Personality and Individual Differences 182 (2021) 111054

Contents lists available at ScienceDirect

Personality and Individual Differences

journal homepage: www.elsevier.com/locate/paid

# Self-reported sensitivity to physiological signals of satiation and hunger: Assessment of construct validity

Aikaterini Palascha[a,*], Ellen van Kleef[a], Emely de Vet[b], Hans C.M. van Trijp[a]

[a] Marketing and Consumer Behaviour Group, Wageningen University and Research, Hollandseweg 1, 6706, KN, the Netherlands
[b] Consumption and Healthy Lifestyles Group, Wageningen University and Research, Hollandseweg 1, 6706, KN, the Netherlands

ARTICLE INFO

*Keywords:*
Satiation
Hunger
Self-report
Behavioural indicator
Water load test
Preload test
Sensitivity
Construct validity

ABSTRACT

The ability to perceive bodily signals of satiation and hunger is key for the self-regulation of food intake. Measuring this competence in large populations and/or in ecologically valid conditions requires valid self-reports. In this research, we tested the construct validity of two self-report measures of the Multidimensional Internally Regulated Eating Scale (MIRES); Sensitivity to physiological signals of satiation (SS) and Sensitivity to physiological signals of hunger (SH). In two pre-registered studies, we examined associations of SS and SH with behavioural indicators of the incidental ability to perceive the onset of satiation and hunger, respectively, but also with a generic self-report of interoceptive awareness (Multidimensional Assessment of Interoceptive Awareness - MAIA). The associations of MAIA with the behavioural indicators were also examined. In a healthy sample of 113 males/females (19–68 years), SS was not associated with satiation threshold as measured with the water load test in the laboratory (Study 1). Likewise, in a healthy sample of 107 females (18–27 years), SH was not associated with hunger threshold as measured with the preload test in a semi-controlled setting (Study 2). Neither MAIA was associated with the thresholds, but was positively associated with SS and SH, providing preliminary evidence for their construct validity.

## 1. Introduction

Bodily sensations of satiation and hunger are important determinants of the human eating behaviour. Yet, the relative contribution of such sensations in eating-related decisions varies substantially between individuals (Tuomisto et al., 1998). Some have a stronger tendency than others to rely on bodily signals to determine when and how much to eat (Palascha et al., 2020a) and this depends, among other factors, on one's own ability to perceive such signals. This ability can be seen as a domain-specific type of interoception (i.e., the ability to perceive/sense changes in the internal state of the body (Murphy et al., 2017)) and is considered adaptive since it associates positively with proactive coping, satisfaction with life, self-esteem, and body appreciation, and negatively with eating disorder symptomatology, BMI, and weight cycling (Palascha et al., 2020a).

The ability to perceive bodily signals of satiation and hunger is, thus, a plausible predictor of health outcomes; yet it is often overlooked and there is lack of valid measures to easily capture this ability in large and diverse samples of the population and/or in ecologically valid settings. Palascha et al. (2020a) have recently developed the Multidimensional Internally Regulated Eating Scale (MIRES), a self-report measure that assesses, among other individual-difference characteristics, one's sensitivity to physiological signals of satiation (SS subscale) and hunger (SH subscale), defined as the ability to sense/perceive and interpret the signals that the body generates in response to satiation and hunger (Palascha et al., 2020b). SS and SH are reliable and table, and as mentioned previously, predict self-reported physical, psychological, and behavioural outcomes in expected ways (Palascha et al., 2020a). However, construct validity of these subscales has not been fully examined yet.

This research aimed to test the construct validity of SS (Study 1) and SH (Study 2) by examining their association with behavioural indicators of the incidental ability to perceive the onset of satiation (i.e., satiation threshold as measured with the water load test (WLT)) and hunger (i.e., hunger threshold as measured with the preload test), respectively. It is known that signals of satiation and hunger emerge in subtle forms (low intensity) and become stronger as long as we do not respond to them by ceasing or initiating a meal (Murray and Vickers, 2009). Also,

* Corresponding author at: Marketing and Consumer Behaviour Group, Wageningen University and Research, Hollandseweg 1, 6706, KN, Wageningen, The Netherlands.
*E-mail address:* aikaterini.palascha@wur.nl (A. Palascha).

https://doi.org/10.1016/j.paid.2021.111054
Received 29 January 2021; Received in revised form 28 April 2021; Accepted 1 June 2021
Available online 18 June 2021

individuals differ substantially in how easily they perceive such signals (Stevenson et al., 2015). For example, when stomach distention was induced in healthy individuals by a water-inflated gastric balloon, some individuals needed almost 10 times higher gastric wall pressure (four times larger volume) than others to reach the same subjective level of fullness (Stephan et al., 2003). Similarly, in the study of Sepple and Read (1989) some participants perceived the return of hunger following the ingestion of a standardized meal four times sooner than others (range 90-360 min). Also, while the majority had less than 20% of the meal remaining in the stomach upon the onset of hunger, others started feeling hungry with fuller stomachs. Thus, some individuals require a stronger signal and others a weaker signal to reach the same subjective state of satiation or hunger (Fig. 1). In other words, at a given level of signal intensity, individuals experience a stronger or a weaker sensation depending on how sensitive they are.

We hypothesized that SS is negatively associated with satiation threshold, i.e., the higher individuals score on SS the smaller percentage of their stomach capacity they need to fill with water to perceive the onset of satiation. Similarly, SH was expected to be negatively associated with hunger threshold, i.e., the higher individuals score on SH the less time they need to perceive the onset of hunger following the consumption of a standardized preload. In line with common practice in scale validation and to provide additional evidence on the construct validity of SS and SH, we also examined associations with a generic self-report measure of interoception, the Multidimensional Assessment of Interoceptive Awareness (MAIA) (Mehling et al., 2012), which assesses body awareness, a conceptually similar but broader, non-domain-specific construct. Given this conceptual similarity, a positive association was expected between SS/SH and MAIA. More importantly, SS and SH, were expected to correlate more strongly than MAIA with their respective threshold.

This research contributes to the sparse literature that has examined the validity of self-report measures within the eating domain (but also more broadly) beyond testing for associations with other self-reports. In this way, strong evidence of construct validity can be obtained for these measures. Furthermore, it informs decisions on whether laborious procedures that assess the perception of satiation and hunger can be substituted by survey-based questionnaires, which can be applied conveniently in large population samples and in ecologically valid conditions. The studies presented in this paper were pre-registered[1] and were pre-approved by the Social Sciences Ethics Committee of Wageningen University & Research. Participants provided their written consent at the beginning of each study.

## 2. Study 1

This study examined the association of SS (and MAIA) with satiation threshold, as measured with the WLT (van Dyck et al., 2016); a non-invasive laboratory procedure that assesses how much water individuals need to ingest, starting from an empty stomach, to perceive their first signal of satiation corrected for maximum stomach capacity (referred to as *satiation threshold*). We selected this methodology because water, as opposed to caloric stimuli, restricts the process of satiation to gastric distention and rules out a series of cognitive factors that can also influence the quantities that individuals ingest to reach satiation (e.g., satiation expectations, sensory-specific satiation, cognitive restraint). Previous research has found that meal volume rather than energy content determines perception of satiation (Goetze et al., 2007; Rolls et al., 2000) and fullness ratings are related to total gastric volume for both nutrient and non-nutrient meals (Marciani et al., 2001). Thus, the WLT seemed a valuable alternative to assess the incidental ability to perceive the onset of bodily signals of satiation.

### 2.1. Methods

#### 2.1.1. Sample size rationale

The required sample size to detect a moderate correlation between SS and satiation threshold ($r = 0.3$) (i.e., smallest effect size that we considered meaningful) with an alpha level of 0.05 and a power level of 0.9 in a two-tailed bivariate correlation was 112 participants (as calculated in G Power 3.1). We aimed to recruit a total of 120 participants to account for potential losses during data collection.

