

Interoception, eating behaviour and body weight

Robinson, Eric; Marty, Lucile; Higgs, Suzanne; Jones, Andrew

DOI:

[10.1016/j.physbeh.2021.113434](https://doi.org/10.1016/j.physbeh.2021.113434)

License:

Creative Commons: Attribution-NonCommercial-NoDerivs (CC BY-NC-ND)

Document Version

Peer reviewed version

Citation for published version (Harvard):

Robinson, E, Marty, L, Higgs, S & Jones, A 2021, 'Interoception, eating behaviour and body weight', *Physiology and Behavior*, vol. 237, 113434. <https://doi.org/10.1016/j.physbeh.2021.113434>

[Link to publication on Research at Birmingham portal](#)

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

Interoception, eating behaviour and body weight

Eric Robinson¹, Lucile Marty¹, Suzanne Higgs² & Andrew Jones¹

¹Institute of Population Health Sciences, University of Liverpool, Liverpool, UK

²School of Psychology, University of Birmingham, Birmingham, UK

Correspondence: Eric Robinson, email: eric.robinson@liv.ac.uk

Running title: Interoception and heavier body weight

Word count: 3884

Funding, disclosure, author contributions: See end of document

Abstract

Background: Interoception refers to the process of identifying and listening to internal bodily signals, which may be a modifiable determinant of appetite regulation and weight gain. The objective was to examine whether the extent to which self-reported interoception is associated with eating behaviour traits and higher BMI.

Methods: UK adults (N=1181, 49% female, 53% with overweight/obesity) completed validated self-report measures of interoception, habitual tendencies to eat in response to satiety signals (intuitive eating), emotional over-eating and other eating traits.

Results: Poorer self-reported ability to detect interoceptive signals (deficits in interoceptive accuracy) was predictive of higher BMI ($r = -.07$ (95% CI $-.13; -.01$), $p < .05$). In parallel mediation analyses, participants with poorer interoceptive accuracy were significantly less likely to report considering satiety signals when eating and this explained the association between interoceptive accuracy and higher BMI. There was also some evidence that participants with poorer interoceptive accuracy were more likely to report emotional overeating and this also in part explained why interoceptive accuracy was predictive of higher BMI.

Conclusions: Deficits in interoception may decrease the likelihood that satiety signals are integrated into eating behaviour related decision making and in doing so contribute to higher BMI.

Keywords: Obesity; BMI; interoception; adult eating behaviour, intuitive eating

Introduction

The obesity crisis has been the result of changes to the food environment promoting population level-wide imbalance between energy expenditure and intake (1). Obesity prevalence has increased in many developed countries, but a sizeable proportion of the population have remained a 'normal' body weight (2, 3). An early psychological theory of obesity was Schachter's externality theory, which posited that obesity was characterised by a particularly strong tendency to eat in response to 'external' cues (4). Subsequent studies did not provide strong support for the externality theory, as people of normal weight and people with obesity were found to be similarly influenced by external factors when eating (5-7). Schachter also posited that people with obesity may be less sensitive to internal signals when eating, but this aspect of the externality theory received less empirical attention (6).

Interoception is defined as 'the process by which the nervous system senses, interprets, and integrates signals originating from within the body, providing a moment-by-moment mapping of the body's internal landscape across conscious and unconscious levels' (8, pg 501). As defined by Murphy et al. (9), two of the most widely studied facets of interoception are *interoceptive accuracy* (the ability to detect internal signals) and *interoceptive attention* (the tendency to attend to internal signals) (9). Individual differences in interoception have been shown to be associated with psychiatric disorders (8,10). Likewise, deficits in interoceptive accuracy have been identified in eating disorder patients (11, 12).

Alongside other factors such as hedonic goals and emotion, bodily signals related to nutrient ingestion and metabolism are factored into decision-making processes that drive what and how much people eat (13). Therefore, deficits in interoception may result in bodily signals that promote satiety being less strongly weighted into eating behaviour related decision making (12). In individuals with a predisposition towards overeating, failure to

integrate satiety signals into eating behaviour related decision making may in turn promote weight gain in the current food environment. In line with this suggestion, there is some evidence that deficits in interoceptive accuracy are associated with overweight and obesity (14, 15), although other studies have failed to find this association (16-18). However, the mixed evidence to date may be attributable to methodological issues, such as failing to account for the multi-faceted nature of interoception (i.e. examining interoceptive accuracy but not also measuring and adjusting for attention) or studies not accounting for confounding variables that are associated with both body weight and interoception, such as existing psychiatric conditions (10) or physical activity (19).

