examine mood dysregulation during hunger we need valid and reliable measurements. Most studies on hunger and mood have used experimental fasting protocols, which are not always feasible. With that in mind, we present the development and validation of a self-reported measure of hunger-related mood dysregulation. For such a measure to be valuable it should be associated not only with functioning and mental health but also with experimental mood induction, such as frustration, to complement prior studies. One frustrating environment in daily life is being forced to wait (Jangraw et al., 2023). Waiting is generally aversive (e.g. the impatience felt when queuing), and one possible reason is that it obstructs the adaptive behaviour of exploring or exploiting the environment. It is expected that hunger - which can represent threat or absence of reward, and can reduce emotions regulation abilities - would make people more sensitive to experience aversion during waiting, as it is an additional signal that the organism is in a non-optimal state (Jangraw et al., 2023).

We developed (aim 1) the Mood, Emotions and Appetite List (MEAL) to measure inter-individual differences in hunger-related mood dysregulation in community adults and adolescents, and individuals with a history of mental health disorder (depression, anxiety or eating disorders). To refine the MEAL, we used an iterative process of exploratory and confirmatory factor analysis (EFA and CFA, respectively), with expert input and participants' qualitative responses. We hypothesised that hunger-related mood dysregulation would show a multifactorial structure with good psychometric properties and invariance across samples. Next, we examined (aim 2) the relationship of the MEAL to mental health and functioning. We hypothesised that hunger-related mood dysregulation would be positively associated with irritability, depression, anxiety, impacts on daily life and menstrual symptoms (motivated by reported concurrent menstrual appetite and mood changes). Lastly (aim 3), we examined whether MEAL scores moderated momentary mood responses during the mood drift task. We

hypothesised that higher MEAL scores would predict faster mood worsening. Our hypotheses were pre-registered at [https://osf.io/drst5].

Methods

Participants and procedures

We recruited six samples for the present study. The first three samples were adults recruited from Prolific (www.prolific.com), aged 18-30, living in the United Kingdom (UK), fluent in English, with a Prolific approval rating of >90%. We recruited sample 1 (n=202) for EFA, sample 2 (n=160) for the purpose of CFA and sample 3 (n=84) for test-retest analysis (52/84 completed the MEAL twice). Samples 1-3 completed all questionnaires and the mood drift task (hosted on Gorilla, www.gorilla.com).

Samples 4 and 5 (aged 14-18) were recruited from schools in England, and tested in groups in classrooms, to validate the MEAL in adolescents. Adolescents provided demographic information through REDCap (Harris et al., 2009), and could skip questions they did not wish to answer. Sample 4 (n = 135) completed questionnaires followed by the mood drift task (9 participants do not have task data due to technical issues). Sample 4 were cluster-randomised to receive a snack bar before or after testing, but we determined that this manipulation did not impact the results and therefore participants from both conditions are presented together. Sample 5 completed the MEAL and questionnaires for symptoms of depression and anxiety. Thirteen participants in sample 5 answered less than half the MEAL items and were excluded, resulting in n = 201.

Sample 6 was recruited from two studies run by King's College London (KCL): the Genetics Links to Anxiety and Depression (GLAD) Study (Davies et al., 2019) and the Eating Disorders Genetics Initiative UK (EDGI UK, Monssen et al., 2024). Invitations were sent to the studies' Patient and Public Involvement panels. Participants were based in the UK, aged ≥ 16 years. The sample was enriched for people who self-identified as having experienced an affective disorder or eating disorder and is referred to as the enriched sample. Our results are limited to the MEAL, mental health history, demographics, height and weight. Of 371 participants, 337 completed the MEAL (n = 249 from the GLAD Study, n = 62 from EDGI UK and n = 26 from both).

Ethical considerations

UCL's Ethics Committee (24867, 28647) and KCL's Health Faculties (Purple) Research Ethics Subcommittee (HR/RGO-24/25-46471) approved the study, and all participants provided consent.

Measures

MEAL

Initially, we developed 20 items on hunger-related mood dysregulation, in consultation with clinicians, and mental health and appetite researchers. Before completing the MEAL, participants in samples 1-5 were asked "Do you think that being hungry changes your mood in day-to-day life? What changes do you notice? Does this impact your work, school, relationships or other aspects of your life?" (free-text response). We coded all responses, and grouped them into themes for mood, somatic feelings and impacts. Responses from sample 1 were used to inform the refinement of the questionnaire. For the MEAL, all participants were presented with the instruction "Please indicate how much of the time you think the following statements apply to you". The response options were "Never / Almost Never", "Rarely", "Sometimes", "Often" and "Always / Almost Always", which were coded as 0 to 4. We collected responses to these items from sample 1. Using EFA (details in Section 1 of Supplementary Materials) and qualitative feedback, we formed an updated set of 16 items. This comprised 15 core items and one impact item. Impacts covered four areas: (1) relationships with family, (2) relationships with friends or partners, (3) hobbies and/or interests and (4) school and/or work. Sample 2 answered these 16-items (15 + 1), and CFA was performed. After removing items for parsimony, the final version of the MEAL had 12 items (11 + 1), with three subscales for hunger-related irritability, low mood and somatic feelings (MEAL-i, MEAL-l and MEAL-s, respectively). This final version was administered twice (two-weeks apart) in sample 3, and once in samples 4-6.

Physical health and physiology

Adult participants (samples 1-3 and 6) were asked for their height and weight, to calculate body mass index (BMI). The five-item hunger sensitivity subscale of the Adult Eating Behaviour Questionnaire (AEBQ-h) was included for samples 1-3 to test convergent validity (Hunot et al., 2016). Participants rated their current hunger from 0 to 100 using a visual analogue scale (VAS). The resulting distribution was bi-modal, thus current hunger was dichotomised using a median

split. We asked female participants in samples 2 and 3 optional questions about regularity of their menstrual cycles, symptoms they experience before and during menstruation (e.g. increased appetite, irritability; coded as 1 or 0 for presence or absence, respectively) and use of hormonal contraception.

Mental health

All participants were asked if they had ever been diagnosed with or suspected they have a mental health condition. For samples 1-4, the Affective Reactivity Index (ARI) was included to measure irritability (Stringaris et al., 2012). For samples 1-5, the Patient Health Questionnaire-8 (PHQ-8) was included to measure depression symptoms (Kroenke et al., 2001) and the seven item version of the Generalised Anxiety Disorder (GAD-7) scale was included to measure anxiety symptoms (Spitzer et al., 2006).

Mood drift task

Samples 1-4 completed the mood drift task (Jangraw et al., 2023). In each trial participants waited for 30 seconds, while looking at a fixation cross, and then rated their mood from 0-100 on three VAS scales (happy, bored and frustrated). There were 12 trials, with a total six minutes of waiting time, and there was an additional mood rating before the first trial. Participants could take any amount of time on mood ratings so we removed outlier participants for total time on the task ($> Q3 + 1.5 * IQR$ or $> Q1 - 1.5 * IQR$, where Q = quartile and IQR = interquartile range). After removing 40 outliers; 15 participants who had technical issues with the task (6 adults, 9 adolescents); and the final N for the task was 526 (400 adults and 126 adolescents).

After removing 40 outliers and 6 participants who had technical issues (all adults) the final N for the task was 526 (400 adults and 126 adolescents).

Statistical analyses

We ran all analyses in R (R Core Team, 2022), using Lavaan (Rosseel, 2012) for factor analysis and lme4 (Bates et al., 2015) for linear mixed effects models.

Exploratory factor analysis

We computed a Pearson's correlation matrix for all items prior to both EFA and CFA steps. Items which correlated > 0.8 with other items were removed, retaining one item. Any item with correlations < 0.3 with all other items were also removed.

We performed EFA on sample 1 data to reduce and refine items. Parallel analysis (Horn, 1965) was performed to indicate the number of factors. Items were removed according to the following criteria: no loading > 0.4, or cross-loadings > 0.3 (Vitoratou et al., 2021). Models were tested separately by sex, and items which loaded onto different factors by sex were removed.