#### 2.1.2. Participants and procedure

Participants were recruited in a Dutch city via posters, flyers, mailing lists, social media posts, as well as via a market research agency. Only Dutch people who said they understand English moderately well, very well, or extremely well (on a scale ranging from 1 = "not well at all" to 5 = "extremely well") could participate because the study was conducted in English, but one (filler) task was in Dutch. Interested individuals filled in an online questionnaire with the study's eligibility criteria and SS. Individuals with the following conditions were excluded: any type of diabetes, any type of gastrointestinal diseases (including mild conditions, e.g., heartburn, dyspepsia, bloating, irritable bowel syndrome), hypertension, cardiovascular diseases, diseases of the respiratory system, mental illnesses, eating disorders, history of bariatric surgery, use of medication that is known to affect appetite and weight, pregnant and lactating women. Data from 119 participants was collected. Six participants were excluded because they failed to comply with the instructions for preparation (described below), leaving a sample of 113 participants for analysis (29 males, 84 females). Participants' average age was 32.08 years (SD = 15.58) and average Body Mass Index (BMI) was 23.23 kg/$m^2$ (SD = 3.48) (3.7% underweight, 70.6% normal weight, 22.0% overweight, 3.7% obese). Five participants (4.4%) reported dieting for weight loss purposes at the time of the study.

Lab sessions took place between 9:00 and 11:30. Participants were instructed to refrain from eating (including caloric drinks) for at least 3 h prior to their session, from drinking (including water, coffee, or tea) for at least 2 h prior to their session, from intense physical activity in the morning of their session, and from alcohol consumption the day prior to their session. In this way, participants were at the same physical state at baseline and situational factors that can influence the processes of gastric distention and emptying were controlled for (Costa et al., 2017). Instruction compliance was checked verbally but also by calculating the time interval since participants had last eaten and drank something. First, participants were asked to imagine how they typically experience the states of comfortable satiation (Concept T1) and complete fullness (Concept T2) in a normal consumption situation and to rate those states in terms of satiation sensations. Then, they reported their baseline (T0) momentary sensations of satiation and hunger and disposition to eat (DTE). After a filler task,[2] the WLT took place. Sensations of satiation and DTE were assessed after the first (T1) and after the second (T2)

[1] The following deviations from the pre-registration took place during data collection and analysis. 1. The age range in Study 2 was adjusted from 18 to 25 to 18–29 to allow for the timely completion of data collection. 2. The measure of extreme response style was not used as control variable in the main analyses because there was no reason to expect this tendency to account for variance in satiation and hunger thresholds. Also, extreme response style was not significantly correlated to any of the main dependent and independent variables of this research. 3. Hunger sensations reported after the preload were not included as control variables in the main analysis in Study 2 because these could vary systematically with the DV, introducing multicollinearity issues to the model.

[2] The filler task (i.e., listening and evaluating a short audio fragment) served as a neutral activity that kept participants busy for about the same amount of time as a mindfulness exercise that was conducted in a different group of participants (not described in this paper). In another manuscript, we discuss the effect of the mindfulness manipulation on satiation and hunger threshold (authors, Manuscript accepted for publication).

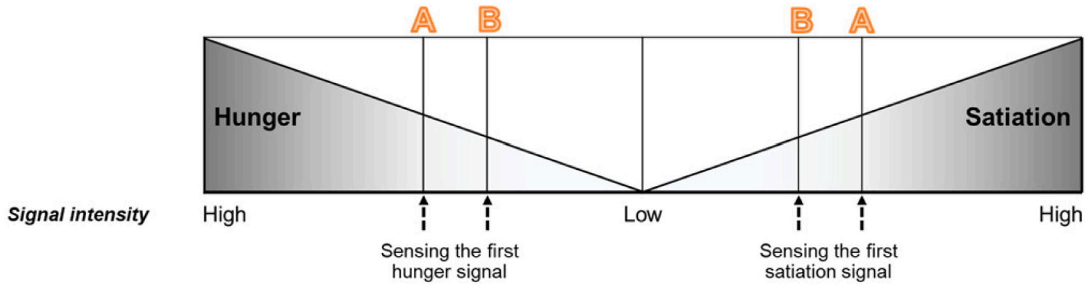


**Fig. 1.** Individual differences in perception of satiation and hunger signals. Individual B perceives the onset of satiation and hunger at lower signal intensity level than individual A (i.e., has lower satiation threshold and lower hunger threshold) because B is more sensitive than A.

drinking round. In the end, participants filled in the remaining self-reports and control measures. Participants were rewarded with snacks and shopping vouchers (Fig. 2) and received a debriefing email upon completion of data collection.

### 2.1.3. Measures

*2.1.3.1. Satiation threshold.* Participants were given a covered 1.5 l bottle of water and a straw and were asked to drink ad libitum until perceiving a first signal of satiation. The following instructions were given (slightly adapted from van Dyck et al. (2016)): 'We ask you to drink water with the straw until you perceive your first sign of satiation. By satiation we mean the comfortable sensation you perceive when you have eaten a meal and you have eaten enough, but not too much. You have 5 min to complete this task. Start drinking now.' Then, the bottle was replaced by a new identical bottle and participants were asked to continue drinking until reaching the point of maximum stomach fullness. The new instructions were: 'We now ask you to drink again using the straw. Please continue drinking until your stomach is completely full, that is, entirely filled with water. You have 5 min to complete this task. Start drinking now.' The following indices were calculated: (1) water volume (in ml) ingested to perceive the first sign of satiation (Intake_Satiation); (2) additional water volume ingested to reach full stomach capacity (Intake_Fullness); (3) total water volume ingested (Intake_Total = Intake_Satiation + Intake_Fullness); and (4) satiation threshold, calculated as the percentage of stomach capacity at which the first signal of satiation is perceived (Intake_Satiation / Intake_Total * 100). The validity of the WLT is supported by the positive association with the barostat method (Boeckxstaens et al., 2001).

*2.1.3.2. Sensitivity to physiological signals of satiation.* The SS subscale of MIRES (Palascha et al., 2020a) was used to assess the ability to perceive and interpret the signals that the body naturally generates in response to satiation. The nine items were administered with 7-point scales (1 = "Completely untrue for me" to 7 = "Completely true for me"). Cronbach's alpha was 0.88 in this study. Responses were averaged to a mean score.

*2.1.3.3. Interoceptive awareness.* The MAIA was used to assess interoceptive awareness defined as the 'sensory awareness that originates from the body's physiological states, processes, and actions, and functions as an interactive process that includes a person's appraisal and is shaped by attitudes, beliefs, and experience in their social and cultural context' (Mehling et al., 2012). The 32 items were administered with 6-point frequency scales (0 = "Never" to 5 = "Always"). Known-groups-testing (students vs instructors experienced with body-awareness therapies) and correlations with related constructs (e.g., body consciousness, body connection) have provided support for the scale's construct validity (Mehling et al., 2012). Cronbach's alpha was 0.87 in this study and responses were averaged.