The underlying behavioural processes that link deficits in interoception to heavier body weight remain unclear and in the present research we examine these processes. Deficits in interoception are known to be associated with disordered eating patterns, but the majority of research to date on eating behaviour has been in clinical eating disorder patients (11, 12), rather than the general population. If deficits in interoception do lead to ‘down-weighting’ of appetite signals in food-based decision-making, we theorize this process may lead to differences in trait eating behaviour that would eventually lead to weight gain. For example, interoceptive deficits could cause a person to not consciously try and eat in response to satiety signals (otherwise known as ‘intuitive eating’) as detecting signals may be more difficult. Likewise, deficits in interoception could increase the likelihood that a person feels chronically hungry (trait hunger) or result in a blunted satiety response when eating (satiety responsiveness), all of which are eating behaviour traits associated with overeating and weight gain (20-22). Likewise, because interoception may play an important role in emotion regulation (23), down-weighting of internal appetite signals may make it likely that eating behaviour is more easily driven by emotion (emotional eating) among individuals with a predisposition to eat in response to negative emotions (24, 25). In line with some of these

suggestions, Herbert et al. found that interoceptive ability was associated with greater intuitive eating among normal weight participants (26), and Young et al. found individual differences in interoception to be related to trait emotional eating and the tendency to eat in response to external rather than internal cues (16). However, there is a lack of research examining the behavioural pathways (i.e. eating behaviour traits) between interoceptive accuracy and heavier body weight, and a lack of evidence on how interoceptive attention relates to heavier body weight.

The aims of the present research were to examine the associations that both self-reported interoceptive accuracy and attention have with BMI and eating behaviour traits commonly associated with weight gain. By doing so, we were also able to examine whether eating behaviour traits in part explain why individual differences in interoception predict higher BMI. We predicted that deficits in interoception may result in a chronic state of elevated hunger (trait hunger), reduced feelings of satiety when eating (low satiety responsiveness) and/or a person being less likely to report eating based on internal appetite signals (intuitive eating). Because deficits in interoception are also associated with emotional regulation problems, we predicted that deficits in interoception may also be associated with an increased tendency to eat in response to negative emotions (emotional overeating). In turn, we predicted that these eating habits may explain the association between deficits in interoception and higher BMI.

Materials and Methods

Data Source

The measures analysed in the present research were collected at the end of an online study that examined the effect of energy labelling on virtual portion size selection (27). A group of UK adults were recruited from the online panel provider Prolific Academic and recruitment

was stratified by participant gender and highest education level to be broadly representative of the UK adult population. In the main study, participants provided demographic information, before making hypothetical food portion size selections in the presence vs. absence of energy labelling and completing measures of food choice motives and executive function. At the end of the study, participants completed additional measures in a randomized order for the purpose of the present research (see below). For detailed information about the larger online study and all measures included, see (27).

Study Measures

Self-reported Interoceptive Accuracy. Participants completed the Interoceptive Accuracy Scale (IAS) (9). The IAS is a 21-item validated questionnaire that measures beliefs regarding ability to perceive accurately interoceptive signals. Participants responded to items (e.g. ‘I can always accurately perceive when my heart is beating fast’, ‘I can always accurately perceive when I am breathing fast’) using a 5-point Likert scale (Strongly Agree to Disagree Strongly), with higher scores indicating greater interoceptive accuracy. The scale has been validated and is predictive of objectively (i.e. performance on a laboratory heartbeat perception task) measured interoceptive accuracy (9). Present study $\alpha = .87$.

Interoceptive Attention. Participants completed the Body Awareness subscale of the Body Perception Questionnaire-Short Form ($\alpha = .97$). Participants rated attention paid towards 26 bodily functions, ‘During most situations, I am aware of...’ (e.g. ‘How hard my heart is beating’, ‘How fast I am breathing’) using a 5-point response format (Never to Always). Higher scores indicate greater interoceptive attention and the measure has been validated against other measures of interoceptive attention (28).

Intuitive Eating. Participants completed the Intuitive Eating Scale-2 (IES-2) (29). The IES-2 is a validated 23-item questionnaire and participants completed items (e.g. ‘I trust my body to tell me how much to eat’) using a 5-point Likert scale response format (Strongly Agree to Disagree Strongly), with higher scores indicating greater intuitive eating tendencies ($\alpha = .56$). In addition to the scale total, for the purposes of unplanned sensitivity analysis we also made use of the Reliance on Hunger and Satiety Cues subscale ($\alpha = .85$), which consists of 6 items from the full scale (e.g. ‘I rely on my fullness signals to tell me when to stop eating’).

Adult Eating Behaviour Questionnaire (AEBQ). Participants completed the Emotional Overeating (5 items, e.g. ‘I eat more when I’m worried’, $\alpha = .92$), Satiety Responsiveness (4 items, e.g. ‘I often leave food on my plate at the end of a meal’, $\alpha = .81$) and Hunger (5 items, e.g. ‘I often feel hungry’, $\alpha = .75$) subscales of the AEBQ (20). The AEBQ has been validated against other self-report eating behaviour trait measures (20) and participants responded using a 5-point Likert scale response format (Strongly Agree to Disagree Strongly), whereby higher scores indicate greater endorsement.

Depression, Anxiety and Stress. The DASS21 (30) is a widely used and validated measure of depression ($\alpha = .92$), anxiety ($\alpha = .79$) and stress ($\alpha = .86$). Participants read statements (e.g. ‘I felt that life was meaningless’) and responded on a 4-point response scale for how much each statement applied to them over the last year (Did not apply to me at all to Applied to me very much or most of the time).