We evaluated factor models using multiple fit indices including the comparative fit index (CFI), Tucker–Lewis index (TLI), root mean squared error of approximation (RMSEA), the standardised root mean squared residual (SRMR), relative χ^2 and the model χ^2 p value (Vitoratou et al., 2021). Models were evaluated against the following criteria: (1) CFI > 0.90 indicates close fit; (2) TLI > 0.90 indicates close fit; (3) RMSEA values below 0.08 are deemed adequate fit, and below 0.05 are a close fit (Browne & Cudeck, 1992); (4) SRMR < 0.05 indicates a good fit; (5) relative chi-square values close to 2 (calculated as $\chi^2 / degreesoffreedom$, Alavi et al., 2020) and (6) the p value for the χ^2 test is expected to be greater than 0.05. Additionally, the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were used for model comparison. All models were estimated using maximum likelihood (ML) and unweighted least squares (ULS) as the data were ordinal. As no models showed a substantial difference between ML and ULS, only ML versions are reported. All EFA models were run with geomin oblique rotation.

Confirmatory factor analysis

We performed CFA on the responses to 15 items in sample 2. We hypothesised a three-factor solution, which was assessed according to the same fit criteria as EFA. We compared the three-factor model to one- and two-factor models. CFA models were estimated in the same manner as EFA and only ML estimated models are presented. For adolescents, full information maximum likelihood (FIML) was used to handle missing data. After removing items to avoid redundancy we ran CFA again on the 11 core MEAL items. While it is generally not advised to iterate during CFA, we deemed removal of items to be acceptable, as it did not involve extensive re-specification of the model.

Reliability and validity

Factors were assessed for internal consistency, and to minimise redundancy, using Cronbach's α with > 0.7 being classed as acceptable (Cronbach, 1951). Test-retest reliability was assessed using the intraclass correlation coefficients (ICC[3,1]) with 2-way mixed effects (Trevethan, 2017). In community adults, convergent validity was assessed using Pearson's correlation of the MEAL and AEBQ hunger subscale (Hunot et al., 2016).

Measurement invariance

We tested the final three-factor MEAL model for measurement invariance between (1) community adults and adolescents; and (2) community adults and the sample enriched for mental health disorders. The latter was split into two subsamples: individuals with any eating disorder experience and individuals with affective disorder experience but no history of eating disorder. This method for dividing the enriched sample was chosen as we expected eating disorder experience would result in more variation in MEAL responses. We tested for loading, intercept and residual invariance (according to Chen, 2007). As our sample sizes were unequal we used the following criteria: for loading noninvariance a change of ≤ -0.005 in CFI, supplemented by a change of ≥ 0.010 in RMSEA or a change of ≥ 0.025 in SRMR; and for intercept and residual noninvariance the last criterion becomes a change of ≥ 0.005 in SRMR.

MEAL correlates

We examined MEAL associations with participant sex, age, mental health symptoms (ARI, PHQ-8, GAD-7), BMI and menstrual symptoms, using Pearson's correlations, Student's two sample t-tests and linear regressions.

Impact analysis

As exploratory analysis, we ran ANOVAs with Scheffe's post-hoc test to examine associations between MEAL scores and the four impact areas.

Mood drift task

We analysed mood drift task data with linear mixed effects (LME) models with two formulations. The first had time as the only fixed effect to confirm mood drift, in line with Jangraw et al. (2023). The second model had an interaction of time with the sum score of

MEAL-i. Models were run separately for happiness, frustration and boredom (Ridler et al., preprint), and all models included participant and time as random effects.

$$mood \sim 1 + time + (1 + time|participant) \quad (1)$$

$$mood \sim 1 + time * MEAL\text{-}i + (1 + time|participant) \quad (2)$$

For Equation 2, the MEAL-i was used because irritability is of particular relevance to hunger-related mood dysregulation, and because items were consistent across samples 1-4, thus providing greater statistical power.

We also tested whether current hunger (dichotomised) was associated with responses in the task. As exploratory analyses, we tested whether ARI, PHQ-8 or GAD-7 were associated with mood drift responses.

Results

Sample characteristics

Demographic information is presented in Table 1. Community adult samples were balanced for sex, whereas there were more males in sample 5 and more females in sample 6. A majority of adult participants had diagnosed or self-diagnosed mental health conditions, present or past.

Table 1: Demographic characteristics of samples in the present study

	Community Adult			Community Adolescent		Enriched
Measure	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Total N	202	160	84	135	201	337
Female, n (%)	100 (50)	80 (50)	40 (48)	69 (51)	85 (42)	279 (83)
Age M (SD)	25 (3.2)	25.6 (3.4)	25.5 (3.2)	16.7 (0.7)	16.2 (1.2)	49.7 (15.2)
Ethnicity, n (%)						
Asian	29 (14)	20 (12)	6 (7)	9 (7)	83 (41)	2 (1)
Black	17 (8)	25 (16)	25 (30)	7 (5)	21 (10)	1 (0)
Mixed	14 (7)	12 (8)	5 (6)	10 (7)	21 (10)	7 (2)
Other	1 (0)	3 (2)	1 (1)	5 (4)	5 (2)	1 (0)
White	141 (70)	99 (62)	44 (52)	99 (73)	67 (33)	325 (96)
Unknown	-	1 (1)	3 (4)	5 (4)	4 (2)	1 (0)

Employment Status, n (%)						
Full-Time	81 (40)	65 (41)	35 (42)	-	-	-
Part-Time	34 (17)	24 (15)	16 (19)	-	-	-
Not Working	42 (21)	36 (22)	13 (15)	-	-	-
Other	9 (4)	9 (6)	4 (5)	-	-	-
Unknown	36 (18)	26 (16)	16 (19)	-	-	-
Lifetime mental health diagnosis and self-diagnosis, n (%)						
Any	144 (71)	107 (67)	62 (74)	26 (19)	23 (11)	325 (96)
Depression	80 (40)	60 (38)	37 (44)	17 (13)	4 (2)	277 (82)
Anxiety	112 (55)	77 (48)	47 (56)	28 (21)	8 (4)	233 (69)
Eating disorders	22 (11)	20 (12)	10 (12)	7 (5)	2 (1)	190 (56)

Community adults from samples 1-3 were Prolific users; community adolescents from samples 4 and 5 were recruited from secondary schools in South East England, East England and London; and adults from sample 6 were recruited from the GLAD and EDGI UK studies. Mental health conditions are both diagnosed and self-diagnosed for all samples excluding 5, where only diagnoses were recorded.

MEAL factor analysis

We used EFA to iteratively develop the MEAL (Tables S1-10, Section 1 of Supplementary Materials). Based on qualitative feedback (Table S14 in Section 2 of Supplementary Materials) from sample 1, we developed additional items and modified wording of some items. Regarding low mood, we removed "I get more sad than other people I know", and added "I become tearful or weepy". A theme of somatic feelings emerged, with 29% of participants citing a range of sensations (e.g. "having less energy", "feel weak and faint", "physical issues like a headache or feeling sick"). We also simplified some language, e.g. "I have more arguments with people or snap at people more" was changed to "I argue or snap at people more". 102 (52%) participants noted that hunger impacts their work, relationships or other activities (e.g. "I concentrate less and am probably less productive", "[hunger] can impact me in social situations as I'm not as friendly as I would like"). Thus, we added the impact question.

We hypothesised a three-factor model of MEAL-i, MEAL-l and MEAL-s for CFA (details in Section 1 of Supplementary Materials; Tables S11-13). The model fit with 11 items was excellent (Table 2, CFI = 1, TLI = 0.99, RMSEA = 0.03, SRMR = 0.03, relative χ^2 = 1.12 and χ^2 = 46.03 [p = 0.272]). The three-factor model fit more closely than either a one- or two-factor

model. The internal consistency and test-retest reliability were also good (Table 2). The observed Pearson's *r*s between factors were: 0.77 for MEAL-i and MEAL-l, 0.63 for MEAL-i and MEAL-s, and 0.74 for MEAL-l and MEAL-s. MEAL scores showed a large correlation with AEBQ hunger sensitivity (Pearson's $r = 0.71$, $p < 0.001$), demonstrating convergent validity.