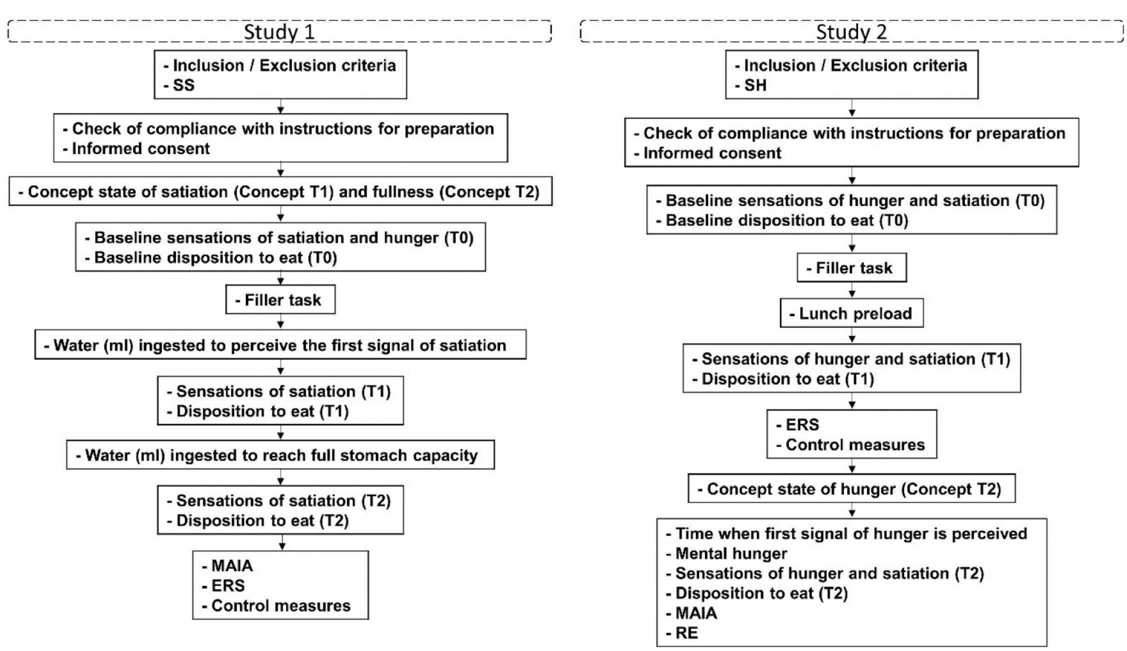


**Fig. 2.** Timeline of Studies 1 and 2.

*2.1.3.4. Sensations of satiation and hunger.* A list of 18 sensations commonly used to describe the experience of satiation and hunger was used to assess participants' subjective sensations at baseline (T0) and after each drinking round (T1 and T2) (Monello and Mayer, 1967; Murray and Vickers, 2009). Items were administered with 100 mm visual analogue scales (VAS) (0 = "Not at all" to 100 = "As much as I can imagine") and were averaged using the following structure as indicated by Principal Component Analysis (PCA) (Supplementary material 1): Hunger sensations (weakness, rumbling stomach, lack of concentration, lightheaded, irritated, nervous, tense), Early sensations of satiation (full stomach, satisfied, relaxed, happy), and Late sensations of satiation (heavy feeling, feeling bloated, discomfort, nausea, regret, disgust with yourself). A mean score was calculated for each set of items and each time point.

The satiation sensations were also used to assess how participants subjectively interpret the terms *comfortable satiation* and *complete fullness* that are relevant when performing the WLT. Specifically, participants were asked "Imagine you have just eaten a meal and you have eaten enough but not too much. How would you describe this sensation in terms of the following factors?". By averaging scores on the early and late sensations of satiation, as indicated above, we calculated two indices of participants' concept state of comfortable satiation (Concept T1). Likewise, to assess participants' concept state of complete fullness (Concept T2) participants were asked "Now imagine you have just eaten a meal until your stomach is completely full. How would you describe this sensation in terms of the following factors?" and the respective items were also averaged in two indices (early and late sensations). The four indices were used as control variables in the main analysis because we wanted to rule out any variation in satiation threshold that was caused by variation in interpretation of the WLT's instructions. Finally, participants also reported how frequently they stop eating once they reach the satiation state (Frequency_Satiation) and how frequently they reach the fullness state (Frequency_Fullness) (1 = "Never" to 5 = "Always") in their regular eating occasions.

*2.1.3.5. DTE.* DTE familiar foods has been shown to be a very sensitive indicator of appetite (Booth, 2009). In this study, DTE was measured to assess whether the ingestion of water impacted participant's appetite for food, which would indicate whether water is an appropriate stimulus for inducing satiation and fullness. Participants saw two images that each contained 20 items of a sweet (digestive biscuit) or a savoury (cracker with cheese) food cut into smaller pieces and were asked to click on the images to highlight how many quarters (for digestive biscuits) or halves (for crackers with cheese) they would eat if each food offered by itself at that moment. The sum of digestive biscuit quarters provided an indicator of DTE something sweet (DTE_sweet) and the sum of cracker and cheese halves indicated the DTE something savoury (DTE_savoury) at each time point.

*2.1.3.6. Extreme response style.* The tendency to consistently select the extremes of rating scales independently of item content was measured with the 16-item Extreme Response Scale (ERS) (Greenleaf, 1992). The scale has been found to be stable and its items exhibit low inter-item correlations as is desired in such measures (Greenleaf, 1992). ERS was used to purify SS from extreme responding bias. Therefore, the items were administered with the same 7-point scale as the SS measure (1 = "Completely true for me" to 7 = "Completely true for me"). Participants who selected the extremes of the rating scale in both ERS and SS 80% of the time or more were identified as extreme responders and were excluded from the analysis.

*2.1.3.7. Demographic and control variables.* Participants reported their gender, age (years), weight (kg), height (cm), whether they were dieting for weight loss (Yes/No), whether they were smokers (Yes/No), how many hours they slept the previous night, how physically active (PA) they had been the last days (1 = "Not active at all" to 5 = "Extremely active"), how frequently they consume breakfast (1 = "Never" to 5 = "Always"), what was the last time they ate and drank something, and whether they had any reason that prevented them from eating digestive biscuits and crackers with cheese (Yes/No). These variables were measured to characterize the sample, to check participant's compliance with the instruction for preparation, and/or to be used as control variables in the main analyses.

### 2.2. Analysis

Analysis was conducted with SPSS 26. No participant was identified as extreme respondent; thus, all were included in the analyses. To address the main hypothesis, we conducted multiple linear regression analysis with satiation threshold as dependent variable (DV) and SS as independent variable (IV) with and without control variables. The same analysis was conducted with MAIA as the main IV. Bootstrapping (10,000 samples) was used to accurately estimate the 95% Confidence Intervals (CI). The assumptions of normality and homoscedasticity were met in both analyses (Supplementary material 2), thus, results are generalizable beyond the study sample. Independent variables were standardized to prevent multi-collinearity issues. Variance Inflation Factors (VIF) and condition indices were inspected for presence of multicollinearity (desired values below 10) and the Durbin-Watson test was inspected for presence of auto-correlation (desired values around 2). Four repeated-measures ANOVA were conducted to understand how the various stages of the WLT impacted participants' early and late sensations of satiation as well as DTE_sweet and DTE_savoury. To determine whether participants adequately simulated their concept states of satiation and fullness by ingesting water, we used pairwise tests (Bonferroni adjustment) comparing the satiation sensations reported for the concept states (Concept T1 and Concept T2) with those experienced during the WLT (T1 and T2) ($\alpha = 0.005$). Likewise, we assessed changes in DTE (T1 vs. T0 and T2 vs. T1) ($\alpha = 0.017$).