Psychiatric and chronic health conditions. Participants were asked: ‘Have you ever been diagnosed with a psychiatric condition (e.g. Depression, Schizophrenia)? (Yes or No)’, and:

‘Do you have any chronic medical conditions that affect your health (e.g. Diabetes, Heart Disease)? (Yes or No)’.

Other Measures Collected During Main Study

We also used some of the measures collected as part of the main study. Participants reported their age (in years), gender, ethnicity, highest education level achieved, whether they were currently dieting (yes or no), weight and height (to calculate self-reported BMI as $\text{weight}/\text{height}^2$). Participants also completed a 0-100 visual analogue scale measuring current hunger (‘How hungry do you feel?’, anchors: not at all hungry and extremely hungry) and the International Physical Activity Questionnaire Short Version (IPAQ-SF). The IPAQ-SF (31) asks participants to record the number of times per week and typical duration of activities varying in level of intensity (e.g. vigorous-intensity activities, moderate-intensity activities, walking, sitting). Participants reported on a usual week. We calculated the total number of metabolic equivalent task (MET) minutes per week. When time spent walking, doing moderate-intensity or vigorous-intensity activities was below 10 minutes it was recoded to be equal to 0 and when it was above 180 minutes to be equal to 180 (32). Because data collection took place during COVID-19 social lockdown in the UK (April-May, 2020), as part of the main study participants completed two measures about whether they suspected they currently or previously had COVID-19 (yes or no) and how worried they were about COVID-19 (Not at all worried to very worried). Participants also completed 3 attention checks (e.g. ‘How many times have you visited the planet Mars?’).

Main Planned Analyses

Our pre-registered analysis plan and study data are available at <https://osf.io/csزد/> . We planned to exclude participants who did not have complete data for all measures described

above, failed one or more attention checks, completed the study more than once or reported implausible weight, height or BMI data; weight <30 kg or >250 kg, height <145 cm or >3m, BMI < 14 or BMI > 48, as in (33). Because very low body weight and psychiatric conditions have both been associated with deficits in interoception (34, 35), we planned to exclude participants with a BMI < 18.5 (underweight BMI category) or who reported a psychiatric condition. We first planned to conduct zero-order correlations (Pearson's r) between interoception, eating behaviour trait and BMI variables. Next, we examined whether interoceptive accuracy and interoceptive attention predicted BMI and eating behaviour traits when accounting for other variables. We used linear regression and the first step of each model included the two interoception measures alongside the following participant characteristics: age, ethnicity, gender, education level, presence of a health condition, dieting status, physical activity level, current hunger. In a second step, we included potential confounding psychological factors: depression, stress and anxiety, to examine whether adding these variables altered results, as there is evidence that both interoception and higher BMI are associated with mental health (8, 10). When predicting eating behaviour traits, we also included BMI in the first model step. We also planned to conduct mediation analyses. If either interoception measure was associated with BMI, we identified eating behaviour traits significantly associated with the interoception measure and BMI and tested the indirect effect of the interoception measure on BMI via these eating behaviour trait(s). We planned to include any variables significantly associated with BMI or the measures of interoception and eating behaviour as covariates in the indirect effect analysis so that we could be confident of the independent effect that potential mediators had on the relationship between interoception and BMI. Indirect effects analyses were conducted using the PROCESS Macro for SPSS25 (MODEL 4). Significance was set at $p < .05$.

Sample Size Requirement

To detect statistically small zero order correlations ($r=0.1$) between variables of interest we estimated we required a minimum sample size of 891 participants (GPOWER 3.1.3, 85% power, $p < .05$). This approximate sample size also provides reasonable power for the planned indirect effect analyses (34).

Results

Of the 1657 participants who passed all attention checks and had complete data for all variables, 34 were excluded on the basis of implausible weight, height or BMI values. A further 50 participants had BMIs in the underweight range ($BMI < 18.5$) and were excluded. A further 392 (24.9%) reported a previous psychiatric disorder diagnosis and were excluded from primary analyses. The final analytic sample was $n=1181$. Mean age was 37 years, 49% were female and the majority of participants were white (89%). Mean BMI was within the overweight BMI range (26.3) and 53% of participants were classed as having overweight or obesity. Full sample characteristics are reported in Table 1.

Table 1. Sample characteristics, N = 1181

	Mean (SD) or N (%)
Age (Years)	37.2 (12.6)
Gender (Female)	576 (49%)
Ethnicity (White)	1052 (89%)
Education level (Lower than degree level)	643 (54%)
Chronic health condition (Yes)	86 (7%)
Currently dieting (Yes)	146 (12%)
BMI (Weight/height ²)	26.3 (4.9)
BMI categories	549 (47%) = NW, 395 (33%) = OW, 237 (20%) = OB
IPAQ MET mins per week	2435 (2094)

Current hunger (100-point scale)	38.1 (26.2)
Intuitive eating trait score	3.4 (0.5)
Emotional overeating trait score	13.3 (5.0)
Satiety responsiveness trait score	9.5 (3.4)
Hunger trait score	15.2 (3.9)
Interoceptive accuracy	80.9 (9.5)
Interoceptive attention	58.7 (22.8)

IPAQ MET = International physical activity questionnaire metabolic equivalent minutes.