Table 2: The MEAL Questionnaire: psychometric properties of the eleven core items with three factors, and wording for the impact item

			Community Adult			Community Adolescent		Enriched	
Factor	#	Label	Est	alpha (95%CIs)	ICC (95%CIs)	Est	alpha (95%CIs)	Est	alpha (95%CIs)
MEAL-i	10	When I have not eaten in a while I argue or snap at people more	0.88	0.88 (0.85, 0.91)	0.72 (0.55, 0.83)	0.82	0.85 (0.82, 0.88)	0.89	0.90 (0.88, 0.92)
	1	When I have not eaten in a while other people notice a change in my mood or behaviour	0.70			0.68		0.72	
	7	When I have not eaten in a while I feel more irritated or grumpy than others	0.84			0.87		0.88	
	11	When I have not eaten in a while I feel impatient	0.84			0.71		0.86	
MEAL-l	9	When I have not eaten in a while I become tearful or weepy	0.64	0.84 (0.79, 0.87)	0.66 (0.48, 0.79)	0.62	0.75 (0.69, 0.79)	0.67	0.85 (0.82, 0.87)
	5	When I have not eaten in a while I feel sad	0.84			0.69		0.78	

	8	When I have not eaten in a while I feel anxious or nervous	0.73			0.66		0.78	
	3	When I have not eaten in a while I lose motivation and interest in things	0.79			0.69		0.84	
MEAL-s	2	When I have not eaten in a while I get a headache	0.66	0.79 (0.72, 0.84)	0.76 (0.61, 0.85)	0.69	0.75 (0.70, 0.80)	0.59	0.72 (0.65, 0.78)
	4	When I have not eaten in a while I feel sick or nauseous	0.72			0.69		0.67	
	6	When I have not eaten in a while I feel weak or dizzy	0.85			0.75		0.79	
Impact	12	When I have not eaten in a while I experience problems with my: - Family - Friends and/or partner - Hobbies and/or interests - School and/or work							

The impact question is included in the MEAL questionnaire but not the factor structure or sum score. # = Order of items when presenting the MEAL, Est = factor loading for each item in the three-factor CFA model, alpha = Cronbach's alpha for measuring internal consistency, ICC = intraclass correlation coefficient for measuring test-retest reliability over a two-week period, 95%CIs = 95% confidence intervals. Community adults n for Est and alpha was 160, for ICC was 52; community adolescents n was 336 (135 + 201); enriched sample n was 337

The three-factor model showed good fit in adolescents (CFI = 0.97, TLI = 0.96, RMSEA = 0.05, SRMR = 0.04, relative χ^2 = 1.95, the model χ^2 = 79.99 [$p < 0.001$]). The significant χ^2 was the only fit statistic which did not meet its criterion. We demonstrated loading, intercept and residual invariance between community adults and adolescents.

The three-factor model showed adequate fit in the enriched sample (Table 2), with all indices apart from the χ^2 significance test and relative χ^2 meeting criteria (CFI = 0.96, TLI = 0.94, RMSEA = 0.08 and SRMR = 0.04, relative χ^2 = 3.34, model χ^2 = 137.05 [$p < 0.001$]). We demonstrated loading, intercept and residual invariance between three groups: community adults, individuals with a history of eating disorders (including those who also had experience of affective disorder) and individuals with experience affective disorder but not eating disorder.

MEAL correlates

Mean MEAL scores for community adults (samples 2, 3), adolescents and the enriched sample are displayed in Table 3.

Table 3: Overall MEAL and factor mean scores and Pearson's correlations with mental health measures

	Mean (SD)			Pearson's r		
Factor	Total	Male	Female	Irritability	Depression	Anxiety
Community Adult (samples 2 and 3)						
MEAL	20.1 (10.8)	17.5 (10.8)	22.7 (10.3)	0.49***	0.53***	0.55***
MEAL-i	8.4 (4.4)	7.5 (4.5)	9.3 (4)	0.5***	0.44***	0.48***
MEAL-l	6.1 (4.2)	5.3 (4.1)	6.9 (4.3)	0.47***	0.53***	0.54***
MEAL-s	5.7 (3.3)	4.7 (3.2)	6.5 (3.1)	0.34***	0.47***	0.48***
Community Adolescent (samples 4 and 5)						
MEAL	18.3 (9.2)	15.1 (8.5)	21.6 (8.6)	0.31***	0.43***	0.43***
MEAL-i	8 (4)	7 (3.8)	9 (4)	0.34***	0.3***	0.29***
MEAL-l	5.2 (3.6)	4.3 (3.5)	6.2 (3.4)	0.15	0.35***	0.36***
MEAL-s	5.2 (3.2)	3.9 (3)	6.5 (2.9)	0.27**	0.48***	0.43***
Enriched (sample 6)						
MEAL	16.5 (9.4)	14.6 (9.9)	16.6 (9.3)			
MEAL-i	6.5 (4.1)	6 (4.1)	6.5 (4.1)			
MEAL-l	5 (3.7)	4.2 (3.7)	5.1 (3.7)			
MEAL-s	4.9 (2.7)	4.4 (2.9)	5 (2.7)			

Community adults N = 244, adolescent N = 336 (apart from ARI where adolescent N = 133), enriched N = 337. *** p <0.001, ** p <0.01. Irritability was measured with the Affective Reactivity Index (ARI), depression symptoms were measured with the Public Health Questionnaire - 8 item version (PHQ-8), and anxiety symptoms were measure with the Generalised Anxiety Disorder - 7 item version (GAD-7).

Female participants had higher mean MEAL scores than male participants (Table 3). A t-test showed the difference to be significant (t[692.63] = 4.96, $p < 0.001$). Age (in years) was associated with MEAL scores such that older participants had lower MEAL scores (B = -0.11, p <0.001; adjusted R^2 = 0.03, F(1), (878) = 32.43, p <0.001).

In the community adults and adolescent samples correlations between MEAL and its subscales with irritability, depression and anxiety symptoms ranged from small (r = 0.27 for MEAL-s and irritability in adolescents) to large (r = 0.55 for MEAL and anxiety in community adults; Table 3). One correlation, between the MEAL-l and irritability in adolescents, was not significant (Table 3).

MEAL scores were lower in the enriched sample compared to community adults (Table 3). In the enriched sample, participants with a history of eating disorder, including co-occurring affective disorder, had a mean MEAL score of 17.74 (SD = 9.54); and those with a history of affective disorder had a mean MEAL score of 14.82 (SD = 8.88). After controlling for sex and age, a linear model showed differences between the community adults and enriched sample to be non-significant (model adjusted R^2 = 0.1, F(3), (559) = 15.99 [$p < 0.001$]).

In exploratory analysis, BMI did not significantly explain further variation in MEAL scores (B = -0.05, p = 0.379, F(3),(537) = 20.9). Independent samples t-tests showed that neither regularity of periods (t[108] = 0.89, p = 0.373) or use of hormonal contraception (t[108] = -0.15, p = 0.879) were associated with MEAL scores. The number of symptoms experienced before or during menstruation was significantly associated with MEAL scores (B = 2.22, p <0.001; adjusted R^2 = 0.09, F(1), (108) = 11.46, p <0.001). Additionally, higher MEAL scores were associated with reporting increased appetite before or during menstruation (mean = 24.67) compared to no appetite increase (mean = 17.86, t[108] = -2.88, p = 0.005).

MEAL impact analysis

We defined substantial impacts as response categories "often" and "always/almost always" and see that community adults report the greatest impacts on school/work (25%). For adolescents we see the greatest impacts on hobbies/interests and school/work (both about 26%). In the enriched sample, more people (15.8%) endorsed hobbies/interests than other impacts. See section 3 of the Supplementary Materials for further analyses of impacts. ANOVAs testing associations between MEAL score and each impact area were significant (all $p < 0.001$). Scheffe's tests revealed that the comparisons between the first four levels (comparisons: 1-0, 2-1, 3-2) were significant for all impact areas ($p < 0.001$). The comparison between the final two levels (4-3), was only significant for hobbies/interests ($p = 0.011$).

MEAL-i and task-based mood drift

As expected, happiness decreased and frustration and boredom increased during the mood drift task. MEAL-i demonstrated a significant interaction with time for happiness, boredom and frustration (Figure 1). Significant associations were in the expected directions, such that higher MEAL-i scores were associated with a steeper decline in happiness and steeper increases in boredom and frustration. MEAL-i was associated with significantly lower initial happiness, and higher initial boredom and frustration (Table 4).