### 2.3. Results

Large individual differences were observed in satiation thresholds. Some participants perceived the first signal of satiation at 15.43% of their stomach capacity, while others had to ingest almost 5 times larger volumes (74.61% of stomach capacity). SS did not significantly predict satiation threshold, neither in the absence (B = 1.28, SE = 1.24, t = 1.04, p = .30) nor presence of control variables (B = 1.54, SE = 1.43, t = 1.08, p = .29) (Table 1). VIF values ranged between 1.00 and 1.14, condition indices between 1.01 and 4.52, and the Durbin-Watson test had a value of 2.02. Neither MAIA predicted satiation threshold significantly (Table 2). Multi-collinearity (VIF between 1.00 and 1.07 and condition indices between 1.00 and 4.49) and auto-correlation (Durbin-Watson test was 2.03) were not present in this model either. A significant positive correlation was observed between SS and MAIA (r = 0.27, p = .004) (Table 3). Positive correlations were observed between the various volumes ingested during the WLT and with satiation threshold. Moreover, sensations of satiation at T1 and T2 were not significantly correlated with satiation threshold (neither with the individual volumes ingested at each drinking round), while early sensations of satiation correlated positively with SS (Table 4).

Early and late sensations of satiation varied significantly during the study (Early: $F(4,109) = 65.33$, $p < .001$, $\eta^2 = 0.71$; Late: $F(4,109) = 144.79$, $p < .001$, $\eta^2 = 0.84$) (Fig. 3). Pairwise comparisons indicated that early sensations were significantly lower at T1 compared with Concept T1 (Mdiff = 10.35, SDdiff = 1.88, $p < .001$). No significant difference in early sensations was observed between T2 and Concept T2 (Mdiff = 4.69, SDdiff = 1.93, $p = .17$), neither in late sensations between T1 and Concept T1 (Mdiff = −0.34, SDdiff = 1.03, $p = 1.00$). Late sensations were significantly lower at T2 compared with Concept T2 (Mdiff = 7.72, SDdiff = 1.90, $p = .001$).

**Table 1**
Crude and adjusted linear regression models predicting satiation threshold by SS.

| | B | SE | t | p | Bootstrap 95% CI | $R^2$ |
|---|---|---|---|---|---|---|
| Crude model | | | | | | |
| SS | 1.28 | 1.24 | 1.04 | 0.30 | −1.18, 3.70 | 0.01 |
| Adjusted model | | | | | | |
| SS | 1.54 | 1.43 | 1.08 | 0.29 | −1.22, 4.49 | 0.06 |
| Age | −1.92 | 1.66 | −1.15 | 0.25 | −5.32, 1.56 | |
| Gender | 2.45 | 3.29 | 0.75 | 0.46 | −4.44, 10.27 | |
| BMI | 1.59 | 1.50 | 1.06 | 0.29 | −1.29, 5.25 | |
| Dieting | −1.80 | 6.56 | −0.27 | 0.79 | −18.88, 14.36 | |
| Satiation early sensations_Concept T1 | 2.23 | 1.53 | 1.46 | 0.15 | −0.75, 6.02 | |
| Satiation late sensations_Concept T1 | 1.12 | 1.63 | 0.69 | 0.49 | −1.59, 4.19 | |
| Satiation early sensations_Concept T2 | −0.80 | 1.61 | −0.50 | 0.62 | −4.21, 2.39 | |
| Satiation late sensations_Concept T2 | −1.16 | 1.80 | −0.64 | 0.52 | −5.28, 2.25 | |

SS: sensitivity to physiological signals of satiation, BMI: Body Mass Index.

**Table 2**
Crude and adjusted linear regression models predicting satiation threshold by MAIA.

| | B | SE | t | p | Bootstrap 95% CI | $R^2$ |
|---|---|---|---|---|---|---|
| Crude model | | | | | | |
| MAIA | −0.09 | 1.24 | −0.07 | 0.94 | −3.23, 3.10 | <0.001 |
| Adjusted model | | | | | | |
| MAIA | 0.20 | 1.33 | 0.15 | 0.88 | −2.99, 3.52 | 0.05 |
| Age | −1.29 | 1.60 | −0.81 | 0.42 | −4.26, 1.93 | |
| Gender | 2.63 | 3.30 | 0.80 | 0.43 | −4.08, 10.75 | |
| BMI | 1.34 | 1.49 | 0.90 | 0.37 | −1.62, 4.71 | |
| Dieting | −0.80 | 6.57 | −0.12 | 0.90 | −19.32, 15.42 | |
| Satiation early sensations_Concept T1 | 2.65 | 1.48 | 1.79 | 0.08 | −0.32, 6.27 | |
| Satiation late sensations_Concept T1 | 1.26 | 1.65 | 0.76 | 0.45 | −1.57, 4.72 | |
| Satiation early sensations_Concept T2 | −1.09 | 1.61 | −0.68 | 0.50 | −4.54, 2.05 | |
| Satiation late sensations_Concept T2 | −1.56 | 1.80 | −0.87 | 0.39 | −5.93, 1.78 | |

MAIA: Multidimensional Assessment of Interoceptive Awareness, BMI: Body Mass Index.

Finally, DTE_sweet and DTE_savoury also varied significantly during the study (DTE_sweet: $F(2,110) = 97.89$, $p < .001$, $\eta^2 = 0.64$; DTE_savoury: $F(2,104) = 72.90$, $p < .001$, $\eta^2 = 0.58$) (Fig. 4). DTE_sweet reduced significantly at T1 compared with T0 (Mdiff = −5.97, SDdiff = 0.66, p < .001) and at T2 compared with T1 (Mdiff = −3.97, SDdiff = 0.31, p < .001). Similarly, DTE_savoury decreased significantly both at T1 (Mdiff = −1.46, SDdiff = 0.18, p < .001) and at T2 (Mdiff = −1.63, SDdiff = 0.16, p < .001).

### 2.4. Discussion

Contrary to our expectations, neither SS, as a domain-specific self-report, nor MAIA, as a generic self-report, predicted satiation threshold; yet the two self-reports were positively associated. Exploratory analysis of the data showed that the higher people scored in SS, the more intense early sensations they reported at T1, suggesting that sensitivity associates with stronger perception of early sensations of satiation, irrespectively of satiation threshold.

The significant reductions in DTE after each round of the WLT, indicate that the ingestion of water is an effective means for inducing satiation and fullness. Nevertheless, we also found that early sensations of satiation at T1 and late sensations of satiation at T2 were significantly lower compared with the respective concept states, which indicates that water (as compared with food) has a reduced capacity to elicit sensations of satiation. This discrepancy might have impacted satiation threshold in an unbalanced way. Participants who are able to perceive early sensations of satiation might have needed to ingest larger volumes (than the ones they would have ingested if a caloric stimulus had been used) to perceive the onset of satiation. In the contrary, those who perceive the onset of satiation only by means of late sensations of satiation likely ingested their usual volumes (late sensations at T1 did not differ from those reported for Concept T1). As a result, the satiation thresholds of sensitive individuals might have inflated, obscuring, thus, the true association between SS and satiation threshold.

Furthermore, it was evident that the more water participants ingested at T1 (Intake_Satiation) the more they ingested at T2 (Intake_Fullness), suggesting that the greater one's stomach capacity, the more one had to drink to perceive the onset of satiation. This underscores the importance of controlling for one's stomach capacity when using the WLT methodology. Yet, this can also mean that the harder it is for one to perceive the onset of satiation, the harder it is to perceive complete fullness or the less aversive one is to stomach stretch. Thus, the ability to perceive sensations of gastric distention may be a generalized individual trait. Finally, we found that sensations of satiation reported at T1 and T2 were not associated with satiation threshold (neither with individual volumes), suggesting that ingesting more water did not cause participants to experience more intense sensations. Thus, our assumption that people need to ingest different volumes to experience the same subjective states of satiation or fullness was at least not rejected by the data.

Overall, the findings of this study indicate that trait sensitivity to bodily signals of satiation does not predict the incidental ability to perceive the onset of satiation but is positively related to trait interoceptive awareness as well as to self-reported early sensations of satiation at the onset of satiation. Some of our findings suggest that the use of water to assess satiation threshold may be accountable for the lack of association with SS.