High scores indicate greater current hunger (0-100 point scale), intuitive eating score (1-5 score), Emotional overeating (5-25 score), Satiety responsiveness (4-20 score), Hunger (5-25 score), Interoceptive accuracy (21-105 score) and Interoceptive Attention (26-130 score).

Zero-order correlations between interoception measures, eating behaviour traits and BMI

Interoceptive accuracy and interoceptive attention were significantly positively associated ($r = .10$). Interoceptive accuracy was significantly positively associated with intuitive eating ($r = .23$) and negatively associated with emotional overeating ($r = -.10$), but not significantly associated with satiety responsiveness or trait hunger. Interoceptive accuracy was also significantly negatively associated with BMI ($r = -.07$). Interoceptive attention was significantly positively associated with emotional overeating ($r = .21$), trait hunger ($r = .19$) and satiety responsiveness ($r = .14$), but not significantly associated with intuitive eating or BMI. Of the eating behaviour traits, intuitive eating ($r = -.31$), trait satiety responsiveness ($r = -.11$) and emotional overeating ($r = .22$) were significantly associated with BMI, whilst trait hunger was not. See Table 2.

Table 2. Zero-order correlations (and 95% CIs) between BMI, interoception, trait eating behaviour measures

	BMI	I-Accuracy	I-Attention	Intuitive Eating	S-Response	EM-Overeating	Hunger
BMI	-	r = -.07 (-.13; -.01) p = .015	r = -.04 (-.09; .02) p = .201	r = -.31 (-.36; -.26) p < .001	r = -.10 (-.16; -.05) p < .001	r = .22 (.17; .28) p < .001	r = -.03 (-.08; .03) p = .364
I-Accuracy	-	-	r = .10 (.04; .16) p < .001	r = .23 (.18; .29) p < .001	r = .01 (-.04; .07) p = .631	r = -.10 (-.16; -.05) p < .001	r = .04 (-.02; .10) p = .155
I-Attention	-	-	-	r = -.04 (-.10; .02) p = .158	r = .14 (.08; .20) p < .001	r = .12 (.07; .18) p < .001	r = .19 (.14; .25) p < .001
Intuitive Eating	-	-	-	-	r = .12 (.06; .17) p < .001	r = -.65 (-.68; -.62) p < .001	r = -.19 (-.24; -.13) p < .001
S-Response	-	-	-	-	-	r = -.01 (-.07; .05) p = .701	r = -.01 (-.07; .05) p = .731
EM-Overeating	-	-	-	-	-	-	r = .38, (.33; .43) p < .001

I-Accuracy = Interoceptive accuracy, I-Attention = interoceptive attention, S-Response = satiety responsiveness, EM-O = emotional overeating, Hunger = trait hunger, brackets indicate 95% CIs

Predicting eating BMI and eating behaviour traits from interoception measures

Intuitive eating. In both the first and second model steps, interoceptive accuracy ($p < .001$) was a significant positive predictor of intuitive eating, but interoceptive attention was not (step 1: $p = .068$, step 2: $p = .753$). See Table S1.

Emotional overeating. In both the first and second model steps, interoceptive accuracy was a significant negative predictor of emotional overeating ($ps < .03$). Interoceptive attention was a significant positive predictor in step one ($p < .001$), but in step 2 the size of this association became smaller and was no longer significant ($p = .117$). See Table S2.

Satiety responsiveness. Interoceptive accuracy was not a significant predictor of satiety responsiveness in either step ($ps > .64$) and in both the first and second steps interoceptive attention was a significant positive predictor of satiety responsiveness ($ps < .004$). Table S3.

Trait hunger. Interoceptive accuracy was not a significant predictor of trait hunger in either step ($ps > .09$) and in both the first and second steps interoceptive attention was a significant positive predictor of trait hunger ($ps < .005$). See Table S4.

BMI. Interoceptive accuracy was a significant negative predictor of BMI in the first step of the model ($p = .021$). In the second step of the model a similar sized association was observed, but it was no longer significant ($p = .057$). Interoceptive attention was not a significant predictor of BMI in either step of the model ($ps > .61$). See Table S5.

Interoceptive accuracy and BMI: indirect effects analysis

Lower interoceptive accuracy was associated with higher BMI and we examined whether this relationship was explained by trait eating behaviour measures. Interoceptive accuracy was associated with both intuitive eating and emotional overeating and these traits were in turn associated with BMI, so we included these variables as potential mediators in a parallel mediation analysis. Satiety responsiveness was predictive of higher BMI, so was also

included as a covariate in the model. We also examined whether results remained the same when depression, anxiety and stress were included as additional covariates (unplanned exploratory analysis). In a parallel mediation model the direct effect of interoceptive accuracy on BMI was no longer statistically significant ($B = -.001$, $SE = .015$ [95% CI $-.030$ to $.028$]; $p = .950$). There was a significant indirect effect of intuitive eating ($B = -.033$, $SE = .006$ [95% CI $-.045$ to $-.021$]), but not emotional overeating ($B = -.002$, $SE = .002$ [95% CI $-.008$ to $.002$]). The total model was significant ($B = -.036$, $SE = .015$ [95% $-.065$ to $-.006$]; $p = .017$) and explained approximately 1.6% variance in BMI ($R^2 = .016$, ($F(2, 1178) = 9.70$, $p < .001$). See Figure 1. Inclusion of DASS Depression, Anxiety and Stress Scales as additional covariates did not significantly alter the path coefficients.