Table 4: Fixed effects of linear mixed effects models showing MEAL-i prediction of mood response in a frustrating waiting task

Mood	Effect	Term	B	95%CI lower	95%CI upper	p value
Happy	fixed	intercept	60.87	56.98	64.75	<0.001
		time (mins)	-1.01	-1.46	-0.56	<0.001
		MEAL-i	-0.76	-1.19	-0.32	0.001
		time*MEAL-i	-0.11	-0.16	-0.06	<0.001
	random	SD intercept	20.89	19.62	22.29	
		SD time	2.33	2.17	2.50	
		SD observation	9.00	8.84	9.17	
Bored	fixed	intercept	40.54	35.59	45.49	<0.001
		time (mins)	2.25	1.72	2.79	<0.001
		MEAL-i	1.32	0.77	1.88	<0.001
		time*MEAL-i	0.06	0.00	0.12	0.043

	random	SD intercept	26.77	25.16	28.55	
		SD time	2.79	2.61	2.99	
		SD observation	10.22	10.03	10.41	
Frustrated	fixed	intercept	13.69	9.12	18.27	<0.001
		time (mins)	2.42	1.82	3.02	<0.001
		MEAL-i	1.79	1.28	2.30	<0.001
		time*MEAL-i	0.12	0.06	0.19	<0.001
	random	SD intercept	24.58	23.08	26.23	
		SD time	3.12	2.91	3.34	
		SD observation	10.89	10.69	11.09	

Note: B = estimate of coefficients from LME models. The n = 523 as 3 adolescent participants did not have complete MEAL-i data.

Current state hunger showed main effect associations with all three mood states, but was not associated with the steepness of mood slopes. Similarly, none of the ARI, PHQ-8 or GAD-7 moderated the steepness of the mood slopes. Details of these analyses are in section 4 of the Supplementary Materials (Tables S18-21).

Discussion

We demonstrated that the MEAL can measure individual differences in hunger-related mood dysregulation, showing good psychometric properties in community adults, community adolescents and individuals with past/current psychiatric disorders. MEAL scores were associated with symptoms of irritability, depression and anxiety. A sizable minority of participants (8.9-26.6%) endorsed that hunger-related mood dysregulation substantially impacted them. This finding was supported by qualitative responses (e.g. “If I’m on an empty stomach [I] can’t function correctly”, “[hunger] affects my mental health in a big way, and even small tasks feel overwhelming”). Finally, we showed that MEAL-i scores predicted faster worsening mood during a frustrating task.

The MEAL’s three-factor structure highlights the importance of considering multiple facets of mood in relation to hunger, consistent with experimental fasting studies which have evidenced changes in multiple mood states (Ackermans et al., 2022; Defeyter & Russo, 2013). It may be that ‘hanger’ has previously received more attention because it is more likely to be externalised, compared to low mood or somatic feelings.

Females and younger participants scored higher than males and older participants on the MEAL, respectively. The pattern of sex differences on the MEAL is in keeping with response trends on self-rated irritability (Vidal-Ribas et al., 2023), depression (Thibodeau & Asmundson, 2014) and anxiety (Spitzer et al., 2006) symptom scales. These sex differences may be driven by a combination of physiology, environmental risk factors, socialisation and methodological features (Patalay & Demkowicz, 2023). The trend of FAMIN declining with age may be partially explained by adolescence being a time of high energy requirements (Das et al., 2017), whereas older age is associated with appetite decline (Giezenaar et al., 2016). The association of menstrual cycle symptoms with the MEAL suggests a role of hormonal fluctuations in hunger-related mood dysregulation.

We also demonstrated the association of hunger-related mood dysregulation to mental health. In community adults, MEAL scores showed correlations with irritability, depression and anxiety; while in adolescents it showed small correlations with irritability and moderate correlations with the depression and anxiety. These associations could represent hunger-related mood dysregulation being a risk factor for poor mental health, although longitudinal designs would be required to test this pathway explicitly. The slightly lower scores in the affective disorder subgroup was surprising given the correlations above, as well as observations of appetite changes in depression (Simmons et al., 2020). The lack of statistical differences in MEAL scores between community adults and the subgroup with history of eating disorder experience was less surprising as food restriction may induce feelings of satisfaction for some people with anorexia nervosa.

We also show that the MEAL captures impairment in people's everyday lives, particularly their inter-personal relationships, indicating further that hunger-related mood dysregulation is not simply a transient and innocuous phenomenon. Previous work showed a link between blood glucose and intermarital conflict (Bushman et al., 2014), but did not test whether hunger-related mood dysregulation mediated this. Participants referenced difficulty focussing at work or school in qualitative feedback. Therefore, hunger-related mood dysregulation may pose a particular risk in settings where meals are regulated such as schools (Afridi et al., 2019), shift work (Heath et al., 2019) and prisons (Kushmerick-McCune et al., 2024).

We demonstrated that the MEAL-i captures sensitivity to environmental changes as MEAL-i scores moderated the extent of mood decline during a frustrating waiting task (Jangraw et al., 2023). As expected, our results show that elevated MEAL-i scores were associated with more negative mood ratings, and faster mood declines in response to the task, which makes MEAL-i a valuable tool for researching mechanisms of mood dysregulation. Other measures - irritability, depression and anxiety symptoms - did not show associations with steepness of mood slopes, suggesting the MEAL is somewhat unique in capturing susceptibility to mood dysregulation in response to environmental triggers.

Strengths and limitations

This pre-registered study has several notable strengths including replication in multiple samples; statistical power and rigorous evaluation of generalisability across samples; experimental validation; and the inclusion of participants' qualitative feedback in item generation for the MEAL.

There were also some limitations to consider. High correlations between factors could suggest redundancy within the questionnaire. However, we did not address this further as the constructs are expected to be related, and the three-factor model fit the data better than one- or two-factor models. As this study is cross-sectional our causal inference is limited.

Future research

Longitudinal designs and embedding the MEAL as a screener in experimental studies would allow exploration of whether hunger-related mood dysregulation is a risk-factor for psychopathology and other negative outcomes.

Conclusions

In this study, we developed a valid and reliable measure of individual susceptibility to hunger-related mood dysregulation with potential utility for clinical, epidemiological and experimental studies. We consider this work foundational to furthering our understandings of hunger-related mood dysregulation, spanning beyond 'hanger' to various mood states, and to mental health symptoms and impacts in daily life.

Data availability

All data for samples 1-5 is available at https://github.com/MirandaCopps/MEAL_dev/tree/main. For sample 6 data please contact the authors, and data will be made available upon reasonable request.

Code availability

All code is available at https://github.com/MirandaCopps/MEAL_dev/tree/main

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Author contribution

CRediT Taxonomy. Conceptualization – MC, PVR, CL, MH, GB, KA, AC, JJ, EV, AS. Data curation – MC, LS, LQ, RCW, SK. Formal analysis – MC, LS, LQ, RCW, SK. Investigation - MC, LS. Methodology - MC, CL, MH, GB, KA, EV, AS. Project administration – MC, AC. Resources - IS. Supervision – EV, AS. Writing original draft – MC, AS. Writing review & editing – MC, PVR, LS, CL, MH, GB, KA, AC, LQ, RCW, SK, IS, JJ, EV, AS.

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Ethical standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