## 3. Study 2

In this study we examined the association of SH with hunger threshold, assessed with the preload test in a semi-controlled setting. The preload test (Blundell et al., 2010), assesses how much time

**Table 3**
Descriptive statistics and correlations for the main variables of Study 1.

| | M | SD | Intake_Satiation | Intake_Fullness | Intake_Total | Satiation threshold | SS | MAIA | Age | BMI | PA | Frequency_Satiation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intake_Satiation | 339.07 | 147.74 | – | | | | | | | | | |
| Intake_Fullness | 412.96 | 191.72 | 0.20* | – | | | | | | | | |
| Intake_Total | 752.04 | 263.83 | 0.70** | 0.84** | – | | | | | | | |
| Satiation threshold | 45.95 | 12.85 | 0.52** | −0.66** | −0.19* | – | | | | | | |
| SS | 5.51 | 0.91 | −0.04 | −0.17 | −0.15 | 0.10 | – | | | | | |
| MAIA | 3.68 | 0.53 | 0.03 | 0.02 | 0.03 | −0.004 | 0.27** | – | | | | |
| Age | 32.08 | 15.58 | −0.16 | −0.11 | −0.17 | −0.05 | 0.34** | 0.25** | – | | | |
| BMI | 23.23 | 3.48 | −0.05 | −0.15 | −0.14 | 0.03 | 0.06 | 0.09 | 0.47** | – | | |
| PA | 3.04 | 0.81 | −0.07 | 0.17 | 0.08 | −0.18 | −0.06 | 0.26** | −0.02 | −0.13 | – | |
| Frequency_Satiation | 3.42 | 0.87 | −0.10 | −0.25** | −0.24* | 0.17 | 0.15 | 0.07 | −0.05 | −0.03 | 0.06 | – |
| Frequency_Fullness | 2.30 | 0.76 | 0.01 | 0.14 | 0.11 | −0.16 | −0.03 | 0.01 | 0.01 | −0.09 | 0.007 | −0.19* |

SS: SENSITIVITY to physiological signals of satiation, MAIA: Multidimensional Assessment of Interoceptive Awareness, BMI: Body Mass Index, PA: Physical activity.
* $p < .05$.
** $p < .01$.

individuals need after the ingestion of a standardized preload to perceive their first signal of hunger (referred to as *hunger threshold,* for correspondence with Study 1). Participants consumed in the laboratory a precisely prepared meal (preload) and continued their day as normal with the task of not eating or drinking anything until the moment they would perceive their first signal of hunger. Because it was not possible in this study to rule out by design confounding effects of cognitive factors that could influence the perception of hunger, we measured and controlled for the mental component of hunger (i.e., thinking about food despite not being physically hungry) in the analysis.

### *3.1. Methods*

#### *3.1.1. Participants and procedure*

The same sample size rationale, recruitment means, and eligibility criteria as in Study 1 were used. In addition, we excluded males and individuals who had medical (e.g., allergy, intolerance), ethical, religious, or other personal reasons that prevented them from eating any of the foods offered in this study. We recruited a rather homogeneous sample of females between 18 and 29 years old to reduce variability in the satiating effect of the preload. Data from 120 participants was collected. Two participants who had incomplete data and seven participants who failed to comply with the instructions for preparation were excluded. Participants' average age was 22.21 years (SD = 2.05) and average BMI was 21.77 kg/m$^2$ (SD = 2.29) (6.5% underweight, 89.7% normal weight, 2.8% overweight, 1.0% obese). One participant reported dieting at the time of the study.

Eligibility criteria and SH were assessed via an online questionnaire. Lab sessions took place between 13:00 and 15:30. Participants were instructed to refrain from eating (including caloric drinks) for at least 4 h prior to their session, from intense physical activity in the morning of their session, and from consuming alcohol the day prior to their session. Instruction compliance was checked verbally but also computationally, by calculating the time interval since participants had last eaten and drank something. First, participants reported their baseline (T0) sensations of hunger and satiation and DTE and conducted a filler task (same as Study 1). Then, they were offered the lunch preload and reported the exact time when they finished it (T1). Then, they reported sensations of satiation and hunger and DTE, followed by the ERS and the remaining control measures. At the end of their lab session, participants described their concept state of hunger (Concept T2) (as in Study 1) and were given a sealed questionnaire that they had to fill in by the time they would notice their first signal of hunger (T2). In this questionnaire, they reported the time when they perceived the hunger signal, hunger as a mental state, hunger and satiation sensations, DTE, interoceptive awareness, and restraint eating. Participants returned this questionnaire to the researcher in person or by post and received a shopping voucher as a reward. Participants received a debriefing email upon completion of data collection.

#### *3.1.2. Measures*

*3.1.2.1. Hunger threshold.* Participants consumed a standardized lunch preload consisted of a hummus and cucumber sandwich, a raisin bun, 200 ml orange juice, and a cup of water (125 ml). The mean caloric content of the preload was 562.87kcals (SD =12.93). Participants filled in the exact time when they finished the preload and were traced in terms of what time they would perceive their first signal of hunger under ecologically valid conditions. They were instructed to not eat or drink anything until they reach this state. The instructions were as follows: "The researcher will now give you a sealed envelope that includes a questionnaire. We ask you to open this envelope the moment you perceive a first sign of hunger. By hunger we mean the sensation you perceive when you haven't eaten for some time and your stomach is ready to receive food. We request that you don't eat or drink anything

**Table 4**
Descriptive statistics and correlations for measures of sensation and disposition to eat in Study 1.

| | M | SD | Range | Satiation threshold | Intake_Satiation | Intake_Fullness | Intake_Total | SS | MAIA |
|---|---|---|---|---|---|---|---|---|---|
| Hunger sensations_T0 | 22.68 | 18.09 | 0–95 | −0.01 | −0.001 | −0.01 | −0.01 | **−0.24*** | **−0.23*** |
| Satiation early sensations_T0 | 37.76 | 17.58 | 0–79 | −0.09 | 0.004 | 0.15 | 0.11 | 0.18 | **0.23*** |
| Satiation late sensations_T0 | 10.27 | 12.22 | 0–90 | −0.02 | 0.04 | 0.06 | 0.06 | −0.15 | −0.08 |
| Satiation early sensations_Concept T1 | 67.52 | 17.95 | 6–100 | 0.16 | 0.08 | −0.11 | −0.03 | **0.19*** | 0.08 |
| Satiation late sensations_Concept T1 | 15.00 | 14.15 | 0–77 | −0.01 | 0.06 | 0.15 | 0.14 | −0.10 | −0.09 |
| Satiation early sensations_Concept T2 | 60.05 | 19.25 | 4–100 | −0.004 | 0.06 | 0.07 | 0.08 | −0.04 | 0.04 |
| Satiation late sensations_Concept T2 | 51.28 | 23.07 | 4–99 | −0.02 | −0.01 | 0.05 | 0.03 | −0.12 | 0.02 |
| Satiation early sensations_T1 | 57.17 | 16.10 | 12–89 | 0.04 | 0.12 | 0.08 | 0.12 | **0.21*** | **0.29**** |
| Satiation late sensations_T1 | 15.34 | 14.76 | 0–98 | 0.09 | 0.06 | 0.02 | 0.05 | −0.17 | −0.08 |
| Satiation early sensations_T2 | 55.37 | 19.28 | 2–99 | −0.10 | −0.03 | 0.08 | 0.04 | 0.17 | **0.20*** |
| Satiation late sensations_T2 | 43.56 | 18.79 | 0–99 | 0.12 | 0.09 | −0.01 | 0.04 | −0.13 | −0.01 |
| DTE sweet_T0 | 13.19 | 9.82 | 0–54 | −0.00 | 0.11 | 0.07 | 0.11 | **−0.20*** | −0.00 |
| DTE savoury_T0 | 4.31 | 3.08 | 0–18 | **0.20*** | **0.28**** | −0.04 | 0.13 | −0.01 | −0.08 |
| DTE sweet_T1 | 7.24 | 5.69 | 0–28 | −0.01 | 0.11 | 0.06 | 0.10 | **−0.19*** | −0.04 |
| DTE savoury_T1 | 2.85 | 2.23 | 0–12 | 0.11 | **0.19*** | −0.03 | 0.09 | −0.06 | −0.11 |
| DTE sweet_T2 | 3.28 | 4.14 | 0–20 | −0.03 | 0.08 | 0.08 | 0.11 | −0.15 | −0.05 |
| DTE savoury_T2 | 1.28 | 1.58 | 0–8 | −0.01 | 0.05 | 0.04 | 0.06 | −0.07 | −0.09 |

SS: sensitivity to physiological signals of satiation, MAIA: Multidimensional Assessment of Interoceptive Awareness, DTE: disposition to eat.
* $p < .05$.
** $p < .01$.