Figure 1. Parallel mediation model of the effects of interoceptive accuracy on BMI, through the indirect effects of intuitive eating and emotional overeating. ** $p < .01$

INSERT FIGURE 1 HERE – SEE END OF DOCUMENT FOR FIGURE

Additional analyses

Using the same approach as in the main analyses, we also examined whether the interoception measures predicted obesity status using logistic regression (BMI < 30 vs. BMI ≥ 30). Neither of the interoception measures was a significant predictor and results were consistent in both steps of the model ($ps \geq .29$). In our main analyses a-priori we excluded participants with a psychiatric disorder diagnosis ($n = 392$), results remained the same in an unplanned exploratory analyses with these participants included (see online supplementary materials). Because internal consistency for the Intuitive Eating Scale (total score) was relatively low, in unplanned exploratory analyses we examined whether replacing it with the

shorter subscale measure of intuitive eating with acceptable internal consistency; 'Reliance on Hunger and Satiety Cues' subscale ($\alpha = .85$), affected the results of any analyses that included measures of interoception and Intuitive Eating. Zero-order correlation results remained the same, as did prediction of intuitive eating using regression analysis results. However, when the Intuitive Eating Scale total was replaced with the Reliance on Hunger and Satiety Cues subscale in parallel mediation analysis, Emotional Overeating became a significant mediator (in addition to Reliance on Hunger and Satiety being a significant mediator). See Figure 2 and online supplementary materials. Consistent with other research [35], we reason this may be because Emotional Overeating was strongly correlated with the Intuitive Eating Scale total ($r = -.65$), but only moderately so with Reliance on Hunger and Satiety ($r = -.35$). See online supplementary materials for full results. Finally, we conducted unplanned exploratory analyses accounting for COVID-19 suspected diagnosis and concerns and results remained the same. See online supplementary materials.

Figure 2. Parallel mediation model of the effects of interoceptive accuracy on BMI, through the indirect effects of reliance on hunger and satiety cues and emotional overeating. ** $p < .01$

INSERT FIGURE 2 HERE - SEE END OF DOCUMENT FOR FIGURE

Discussion

We examined the associations between facets of interoception, eating behaviour traits and BMI. Poorer self-reported interoceptive accuracy was significantly associated with higher BMI. Poorer self-reported interoceptive accuracy was also associated with participants being less likely to report eating in response to internal satiety signals ('intuitive eating') and being more likely to report emotional overeating, and there was evidence that these behavioural

tendencies explained the association between poorer interoceptive accuracy and higher BMI. Self-reported interoceptive attention was not significantly associated with BMI, but was associated with participants reporting higher levels of emotional overeating, trait hunger and trait satiety responsiveness.

The finding that poorer self-reported interoceptive accuracy was associated with a reduced likelihood of reporting intuitive eating practices is in line with the theoretical suggestion that deficits in interoception may result in bodily signals related to nutrient ingestion and metabolism being less strongly factored into decision-making processes relating to food and eating behaviour (12). In the current 'obesogenic' food environment that is characterised by widely available energy dense food, 'down weighting' of internal satiety signals in food-related decision making would likely lead to weight gain. Recent experimental work is also in line with this interpretation, as deficits in interoception have been shown to be associated with a reduced appetitive sensitivity to the energy content of food (36), suggesting that appetite signals are detected and/or perceived differently among individuals with reduced interoceptive ability. Our finding linking lower interoceptive accuracy to higher BMI is consistent with some previous research that has measured interoceptive accuracy using objective laboratory tasks (13, 14) and self-report questionnaires (37). Poorer interoceptive accuracy but not attention being associated with higher BMI may indicate that attending to internal signals alone is not protective against heavier body weight, unless one is able to accurately perceive those internal signals.

The associations that interoceptive attention had with eating behaviour traits were mixed. Higher interoceptive attention was associated with participants reporting frequently experiencing hunger, but also with frequently reporting feeling easily full up when eating (satiety responsiveness). Attention was also associated with greater emotional overeating, but this relationship appeared to be explained by current depression, anxiety and stress levels. In

line with this observation, elevated interoceptive attention has been shown to be associated with heightened anxiety levels (38). The mixed relationships that interoceptive attention had with appetitive behaviours may in part reflect that a tendency to focus on internal body signals causes hypervigilance towards any type of appetitive signal or misattribution of appetite signals (i.e. more frequently perceiving both hunger and fullness). However, this explanation is speculative and further research explaining these associations will be required.

If further research confirms that interoceptive processes contributes to heavier body weight then approaches to train or improve interoceptive abilities may warrant investigation as potential adjunct treatments to support weight management. For example, biofeedback based training paradigms have been developed to improve interoceptive accuracy (39) and have been tested in clinical settings to reduce symptoms of psychological distress (40). It would therefore be informative to examine whether training interoception impacts on eating traits and appetite regulation, because eating traits are only in part determined by genetics and therefore likely to be modifiable (41).