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Figure

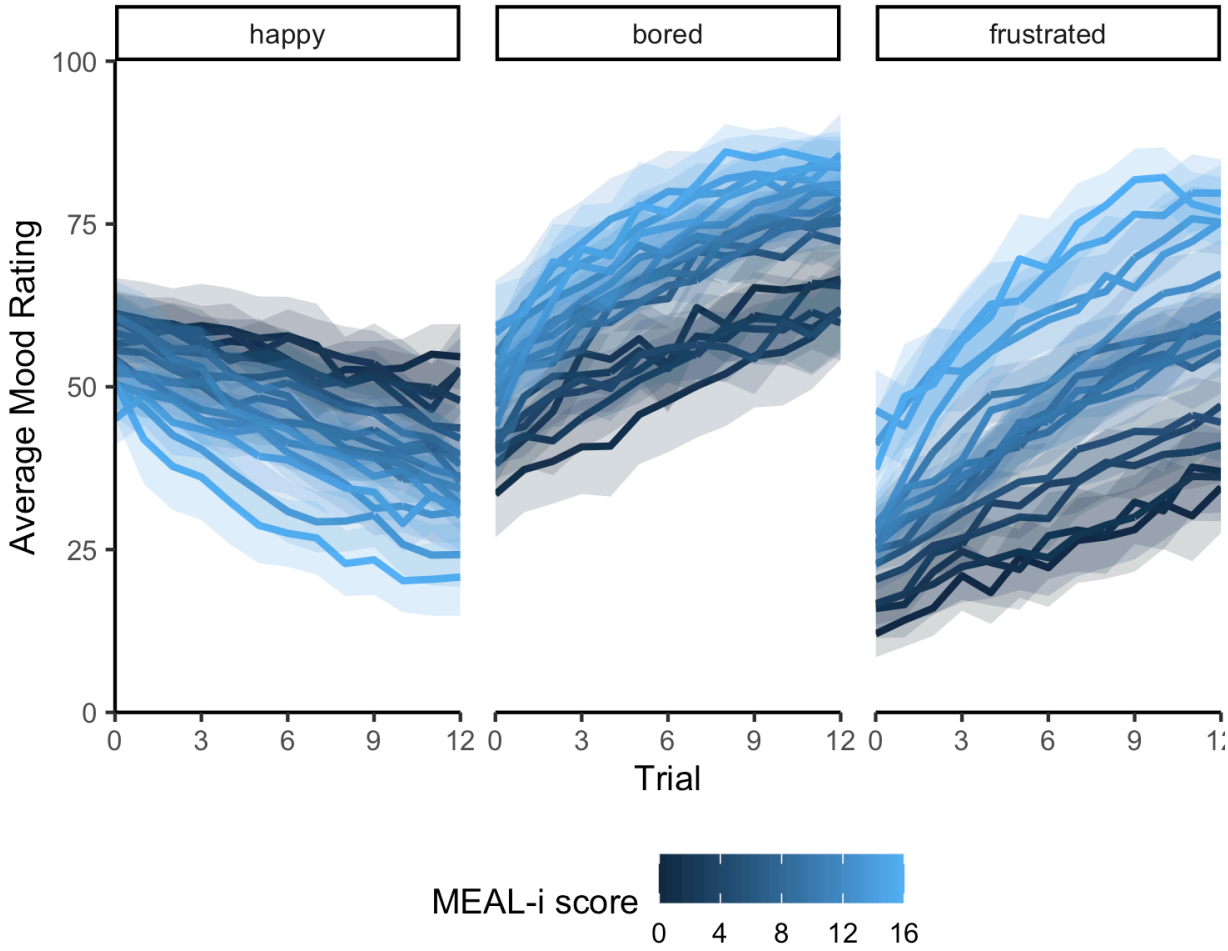

Figure 1: Means and standard errors of mood ratings by trial during the mood drift task, grouped by participants' MEAL-i score. Note: n = 523 as 3 adolescent participants did not have complete MEAL-i data.

Supplementary Materials

Section 1: Additional Factor Analysis Details

This section contains the results of the exploratory and confirmatory factor analyses (EFA and CFA) in order to provide details of the several rounds of iteration which took place.

All EFA pertains to sample 1 (N = 202) and all CFA to sample 2 (N=160), recruited from Prolific.com.

The initial list of 20 items is displayed in Table S1, item numbers (with the prefix HM for hunger and mood) are used to refer to the items throughout this supplement.

Table S1: Labels and items numbers for the initial list of 20 items in the MEAL questionnaire for EFA

Item	Label
HM01	When I have not eaten in a while I get angry easily or can lose my temper
HM02	When I have not eaten in a while I have more arguments with people or snap at people more
HM03	When I have not eaten in a while I feel happy
HM04	When I have not eaten in a while I have said and done things that I have regretted later
HM05	When I have not eaten in a while people think I'm tired
HM06	When I have not eaten in a while even small things can irritate me
HM07	When I have not eaten in a while I find it hard to concentrate or to finish tasks
HM08	When I have not eaten in a while I find it harder to do my work
HM09	When I have not eaten in a while my friends/family/partner/others tend to notice it because of my mood/behaviour
HM10	I make more thoughtful decisions when I have eaten enough
HM11	When I have not eaten in a while I get more irritable than other people I know
HM12	My anger/irritability decreases once I have eaten

HM13	When I have not eaten in a while I have done or said things that have caused problems in my relationships with others
HM14	When I have not eaten in a while I get more sad than other people I know
HM15	When I have not eaten in a while I feel impatient
HM16	When I have not eaten in a while I can feel sad
HM17	When I have not eaten in a while people close to me notice a pattern of me seeming more irritable or short tempered
HM18	When I have not eaten in a while I can feel irritable
HM19	When I have not eaten in a while I get anxious/nervous or worrisome
HM20	When I have not eaten in a while I get frustrated more easily

Note: HM03 was reverse coded

Inspection of the correlation matrix of the initial 20 items resulted in the removal of four items (Table S2). Items HM01, HM08 and HM18 were dropped due to high correlations (> 0.8) and item HM03 was dropped due to all correlations being < 0.3 or non-significant.

Table S2: Pearson's correlation matrix of initial 20 MEAL items

Item	HM02	HM03	HM04	HM05	HM06	HM07	HM08	HM09	HM10	HM11	HM12	HM13	HM14	HM15	HM16	HM17	HM18	HM19	HM20
HM01	0.81***	-0.053	0.7***	0.36***	0.69***	0.43***	0.45***	0.61***	0.27***	0.65***	0.57***	0.62***	0.47***	0.61***	0.47***	0.69***	0.7***	0.51***	0.75***
HM02		-0.036	0.68***	0.31***	0.73***	0.44***	0.43***	0.64***	0.21**	0.63***	0.61***	0.59***	0.46***	0.59***	0.46***	0.7***	0.71***	0.46***	0.71***
HM03			-0.084	0.012	0.075	0.12	0.13	0.08	0.22**	-0.002	0.11	-0.11	-0.14*	0.058	-0.031	-0.0086	0.059	-0.13	0.046
HM04				0.37***	0.64***	0.46***	0.47***	0.56***	0.2**	0.56***	0.41***	0.68***	0.55***	0.58***	0.49***	0.64***	0.6***	0.49***	0.63***
HM05					0.4***	0.4***	0.46***	0.42***	0.33***	0.35***	0.29***	0.32***	0.45***	0.33***	0.48***	0.43***	0.35***	0.45***	0.43***
HM06						0.56***	0.55***	0.7***	0.36***	0.73***	0.55***	0.58***	0.44***	0.71***	0.47***	0.77***	0.82***	0.45***	0.79***
HM07							0.87***	0.47***	0.49***	0.42***	0.4***	0.34***	0.34***	0.57***	0.38***	0.44***	0.55***	0.39***	0.57***
HM08								0.48***	0.51***	0.46***	0.46***	0.35***	0.34***	0.6***	0.42***	0.43***	0.55***	0.42***	0.56***
HM09									0.36***	0.67***	0.57***	0.58***	0.45***	0.61***	0.52***	0.8***	0.7***	0.47***	0.69***
HM10										0.33***	0.45***	0.14	0.18*	0.39***	0.29***	0.27***	0.34***	0.21**	0.38***
HM11											0.5***	0.63***	0.49***	0.63***	0.47***	0.74***	0.68***	0.42***	0.67***
HM12												0.35***	0.27***	0.58***	0.37***	0.53***	0.61***	0.32***	0.61***
HM13													0.55***	0.51***	0.45***	0.63***	0.56***	0.45***	0.55***
HM14														0.48***	0.76***	0.51***	0.44***	0.59***	0.51***
HM15															0.46***	0.63***	0.76***	0.44***	0.74***
HM16																0.54***	0.5***	0.66***	0.55***
HM17																	0.77***	0.5***	0.77***
HM18																		0.5***	0.85***
HM19																			0.6***

Note: * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$.

Parallel analysis on the remaining 16 items indicated that a model with 3 factors would be appropriate (adjusted Eigenvalues > 0). We also tested models with four and five factors for thoroughness, but these both had factors which were unsuitable (i.e. uninterpretable based on content of items). Only the results of models with one to three factors are described here, for brevity.

According to EFA on 16 items, the three-factor model had the best fit with lower AIC, BIC and RMSEA than the one- or two-factor models, although the χ^2 ($p < 0.001$) and RMSEA (0.9) did not meet our fit criteria (Table S3).