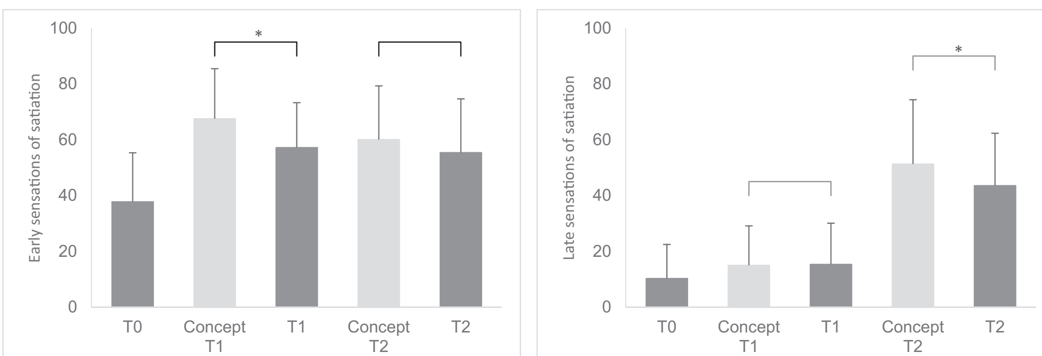


**Fig. 3.** Means and standard deviations for early and late sensations of satiation in Study 1.

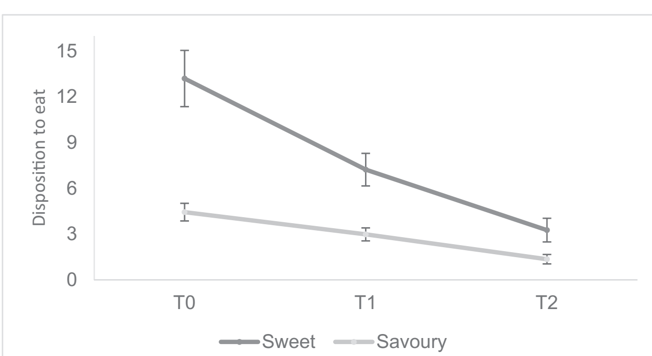


**Fig. 4.** Means (plus 95% CI) for disposition to eat digestive biscuits (quarters) and crackers with cheese (halves) in Study 1.

(except for water) before you reach this state". Hunger threshold (in minutes) was calculated by computing the time between finishing the preload and opening the envelope.

*3.1.2.2. Sensitivity to physiological signals of hunger.* The SH subscale of MIRES (Palascha et al., 2020a) was used to assess the ability to perceive and interpret the signals that the body naturally generates in response to hunger. The nine items were administered with 7-point scales (1 = "Completely untrue for me" to 7 = "Completely true for me"). Cronbach's alpha was 0.88 and items were averaged.

*3.1.2.3. Interoceptive awareness.* MAIA was used to measure interoceptive awareness as Study 1. Cronbach's alpha was 0.90 in this study.

*3.1.2.4. Sensations of hunger and satiation.* Like in Study 1, participants reported their hunger and satiation sensations at baseline (T0), after the preload (T1), and upon the onset of hunger (T2). Items were averaged using the following structure that emerged from PCA (Supplementary material 1): Hunger early sensations (empty stomach, rumbling stomach), Hunger late sensations (weakness, lack of concentration, lightheaded, tense, nervous, irritated), Satiation early sensations (satisfied, relaxed, happy), and Satiation late sensations (heavy feeling, feeling bloated, nausea, discomfort, regret, disgust with yourself). A mean score was calculated for each set of items and each time point. The hunger sensations were also used to assess participants' concept state of hunger (Concept T2). The following question was asked "Imagine that you haven't eaten for some time and your stomach is ready to receive food. How would you describe this sensation in terms of the following factors?". Participants also reported how frequently they start eating the moment they reach this state (Frequency_Hunger) (1 = "Never" to 5 = "Always") in normal consumption situations.

*3.1.2.5. DTE.* DTE_sweet (chocolate chip cookies) and DTE_savoury (salty crackers) were measured as in Study 1.

*3.1.2.6. Mental hunger (MH).* Hunger as a mental state was assessed with one item (Since you left the lab, to what extent did you think about eating despite not being physically hungry?) administered with a 100 mm VAS (0 = "I did not think about eating at all" and 100 = "I was constantly thinking about eating"). Mental hunger was used as control variable because thinking about food can create an attention bias towards food in the environment (Higgs et al., 2015) and could possibly rash the perception of physical hunger.

*3.1.2.7. Extreme response style.* ERS was used to measure extreme response style, as in Study 1.

*3.1.2.8. Restraint eating (RE).* The RE scale of the Dutch Eating Behaviour Questionnaire (DEBQ) (van Strien et al., 1986) was used to measure one's intention to restrict food intake in order to control body weight. The 10 items were administered with a 5-point frequency scale (1 = "Never" and 5 = "Very often"). Positive associations with other self-report measures of restraint eating have provided evidence on the scale's convergent validity (Cebolla et al., 2014). Cronbach's alpha was 0.89 in this study and a mean score was calculated, which was used as control variable in the main analyses.

*3.1.2.9. Demographic and control variables.* The same demographic and control variables as in Study 1 were measured.

### 3.2. Analysis

Same as Study 1. No participant was identified as extreme respondent. Four outliers were excluded for the assumptions of normality and homoscedasticity to be met; thus, analysis was conducted with 107 participants.

### 3.3. Results

Hunger thresholds ranged between 19 and 330 min for the study participants. SH did not significantly predict hunger threshold, neither in the absence (B = 3.04, SE = 6.01, $t = 0.51$, $p = .61$) nor presence of control variables (B = 1.74, SE = 6.37, $t = 0.27$, $p = .79$) (Table 5). There was no evidence of multi-collinearity (VIF values: 1.00–1.04, Condition indices: 1.15–2.05) or auto-correlation (Durbin-Watson: 2.24). Neither MAIA predicted hunger threshold significantly (Table 6). VIF values for this model ranged between 1.00 and 1.02, condition indices between 1.15 and 2.10, and the Durbin-Watson test had a value of 2.23. A significant positive correlation was observed between SH and MAIA ($r = 0.36$, $p < .001$) (Table 7). Hunger threshold was correlated with measures of sensation and DTE reported at T1, but also with early sensations of hunger at T2, while significant correlations were also observed between SH and several measures of late sensations of hunger and satiation (Table 8).[3]

Both early ($F(3,104) = 260.15$, $p < .001$, $\eta^2 = 0.88$) and late sensations of hunger ($F(3,104) = 67.74$, $p < .001$, $\eta^2 = 0.66$) changed significantly during the study (Fig. 5). Pairwise comparisons indicated that both early (Mdiff = 22.50, SDdiff = 2.16, p < .001) and late (Mdiff = 9.72, SDdiff = 1.27, p < .001) sensations were significantly lower at T2 compared with Concept T2.