Strengths of the present research are pre-registration and the recruitment of a large socio-economically diverse sample, allowing us to examine how and why different facets of interoception relate to higher BMI when accounting for a range of potentially confounding variables (e.g. education level, exercise habits, psychological and physical health).

Limitations include reliance on self-reported measures of interoception, eating behaviour traits and body weight. Although the self-report measure of interoceptive accuracy is validated against objective laboratory measurement of interoceptive accuracy (9), self-reported measures of interoception will be prone to bias and therefore our measure of interoceptive accuracy should be thought of as a measure of 'perceived' interoception, as opposed to an objective marker. It is also important to note that interoception and BMI associations were relatively small in size and the amount of variance explained in statistical

models tended to be low. The study design was cross-sectional and reverse causality could theoretically explain some of the associations observed. For example, although deficits in interoception may cause higher BMI, higher BMI could also theoretically make interoception more difficult. Likewise, causality cannot be inferred from the cross-sectional mediation analyses we conducted and as suggested by Herbert et al. (26), it is plausible that interoceptive abilities may be shaped by how frequently a person eats in response to body signals. To understand any contribution that interoceptive processes may have on body weight and the underlying behavioural processes, future work would benefit from objectively and prospectively measuring interoception, appetitive behaviours and changes in body weight. A further consideration is that there are other less well studied facets of interoception that related to meta-cognitive awareness (42) and we were unable to measure in the present study. For example, whether or not a person's beliefs and interpretations of internal signals align with signals (i.e. correctly identifying hunger and labelling it as such) may facilitate eating in line with hunger and satiety needs. Similarly, in the present research the measures of interoception included were not domain specific (i.e. the questions asked about perceived interoception across different bodily signals). Because interoceptive ability may differ across sensory modalities (43), it may be the case that objective measures of interoception that directly characterise sensing and integration of signals relating to the metabolism of food (e.g. gastric distension) would be more strongly associated with eating traits and BMI.

Conclusions

Deficits in interoception may decrease the likelihood that satiety signals are integrated into eating behaviour related decision making and in doing so contribute to higher BMI.

Acknowledgements

Contributions. All authors conceived and designed the study. LM was responsible for data collection. ER and AJ analysed the data. ER drafted the manuscript. All authors revised the manuscript, contributed to the intellectual content and approved the final version. All authors are accountable for the accuracy and integrity of the work.

Access to data. The data analysed are openly available to researchers and accessible from the Open Science Framework (OSF); <https://osf.io/cszgd/>

Conflicts of interest. ER has previously received funding from Unilever and the American Beverage Association. No other authors report potential conflicts of interest.

Role of funder. There was no external funder of this research. Data analysed came from an ERC funded project unrelated to the aims of this research.

References

1. Swinburn BA, Sacks G, Hall KD, McPherson K, Finegood DT, Moodie ML, et al. The global obesity pandemic: shaped by global drivers and local environments. *The Lancet*. 2011;378(9793):804-14.
2. Hales CM, Fryar CD, Carroll MD, Freedman DS, Ogden CL. Trends in obesity and severe obesity prevalence in US youth and adults by sex and age, 2007-2008 to 2015-2016. *JAMA*. 2018;319(16):1723-5.
3. Schneider H, Dietrich ES, Venetz WP. Trends and stabilization up to 2022 in overweight and obesity in Switzerland, comparison to France, UK, US and Australia. *International Journal of Environmental Research and Public Health*. 2010;7(2):460-72.
4. Schachter S. Obesity and eating. *Science*. 1968.
5. Meyers AW, Stunkard AJ. Food accessibility and food choice: A test of Schachter's externality hypothesis. *Archives of General Psychiatry*. 1980;37(10):1133-5.
6. Herman CP, Polivy J. External cues in the control of food intake in humans: the sensory-normative distinction. *Physiol Behav*. 2008;94(5):722-8.
7. Zlatevska N, Dubelaar C, Holden SS. Sizing up the Effect of Portion Size on Consumption: A Meta-Analytic Review. *Journal of Marketing*. 2014;78(3):140-54.
8. Khalsa SS, Adolphs R, Cameron OG, Critchley HD, Davenport PW, Feinstein JS, et al. Interoception and Mental Health: A Roadmap. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*. 2018;3(6):501-13.
9. Murphy J, Brewer R, Plans D, Khalsa SS, Catmur C, Bird G. Testing the independence of self-reported interoceptive accuracy and attention. *Quarterly Journal of Experimental Psychology*. 2020;73(1):115-33.
10. Pollatos O, Traut-Mattausch E, Schandry R. Differential effects of anxiety and depression on interoceptive accuracy. *Depression and Anxiety*. 2009;26(2):167-73.
11. Jenkinson PM, Taylor L, Laws KR. Self-reported interoceptive deficits in eating disorders: A meta-analysis of studies using the eating disorder inventory. *J Psychosom Res*. 2018;110:38-45.