Table S3: Model fit indices of EFA on 16 items, for a one factor, two factor and three factor solution.

n_factors	AIC	BIC	CFI	TLI	RMSEA	SRMR	ChiSq	df	p
1	8,506.71	8,612.57	0.83	0.81	0.14	0.08	489.96	104	<0.001
2	8,343.48	8,498.97	0.91	0.88	0.11	0.05	296.73	89	<0.001
3	8,265.31	8,467.12	0.95	0.92	0.09	0.03	190.56	75	<0.001

Upon inspection of this model, we identified that the second factor was unsuitable as it had significant cross-loadings (> 0.3) for two (HM07 and HM12) out of three items (Table S4).

Table S4: Factor loadings from the three-factor solution EFA on 16 items

Item	Label	f1	f2	f3
HM02	When I have not eaten in a while I have more arguments with people or snap at people more	0.93		
HM04	When I have not eaten in a while I have said and done things that I have regretted later	0.74		
HM05	When I have not eaten in a while people think I'm tired			0.53
HM06	When I have not eaten in a while even small things can irritate me	0.96		
HM07	When I have not eaten in a while I find it hard to concentrate or to finish tasks	0.31	0.41	

HM09	When I have not eaten in a while my friends/family/partner/others tend to notice it because of my mood/behaviour	0.78		
HM10	I make more thoughtful decisions when I have eaten enough		0.6	
HM11	When I have not eaten in a while I get more irritable than other people I know	0.86		
HM12	My anger/irritability decreases once I have eaten	0.58	0.34	
HM13	When I have not eaten in a while I have done or said things that have caused problems in my relationships with others	0.78	.	
HM14	When I have not eaten in a while I get more sad than other people I know		.	0.86
HM15	When I have not eaten in a while I feel impatient	0.66	.	
HM16	When I have not eaten in a while I can feel sad			0.97
HM17	When I have not eaten in a while people close to me notice a pattern of me seeming more irritable or short tempered	0.94		
HM19	When I have not eaten in a while I get anxious/nervous or worrisome			0.67
HM20	When I have not eaten in a while I get frustrated more easily	0.75	.	

These two items were removed and a two-factor model was evaluated (Table S5 for model fit, Table S6 for factor loadings). While the model fit did not substantially improve, the factor loadings were more suitable as there were no significant cross-loadings >0.3 and only one item (HM10) had a loading of <0.4, which was subsequently removed.

Table S5: Model fit measures for EFA on 14 items

n_factors	AIC	BIC	CFI	TLI	RMSEA	SRMR	ChiSq	df	p
1	7,411.29	7,503.92	0.85	0.83	0.14	0.07	375.72	77	<0.001
2	7,250.82	7,386.46	0.94	0.91	0.10	0.04	189.26	64	<0.001

Table S6: Factor loadings from the two-factor solution EFA on 14 items

Item	Label	f1	f2
HM02	When I have not eaten in a while I have more arguments with people or snap at people more	0.83	
HM04	When I have not eaten in a while I have said and done things that I have regretted later	0.62	
HM05	When I have not eaten in a while people think I'm tired		0.41
HM06	When I have not eaten in a while even small things can irritate me	0.99	
HM09	When I have not eaten in a while my friends/family/partner/others tend to notice it because of my mood/behaviour	0.79	
HM10	I make more thoughtful decisions when I have eaten enough	0.35	
HM11	When I have not eaten in a while I get more irritable than other people I know	0.83	
HM13	When I have not eaten in a while I have done or said things that have caused problems in my relationships with others	0.58	
HM14	When I have not eaten in a while I get more sad than other people I know		0.85
HM15	When I have not eaten in a while I feel impatient	0.76	
HM16	When I have not eaten in a while I can feel sad		0.90
HM17	When I have not eaten in a while people close to me notice a pattern of me seeming more irritable or short tempered	0.88	
HM19	When I have not eaten in a while I get anxious/nervous or worrisome		0.63
HM20	When I have not eaten in a while I get frustrated more easily	0.83	

A two-factor model, with 13 items, was then run separately for male and female participants. The female-only model showed significant cross-loadings > 0.3 for items HM04 and HM13, thus these items were removed. The sex-specific models are not printed here for brevity but are available upon request from the corresponding author. Single sex models were underpowered according to the rule of thumb of 10 participants per item, however, this statistical limitation was deemed acceptable due to the exploratory nature of EFA.

For the remaining 11 items, we ran a two-factor model (Table S7) which resulted in a factor for irritability (factor 1) and a factor for low mood (factor 2; Table S8).

Table S7: Model fit indices for EFA on 11 items

n_factors	AIC	BIC	CFI	TLI	RMSEA	SRMR	ChiSq	df	p
1	5,813.67	5,886.45	0.87	0.83	0.16	0.08	264.87	44	<0.001
2	5,649.38	5,755.24	0.97	0.95	0.08	0.02	80.58	34	<0.001

Table S8: Factor loadings for EFA on 11 items

Item	Label	f1	f2
HM02	When I have not eaten in a while I have more arguments with people or snap at people more	0.81	
HM05	When I have not eaten in a while people think I'm tired		0.41
HM06	When I have not eaten in a while even small things can irritate me	0.98	
HM09	When I have not eaten in a while my friends/family/partner/others tend to notice it because of my mood/behaviour	0.78	
HM11	When I have not eaten in a while I get more irritable than other people I know	0.82	
HM14	When I have not eaten in a while I get more sad than other people I know		0.81
HM15	When I have not eaten in a while I feel impatient	0.76	
HM16	When I have not eaten in a while I can feel sad		0.94

HM17	When I have not eaten in a while people close to me notice a pattern of me seeming more irritable or short tempered	0.87	
HM19	When I have not eaten in a while I get anxious/nervous or worrisome		0.63
HM20	When I have not eaten in a while I get frustrated more easily	0.83	

The internal consistency of factor 1 was very high (Cronbach's α = 0.94, 95%CI = 0.93, 0.95), suggesting redundancy. Thus, the Cronbach's α was re-calculated for all possible combinations of four items to obtain a more parsimonious model. Four items - HM02, HM09, HM11 and HM15- were selected for their internal consistency (Cronbach's α = 0.87, 95%CI = 0.84, 0.9) and the coherence of their item content. The internal consistency for factor 2 was good (Cronbach's α = 0.84, 95%CI = 0.8, 0.88).

We then ran EFA for a final time. The two-factor solution on eight items showed acceptable fit to the data according to all criteria (Table S9).

Table S9: Model fit measures for EFA on 8 items

n_factors	AIC	BIC	CFI	TLI	RMSEA	SRMR	ChiSq	df	p
1	4,565.89	4,618.82	0.85	0.79	0.18	0.08	148.87	20	<0.001
2	4,445.59	4,521.68	1.00	1.00	0.02	0.02	14.58	13	0.33

We also deemed the factor loadings to be good, with no cross-loadings and no factor loadings < 0.4 (Table S10).

Table S10: Factor loadings from the two-factor solution EFA on 8 items

Item	Label	f1	f2
HM02	When I have not eaten in a while I have more arguments with people or snap at people more	0.78	
HM05	When I have not eaten in a while people think I'm tired		0.44
HM09	When I have not eaten in a while my friends/family/partner/others tend to notice it because of my mood/behaviour	0.78	

HM11	When I have not eaten in a while I get more irritable than other people I know	0.84	
HM14	When I have not eaten in a while I get more sad than other people I know		0.80
HM15	When I have not eaten in a while I feel impatient	0.74	
HM16	When I have not eaten in a while I can feel sad		0.97
HM19	When I have not eaten in a while I get anxious/nervous or worrisome		0.64

The observed Pearson's correlation between factor 1 and factor 2 had a coefficient of 0.63 ($p < 0.001$). The internal consistency of the overall scale was good (Cronbach's α=0.88, 95%CIs = 0.84, 0.9). This version of the questionnaire also correlated moderately with the AEBQ hunger sensitivity scale (0.52), ARI (0.42), PHQ-8 (0.44) and GAD-7 (0.42; all $p < 0.001$).

For CFA, we collected responses to 16 items (15 core items plus one for impact).