Finally, DTE_sweet ($F(2,104) = 115.82$, $p < .001$, $\eta^2 = 0.69$) and DTE_savoury ($F(2,103) = 111.42$, $p < .001$, $\eta^2 = 0.68$) also changed significantly during the study (Fig. 6). DTE_sweet decreased significantly at T1 compared with T0 (Mdiff = −9.11, SDdiff = 0.75, p < .001) and increased significantly at T2 compared with T1 (Mdiff = 6.67, SDdiff = 0.50, p < .001). Likewise, DTE_savoury decreased significantly at T1 (Mdiff = −8.84, SDdiff = 0.65, p < .001) and increased significantly at T2 (Mdiff = 6.30, SDdiff = 0.54, p < .001).

### 3.4. Discussion

This study failed to confirm the hypothesis that SH and MAIA would predict hunger threshold. However, the two self-reports were positively correlated. Exploratory analysis of the data showed that SH was also negatively associated with late sensations of hunger at T2, thus, the more sensitive participants said they are, the less intense late sensations of hunger they experienced upon the onset of hunger. It is possible, therefore, that sensitive individuals did not need to experience late hunger sensations to perceive the onset of hunger because they were able to sense and respond to early sensations, irrespectively of hunger threshold.

Furthermore, we found that hunger threshold was associated with several measures of sensation and DTE at T1, which indicates that hunger threshold was influenced by how satiated participants felt after the preload. Thus, our efforts to limit variation in the satiating effect of the preload by recruiting a relatively homogeneous sample of young females were not completely successful. Moreover, in this study, hunger threshold was positively correlated with early hunger sensations at T2, which means that early hunger sensations became stronger the more time one needed to perceive the onset of hunger. This is contradictory to what was observed in Study 1, where satiation threshold was not associated with sensations reported after each drinking round, and disconfirms our assumption that people need different amounts of time to reach the same subjective state of hunger after consuming a standardized preload. This inconsistency could be explained by the fact that satiation threshold was controlled for stomach capacity, while hunger threshold was not controlled for the rate of gastric emptying or the hormonal response to the preload, two important confounders in this research.

Finally, we found that participants experienced less intense hunger sensations (early and late) upon the onset of hunger (T2) compared with their concept state of hunger (Concept T2), indicating a heightened ability to perceive the onset of hunger. There are two likely explanations for this finding; either participants perceived the signal sooner than normal because they actively attended to their bodily sensations or a demand effect occurred (i.e., participants exaggerated their competence deliberately).

The findings of this research converge with those of Study 1 and together suggest that trait and state sensitivity to bodily signals do not necessarily go hand in hand. Plausible explanations for this lack of convergence are discussed below.

## 4. General discussion

In this research we conducted a stringent test of construct validity for two self-report measures of sensitivity to physiological signals of satiation and hunger (SS and SH subscales of MIRES), by examining their association with behavioural indicators of the incidental ability to perceive the onset of satiation and hunger, respectively. In addition, we examined the associations of SS and SH with a generic self-report measure of interoceptive awareness (MAIA) and we aimed to compare the ability of the domain-specific and generic self-reports to predict the behavioural indicators. Contrary to our expectations, none of the self-reports predicted the behavioural indicators. Yet, SS and SH were positively associated with MAIA.

There are several plausible explanations for these findings. First, it is likely that either the self-reports or the behavioural indicators (or both) do not really capture the theoretical constructs they are assumed to be capturing. Unfortunately, our data do not allow us to ascertain which measure is (more) problematic. Alternatively, the different measures may be capturing different parts of the same construct. The behavioural

[3] MAIA also manifested significant correlations with measures of sensation and DTE. However, we do not interpret these results because these might have occurred by the fact that MAIA was assessed at the end of the study and responses might have been influenced by participants performance in the previous tasks.

**Table 5**
Crude and adjusted linear regression models predicting hunger threshold by SH.

| | B | SE | t | p | Bootstrap 95% CI | $R^2$ |
|---|---|---|---|---|---|---|
| Crude model | | | | | | |
| SH | 3.04 | 6.01 | 0.51 | 0.61 | −8.30, 14.48 | 0.002 |
| Adjusted model | | | | | | |
| SH | 1.74 | 3.37 | 0.27 | 0.79 | −9.69, 14.17 | 0.05 |
| Age | 1.44 | 6.66 | 0.22 | 0.83 | −12.81, 14.52 | |
| BMI | 2.94 | 6.62 | 0.44 | 0.66 | −11.22, 15.37 | |
| Mental hunger | −9.70 | 6.27 | −1.55 | 0.13 | −22.45, 3.69 | |
| RE | 6.90 | 6.52 | 1.06 | 0.29 | −6.85, 21.82 | |
| Dieting | −60.39 | 67.62 | −0.89 | 0.37 | −113.18, −8.69 | |
| Hunger early sensations_Concept T2 | 2.56 | 7.26 | 0.35 | 0.73 | −11.99, 15.85 | |
| Hunger late sensations_Concept T2 | −3.48 | 7.35 | −0.47 | 0.64 | −17.42, 12.46 | |

SH: sensitivity to physiological signals of hunger, BMI: Body Mass Index, RE: Restrained Eating.

**Table 6**
Crude and adjusted linear regression models predicting hunger threshold by MAIA.

| | B | SE | t | p | Bootstrap 95% CI | $R^2$ |
|---|---|---|---|---|---|---|
| Crude model | | | | | | |
| MAIA | 2.50 | 6.01 | 0.42 | 0.68 | −9.67, 14.90 | 0.002 |
| Adjusted model | | | | | | |
| MAIA | 2.51 | 6.39 | 0.39 | 0.70 | −10.95, 16.61 | 0.05 |
| Age | 1.37 | 6.65 | 0.21 | 0.84 | −12.98, 14.79 | |
| BMI | 3.06 | 6.61 | 0.46 | 0.64 | −11.18, 15.19 | |
| Mental hunger | −9.96 | 6.28 | −1.59 | 0.12 | −23.15, 3.39 | |
| RE | 6.93 | 6.52 | 1.06 | 0.29 | −7.12, 21.90 | |
| Dieting | −62.10 | 67.86 | −0.92 | 0.36 | −120.87, −3.04 | |
| Hunger early sensations_Concept T2 | 2.25 | 7.34 | 0.31 | 0.76 | −13.94, 16.47 | |
| Hunger late sensations_Concept T2 | −3.24 | 7.36 | −0.44 | 0.66 | −17.01, 12.32 | |

MAIA: Multidimensional Assessment of Interoceptive Awareness, BMI: Body Mass Index, RE: Restrained Eating.