12. Martin E, Dourish C, Rotshtein P, Spetter M, Higgs S. Interoception and disordered eating: a systematic review. *Neuroscience & Biobehavioral Reviews*. 2019; 107:166-191.
13. Higgs S. Memory and its role in appetite regulation. *Physiol. Behav* 2005. 85 (1), 67–72.
14. Herbert BM, Pollatos O. Attenuated interoceptive sensitivity in overweight and obese individuals. *Eating Behaviors*. 2014;15(3):445-8.
15. Murphy J, Geary H, Millgate E, Catmur C, Bird G. Direct and indirect effects of age on interoceptive accuracy and awareness across the adult lifespan. *Psychonomic Bulletin & Review*. 2018;25(3):1193-202.
16. Young HA, Williams C, Pink AE, Freegard G, Owens A, Benton D. Getting to the heart of the matter: Does aberrant interoceptive processing contribute towards emotional eating? *PLoS One*. 2017;12(10).
17. Todd J, Aspell JE, Barron D, Swami V. Multiple dimensions of interoceptive awareness are associated with facets of body image in British adults. *Body Image*. 2019;29:6-16.
18. Mata F, Verdejo-Roman J, Soriano-Mas C, Verdejo-Garcia A. Insula tuning towards external eating versus interoceptive input in adolescents with overweight and obesity. *Appetite*. 2015;93:24-30.
19. Georgiou E, Matthias E, Kobel S, Kettner S, Dreyhaupt J, Steinacker JM, et al. Interaction of physical activity and interoception in children. *Frontiers in Psychology*. 2015;6(502).
20. Hunot C, Fildes A, Croker H, Llewellyn CH, Wardle J, Beeken RJ. Appetitive traits and relationships with BMI in adults: Development of the Adult Eating Behaviour Questionnaire. *Appetite*. 2016;105:356-63.
21. Camilleri GM, Méjean C, Bellisle F, Andreeva VA, Kesse-Guyot E, Hercberg S, et al. Intuitive eating is inversely associated with body weight status in the general population-based NutriNet-Santé study. *Obesity*. 2016;24(5):1154-61.
22. Buckland NJ, Camidge D, Croden F, Myers A, Lavin JH, Stubbs RJ, et al. Women with a low-satiety phenotype show impaired appetite control and greater resistance to weight loss. *British Journal of Nutrition*. 2019;122(8):951-9.
23. Critchley HD, Garfinkel SN. Interoception and emotion. *Current Opinion in Psychology*. 2017;17:7-14.
24. Van Strien T. Causes of emotional eating and matched treatment of obesity. *Current Diabetes Reports*. 2018;18(6):35.
25. Zamariola G, Frost N, Van Oost A, Corneille O, Luminet O. Relationship between interoception and emotion regulation: new evidence from mixed methods. *Journal of Affective Disorders*. 2019;246:480-5.
26. Herbert BM, Blechert J, Hautzinger M, Matthias E, Herbert C. Intuitive eating is associated with interoceptive sensitivity. Effects on body mass index. *Appetite*. 2013;70:22-30.
27. Marty. Socioeconomic position, energy labelling and portion size selection: an online study comparing calorie and physical activity calorie equivalent (PACE) labelling in UK adults. <https://osfio/k369t/>. Pre-print.
28. Cabrera A, Kolacz J, Pailhez G, Bulbena-Cabre A, Bulbena A, Porges SW. Assessing body awareness and autonomic reactivity: Factor structure and psychometric properties of the Body Perception Questionnaire-Short Form (BPQ-SF). *Int J Methods Psychiatr Res*. 2018;27(2):e1596.
29. Tylka TL, Kroon Van Diest AM. The Intuitive Eating Scale–2: Item refinement and psychometric evaluation with college women and men. *Journal of Counseling Psychology*. 2013;60(1):137.