Table S11: Labels for the 15 core items in the MEAL questionnaire for CFA

Item	Label
HM09	When I have not eaten in a while other people notice a change in my mood or behaviour
HM23	When I have not eaten in a while I get a headache
HM21	When I have not eaten in a while I lose motivation and interest in things
HM27	When I have not eaten in a while I can get restless or fidgety
HM26	When I have not eaten in a while I feel strange in my body
HM24	When I have not eaten in a while I feel sick or nauseous
HM05	When I have not eaten in a while people think I'm tired
HM16	When I have not eaten in a while I feel sad
HM25	When I have not eaten in a while I feel weak or dizzy
HM11	When I have not eaten in a while I feel more irritated or grumpy than others
HM19	When I have not eaten in a while I feel anxious or nervous
HM14	When I have not eaten in a while I become tearful or weepy

HM02	When I have not eaten in a while I argue or snap at people more
HM22	When I have not eaten in a while my energy is lower
HM15	When I have not eaten in a while I feel impatient

Note: This was supplemented by an impact item "When I have not eaten in a while I experience problems with my: Family School and/or work Friends and/or partner Hobbies and/or interests"

During the CFA, no items were removed according to the item correlations criteria (Table S12).

Table S12: Correlation matrix for 15-items in sample 2

Item	HM23	HM21	HM27	HM26	HM24	HM05	HM16	HM25	HM11	HM19	HM14	HM02	HM22	HM15
HM09	0.39***	0.51***	0.54***	0.48***	0.39***	0.59***	0.56***	0.45***	0.6***	0.43***	0.45***	0.63***	0.46***	0.52***
HM23		0.47***	0.45***	0.48***	0.5***	0.45***	0.46***	0.55***	0.41***	0.46***	0.41***	0.39***	0.39***	0.44***
HM21			0.66***	0.6***	0.51***	0.58***	0.67***	0.59***	0.6***	0.55***	0.44***	0.62***	0.6***	0.65***
HM27				0.62***	0.47***	0.58***	0.52***	0.57***	0.58***	0.48***	0.44***	0.54***	0.59***	0.6***
HM26					0.61***	0.55***	0.6***	0.6***	0.53***	0.57***	0.43***	0.52***	0.53***	0.51***
HM24						0.53***	0.53***	0.61***	0.49***	0.44***	0.46***	0.47***	0.47***	0.44***
HM05							0.6***	0.55***	0.55***	0.43***	0.37***	0.52***	0.59***	0.54***
HM16								0.64***	0.61***	0.62***	0.53***	0.65***	0.55***	0.64***
HM25									0.58***	0.58***	0.52***	0.54***	0.55***	0.54***
HM11										0.51***	0.38***	0.74***	0.63***	0.7***
HM19											0.56***	0.51***	0.43***	0.52***
HM14												0.5***	0.3***	0.43***
HM02													0.6***	0.75***
HM22														0.6***

Note: * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$.

To make the questionnaire more concise, three items were removed from MEAL-s while retaining Cronbach's α of 0.7-0.9 and suitable item content. Leaving 13 items (12 core items + 1 impact item).

On the 12 items, the observed Pearson's *r*s between the factors were: 0.77 for MEAL-i and MEAL-l, 0.71 for MEAL-i and MEAL-s, and 0.76 for MEAL-l and MEAL-s (all $p < 0.001$). To minimise redundancy, factor correlations were re-calculated removing one item at a time. This resulted in one item being removed from MEAL-s. The updated factor correlations were $r = 0.63$ for MEAL-i and MEAL-s, and $r = 0.74$ for MEAL-l and MEAL-s ($p < 0.001$). We compared this final (11 item) model to one-factor and two-factor models (Table S13). Model fit indices favoured the three-factor model (lower AIC and BIC), and this was the only model to meet all criteria. The high Cronbach's α and high correlations between factors could suggest redundancy within the questionnaire. However, we did not address this further as the constructs are expected to be related, and the three-factor model fit the data better than one- or two-factor models.

Table S13: Model fit criteria comparing one-, two- and three-factor CFAs on the final 11 core MEAL items. The two factor model combines MEAL-i and MEAL-l as they had the highest correlation.

n_factors	aic	bic	cfi	tli	rmsea	srmr	chisq	df	p
1	4,937.82	5,005.47	0.93	0.91	0.10	0.05	116.32	44	<0.001
2	4,885.56	4,956.28	0.98	0.98	0.05	0.04	62.06	43	0.03
3	4,873.52	4,950.40	1.00	0.99	0.03	0.03	46.03	41	0.272

Section 2: Qualitative Feedback

Full qualitative data is available upon request. The table below presents the codings and the percentage of each sample which referred to one of these.

Table S14: Summary of the qualitative data codings, grouped by sample

	Frequency (%)		
sample	Mood	Impact	Somatic
1	132 (65)	105 (52)	58 (29)
2	111 (69)	96 (60)	45 (28)
3	57 (68)	51 (61)	25 (30)
4	114 (55)	96 (46)	43 (21)
5	95 (70)	40 (30)	41 (30)

Section 3: Impact Item Analysis

Figure S1: Responses percentages for the impact item of the MEAL. The percentage of participants who selected 'Often' or 'Always/almost always' is shown as this is the classification used for a substantial impact.

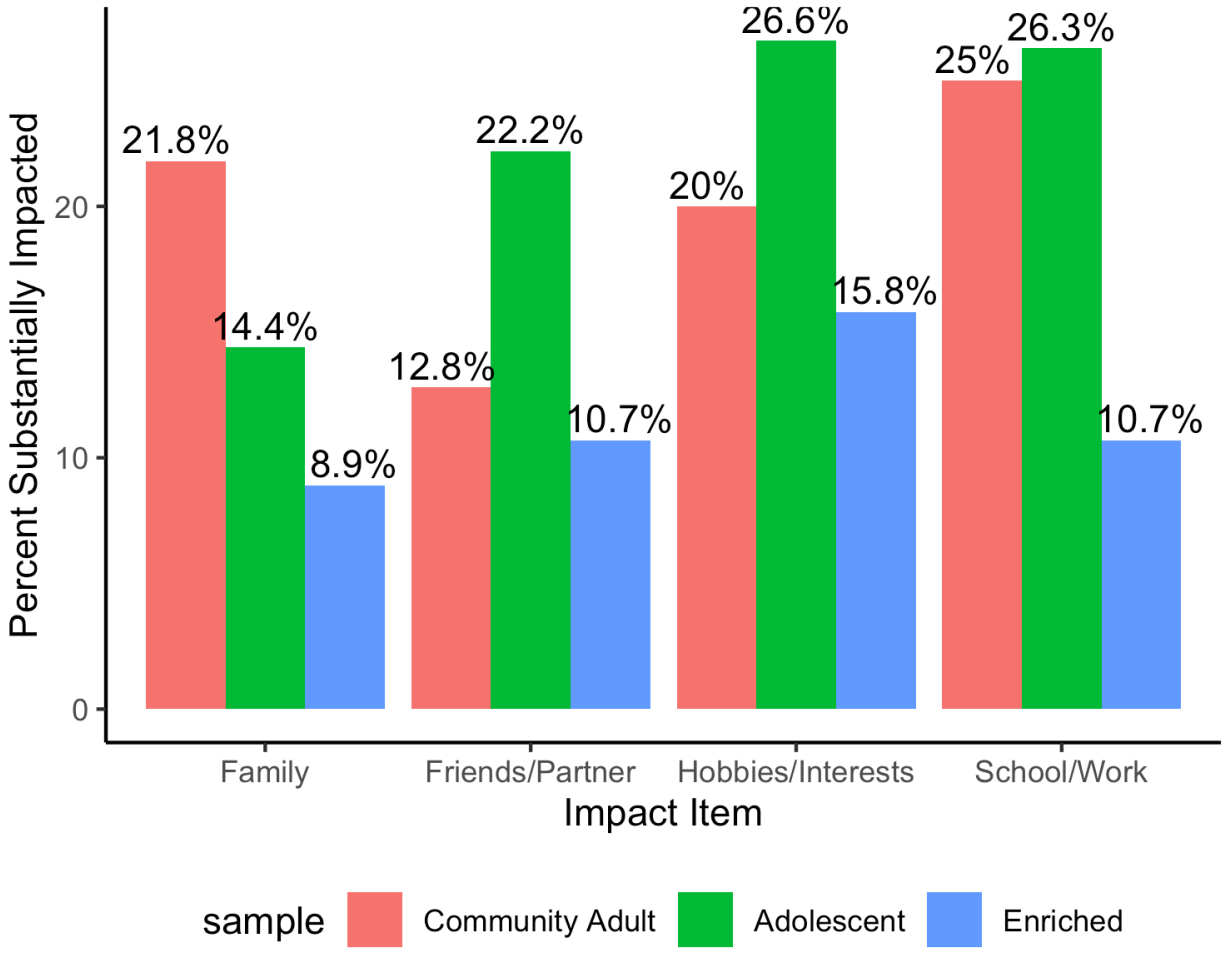

Table S15: Counts and percentages for endorsements of each impact item on the MEAL

	Count (%)				
Impact	Never	Rarely	Sometimes	Often	Always
Community Adults (samples 2 and 3)					
Family	84 (34.4)	69 (28.3)	56 (23)	27 (11.1)	8 (3.3)
Friends/Partner	65 (26.6)	60 (24.6)	65 (26.6)	46 (18.9)	8 (3.3)
Hobbies/Interests	53 (21.7)	44 (18)	82 (33.6)	44 (18)	21 (8.6)

School/Work	64 (26.2)	49 (20.1)	67 (27.5)	48 (19.7)	16 (6.6)
Adolescents (samples 4 and 5)					
Family	101 (30.1)	80 (23.8)	82 (24.4)	58 (17.3)	15 (4.5)
Friends/Partner	110 (32.7)	110 (32.7)	69 (20.5)	34 (10.1)	9 (2.7)
Hobbies/Interests	92 (27.4)	89 (26.5)	87 (25.9)	47 (14)	20 (6)
School/Work	59 (17.6)	92 (27.4)	98 (29.2)	65 (19.3)	19 (5.7)
Enriched (sample 6)					
Family	138 (41.1)	75 (22.3)	94 (28)	21 (6.2)	9 (2.7)
Friends/Partner	151 (44.9)	74 (22)	76 (22.6)	27 (8)	9 (2.7)
Hobbies/Interests	113 (33.6)	83 (24.7)	88 (26.2)	35 (10.4)	18 (5.4)
School/Work	122 (36.3)	88 (26.2)	91 (27.1)	30 (8.9)	6 (1.8)

Adult N = 244, adolescent N = 336, enriched N = 337

Table S16: Mean MEAL score for each impact response option

	MEAL Score Mean (SD)			
	Family	Friends / Partner	Hobbies / Interests	School / Work
Never	10.52 (7.39)	10.75 (7.33)	10.46 (8.01)	10.25 (7.71)
Rarely	18.87 (7.51)	17.87 (7.74)	16.69 (7.84)	16.19 (7.53)
Sometimes	22.33 (7.36)	22.89 (6.94)	21.09 (7.74)	20.9 (7.83)
Often	27.41 (7.83)	29.02 (6.46)	24.98 (7.46)	26.6 (7.79)
Always	29.29 (9.92)	30.74 (9.62)	29.58 (8.81)	29.56 (8.4)

For all samples except sample 1.

ANOVA's were used to test whether the levels of impacts being endorsed could significantly explain variation in the MEAL. Firstly, the results of each ANOVA are presented, followed by the Post Hoc comparisons using Scheffe's method to be conservative given the large number of comparisons (5 levels of response).

Overall anova for impact on family: $F = 153.57$ ($df = 4$, $p<0.001$)

Overall anova for impact on friends or partner: $F = 177.73$ ($df = 4$, $p<0.001$)

Overall anova for impact on school or work: $F = 136.17$ ($df = 4$, $p<0.001$)

Overall anova for impact on hobbies or interests: $F = 123.62$ ($df = 4$, $p<0.001$)

Table S17: Results of ANOVA and Scheffe's post hoc comparison tests for the prediction of MEAL score by each impact question.

Impact	comparison	P value
Family	1-0	<0.001
	2-1	<0.001
	3-2	<0.001
	4-3	0.831
Friends and/or partner	1-0	<0.001
	2-1	<0.001
	3-2	<0.001
	4-3	0.904
School and/or work	1-0	<0.001
	2-1	<0.001
	3-2	<0.001
	4-3	0.349
Hobbies and/or interests	1-0	<0.001
	2-1	<0.001
	3-2	0.001
	4-3	0.011

For all samples excluding sample 1 (N = 917)

Section 4: Additional Mood Drift Results

The main effects of current state hunger (dichotomised) and time were significant for all moods. However, the interaction terms were not significant for any model, indicating that self-rated current hunger was not associated with the steepness of the mood drift slopes. It is possible that the study design did not provide sufficient variation in hunger levels as no participants were asked to fast or delay food. Nonetheless, the finding that hunger showed a main effect association supports the overall notion that being hungry is associated with worse mood

Table S18: LME with interaction of time and current state hunger on happiness, boredom and frustration

Mood	Effect	Group	Term	B	p value	95%CI lower	95%CI upper
Happy	fixed		intercept	57.73	<0.001	55.11	60.35
	fixed		time (mins)	-1.75	<0.001	-2.05	-1.44
	fixed		hunger	-5.29	0.005	-8.98	-1.59
	fixed		time*hunger	-0.32	0.145	-0.76	0.11
	random	participant	SD intercept	21.02		19.74	22.42
	random	participant	cor int time	-0.18		-0.27	-0.09
	random	participant	SD time	2.37		2.21	2.54
	random	Residual	SD observation	8.99		8.83	9.15
Bored	fixed		intercept	48.25	<0.001	44.86	51.64
	fixed		time (mins)	2.68	<0.001	2.31	3.04
	fixed		hunger	5.09	0.037	0.32	9.87
	fixed		time*hunger	0.16	0.546	-0.35	0.67
	random	participant	SD intercept	27.31		25.68	29.12
	random	participant	cor int time	-0.37		-0.45	-0.29
	random	participant	SD time	2.81		2.62	3.01
	random	Residual	SD observation	10.21		10.02	10.40
Frustrated	fixed		intercept	22.12	<0.001	18.98	25.27
	fixed		time (mins)	3.31	<0.001	2.90	3.71
	fixed		hunger	10.78	<0.001	6.36	15.21
	fixed		time*hunger	0.21	0.475	-0.36	0.78
	random	participant	SD intercept	25.18		23.65	26.86
	random	participant	cor int time	-0.14		-0.23	-0.05
	random	participant	SD time	3.17		2.97	3.39

random	Residual	SD observation	10.87		10.68	11.07

Note: B = coefficient estimate from lme model.

LMEs were run which included an interaction between time and several previously established mental health measures: ARI, PHQ-8, GAD-7. The results for happiness ratings are presented below as this was the main hypothesis, the results for frustration and boredom were similar to this, with no significant interaction between the relevant predictor variables and time.

Table S19: LME with interaction of time and ARI on happiness

effect	group	term	B	p value	95%CI lower	95%CI upper
fixed		intercept	60.83	<0.001	58.40	63.27
fixed		time (mins)	-1.78	<0.001	-2.07	-1.48
fixed		ARI	-2.04	<0.001	-2.65	-1.44
fixed		time*ARI	-0.05	0.184	-0.12	0.02
random	participant	SD intercept	20.24		19.01	21.61
random	participant	cor int time	-0.19		-0.28	-0.10
random	participant	SD time	2.37		2.22	2.55
random	Residual	SD observation	8.98		8.82	9.15

Table S20: LME with interaction of time and PHQ-8 on happiness

effect	group	term	B	p value	95%CI lower	95%CI upper
fixed		intercept	68.09	<0.001	65.00	71.17
fixed		time (mins)	-1.86	<0.001	-2.25	-1.47
fixed		PHQ-8	-1.46	<0.001	-1.75	-1.17
fixed		time*PHQ-8	-0.01	0.747	-0.04	0.03
random	participant	SD intercept	19.33		18.14	20.63
random	participant	cor int time	-0.19		-0.28	-0.10
random	participant	SD time	2.38		2.22	2.55
random	Residual	SD observation	8.99		8.83	9.16

Table S21: LME with interaction of time and GAD-7 on happiness

effect	group	term	B	p value	95%CI lower	95%CI upper
fixed		intercept	67.07	<0.001	64.10	70.03
fixed		time (mins)	-1.94	<0.001	-2.31	-1.56
fixed		GAD-7	-1.53	<0.001	-1.84	-1.22
fixed		time*GAD-7	0.00	0.834	-0.03	0.04
random	participant	SD intercept	19.42		18.22	20.73
random	participant	cor int time	-0.17		-0.26	-0.08
random	participant	SD time	2.38		2.22	2.55
random	Residual	SD observation	8.93		8.77	9.10