30. Lovibond PF, Lovibond SH. The structure of negative emotional states: Comparison of the Depression Anxiety Stress Scales (DASS) with the Beck Depression and Anxiety Inventories. *Behaviour Research and Therapy*. 1995;33(3):335-43.
31. Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, et al. International physical activity questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise*. 2003;35(8):1381-95.
32. The IPAQ Group (2015). Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire.
33. R. Hardy JJ, and A. Park, "Harmonised height, weight and BMI user guide," no. July. Closer. Cohort & Longitudinal Studies Enhancement Resources, pp. 1–17, 2016.
34. Fritz MS, Mackinnon DP. Required sample size to detect the mediated effect. *Psychological Science* 2007;18(3):233-9. doi: 10.1111/j.1467-9280.2007.01882.
35. Barrada JR, Cativiela B, Van Strien T, Cebolla A. Intuitive Eating. *European Journal of Psychological Assessment*. 2018; 36: 19-31.
36. Young HA, Gaylor CM, de Kerckhove D, Watkins H, Benton D. Interoceptive accuracy moderates the response to a glucose load: a test of the predictive coding framework. *Proceedings of the Royal Society B: Biological Sciences*. 2019;286(1898):20190244.
37. Iorio D, Margiotta N, D'Orsi P, Bellini O, Boschi V. The Eating Disorder Inventory in evaluation of impaired eating behaviour in subjects requesting nutritional consultation. *Eating and Weight Disorders-Studies on Anorexia, Bulimia and Obesity*. 2000;5(4):206-10.
38. Terasawa Y, Shibata M, Moriguchi Y, Umeda S. Anterior insular cortex mediates bodily attention and social anxiety. *Social Cognitive and Affective Neuroscience*. 2012;8(3):259-66.
39. Meyerholz L, Irzinger J, Witthöft M, Gerlach AL, Pohl A. Contingent biofeedback outperforms other methods to enhance the accuracy of cardiac interoception: A comparison of short interventions. *Journal of behavior therapy and experimental psychiatry*. 2019 Jun;63:12.
40. Schaefer M, Egloff B, Gerlach AL, Witthöft M. Improving heartbeat perception in patients with medically unexplained symptoms reduces symptom distress. *Biological Psychology*. 2014 Sep 1;101:69-76.
41. Sung, J., Lee, K., Song, Y.M., Lee, M.K. and Lee, D.H., 2010. Heritability of eating behavior assessed using the DEBQ (Dutch Eating Behavior Questionnaire) and weight-related traits: the Healthy Twin Study. *Obesity (Silver Spring, Md.)*, 18(5), pp.1000-1005.
42. Quadt L, Critchley HD, Garfinkel SN. The neurobiology of interoception in health and disease. *Annals of the New York Academy of Sciences*. 2018;1428(1):112-28.
43. Ferentzi E, Bogdány T, Szabolcs Z, Csala B, Horváth Á, Köteles F. Multichannel Investigation of Interoception: Sensitivity Is Not a Generalizable Feature. *Front Hum Neurosci*. 2018 1;12:223.

Figure 1. Parallel mediation model of the effects of interoceptive accuracy on BMI, through the indirect effects of intuitive eating and emotional overeating. **p<.01

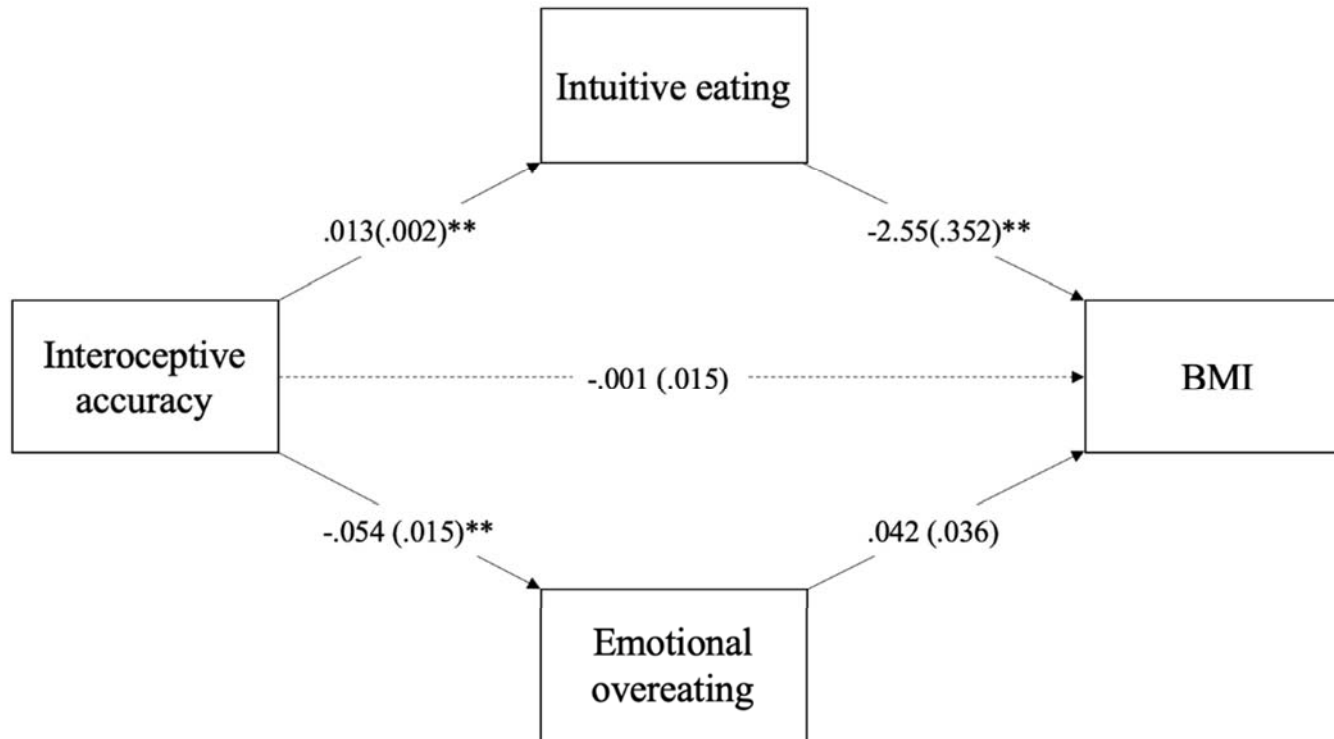


Figure 2. Parallel mediation model of the effects of interoceptive accuracy on BMI, through the indirect effects of reliance on hunger and satiety cues and emotional overeating. ** $p < .01$