**Table 7**
Descriptive statistics and correlations for the main variables of Study 2.

| | M | SD | Hunger threshold | SH | MAIA | MH | RE | Age | BMI | PA |
|---|---|---|---|---|---|---|---|---|---|---|
| Hunger threshold | 173.01 | 61.66 | – | | | | | | | |
| SH | 5.77 | 0.82 | 0.05 | – | | | | | | |
| MAIA | 2.89 | 0.55 | 0.04 | 0.36** | – | | | | | |
| MH | 4.57 | 2.42 | −0.14 | −0.08 | 0.04 | – | | | | |
| RE | 1.55 | 0.76 | 0.09 | −0.03 | −0.02 | 0.05 | – | | | |
| Age | 22.21 | 2.05 | 0.03 | 0.09 | 0.09 | 0.05 | −0.11 | – | | |
| BMI | 21.77 | 2.28 | 0.07 | 0.11 | 0.06 | 0.05 | 0.22* | 0.20* | – | |
| PA | 3.01 | 0.72 | −0.09 | 0.05 | 0.08 | 0.15 | 0.20* | 0.07 | 0.02 | – |
| Frequency_Hunger | 3.94 | 0.70 | 0.04 | −0.11 | −0.04 | 0.17 | −0.01 | 0.16 | −0.03 | −0.04 |

SH: sensitivity to physiological signals of hunger, MAIA: Multidimensional Assessment of Interoceptive Awareness, MH: Mental Hunger, RE: Restrained eating, BMI: Body Mass Index, PA: physical activity.
* $p < .05$.
** $p < .01$.

indicators we employed in this research perhaps focused too heavily on visceral sensations, while SS and SH may in fact be capturing sensitivity to a broader range of bodily sensations of satiation (e.g., a general feeling of being re-energized) and hunger (e.g., general weakness). Second, our data suggest that the experimental stimuli (Study 1) or the experimental procedure itself (Study 2) may have introduced bias to the behavioural indicators. For example, in Study 1 the use of water perhaps backfired, leading highly sensitive individuals to ingest larger volumes than they would normally need to perceive the onset of satiation. In contrast, in Study 2 both early and late hunger sensations reported at the onset of hunger were lower compared with the concept state of hunger, indicating a general deflation of hunger thresholds, caused either by the active attendance to bodily sensations or by a demand effect. It is also possible that the true associations between self-reports and behavioural indicators were of smaller magnitude than the ones our studies were powered to detect. Finally, several types of self-report bias (e.g., socially desirable responding, acquiescent responding), the lack of sufficient self-awareness, or self-deception, might have also influenced our results (McDonald, 2008). These biases concern both the self-reports and the behavioural indicators of this research since the latter too involve subtle elements of self-reporting.

A useful theory to interpret these result is the signal detection theory (Green and Swets, 1966). This theory holds that the detection of a signal is a decision-making process that takes place under conditions of uncertainty and depends on the intensity of the signal, the sensitivity of the individual to the signal, as well as on cognitive factors (e.g., attention, perceived consequences of signal misattribution). In our research, signal intensity was gradually increased until participants could reach their detection threshold and trait sensitivity was assumed to be reflected on this threshold. However, cognitive factors were not controlled for. It is likely, therefore, that a large amount of unexplained variance in thresholds is accounted for by variability in attention paid during the

**Table 8**
Descriptive statistics and correlations for measures of sensation and disposition to eat in Study 2.

| | M | SD | Range | Hunger threshold | SH | MAIA |
|---|---|---|---|---|---|---|
| Hunger early sensations_T0 | 57.98 | 23.12 | 3–100 | 0.02 | 0.07 | 0.001 |
| Hunger late sensations_T0 | 24.83 | 17.89 | 0–78 | −0.11 | **−0.20*** | −0.18 |
| Satiation early sensations_T0 | 44.60 | 18.98 | 2–91 | 0.11 | 0.13 | **0.22*** |
| Satiation late sensations_T0 | 12.75 | 12.68 | 0–62 | −0.12 | −0.17 | −0.15 |
| Hunger early sensations_T1 | 6.83 | 13.48 | 0–83 | **−0.20*** | 0.03 | −0.15 |
| Hunger late sensations_T1 | 9.25 | 9.24 | 0–58 | −0.15 | −0.18 | **−0.29**** |
| Satiation early sensations_T1 | 64.19 | 18.19 | 13–100 | 0.11 | −0.06 | **0.21*** |
| Satiation late sensations_T1 | 28.02 | 15.86 | 0–74 | **0.28**** | 0.01 | −0.01 |
| Hunger early sensations_Concept T2 | 68.70 | 20.89 | 16–99 | 0.03 | 0.06 | 0.11 |
| Hunger late sensations_Concept T2 | 32.47 | 20.86 | 1–89 | −0.05 | **−0.19*** | −0.15 |
| Hunger early sensations_T2 | 46.19 | 19.38 | 3–86 | **0.20*** | 0.06 | 0.17 |
| Hunger late sensations_T2 | 22.75 | 15.79 | 1–71 | 0.01 | **−0.30*** | **−0.20*** |
| Satiation early sensations_T2 | 49.09 | 16.76 | 5–80 | −0.11 | 0.10 | **0.25*** |
| Satiation late sensations_T2 | 12.56 | 10.56 | 0–60 | 0.12 | **−0.23*** | −0.18 |
| DTE sweet_T0 | 12.77 | 9.27 | 0–60 | −0.03 | −0.14 | −0.16 |
| DTE savoury_T0 | 11.63 | 7.71 | 0–40 | −0.03 | −0.09 | −0.11 |
| DTE sweet_T1 | 3.66 | 3.58 | 0–20 | **−0.20*** | −0.10 | **−0.21*** |
| DTE savoury_T1 | 2.91 | 3.47 | 0–22 | **−0.25*** | −0.01 | −0.14 |
| DTE sweet_T2 | 10.31 | 6.33 | 0–40 | 0.14 | −0.09 | **−21*** |
| DTE savoury_T2 | 9.13 | 5.85 | 0–30 | 0.16 | −0.01 | **−0.22*** |

SH: sensitivity to physiological signals of hunger, MAIA: Multidimensional Assessment of Interoceptive Awareness, DTE: disposition to eat.
* $p < .05$.
** $p < .01$.

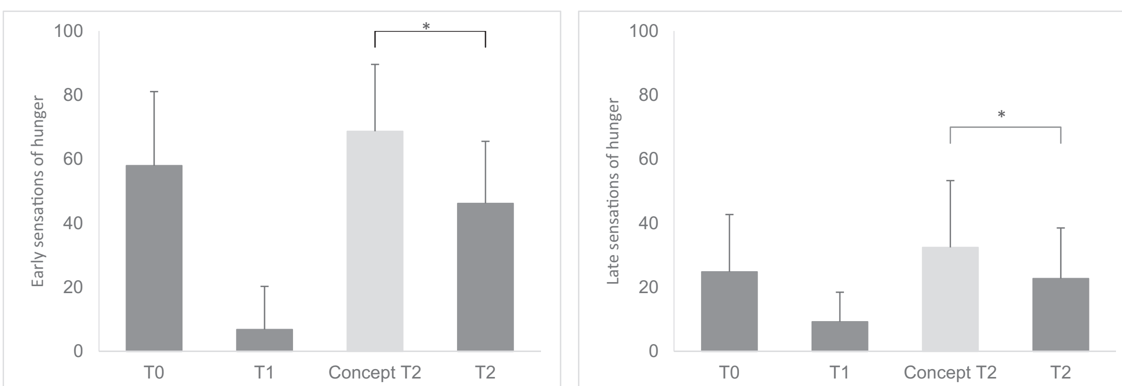


**Fig. 5.** Means and standard deviations for early and late sensations of hunger in Study 2.

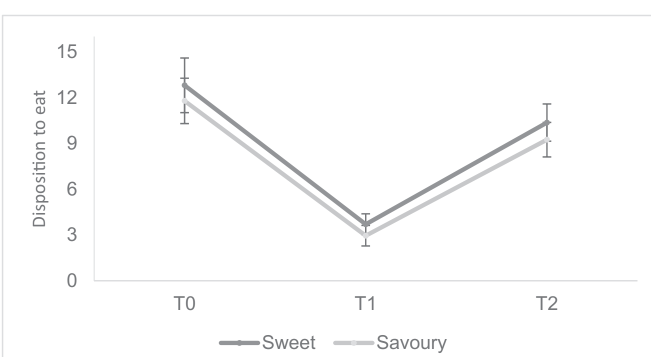


**Fig. 6.** Means (plus 95% CI) for disposition to eat chocolate chip cookies (quarters) and salty crackers (halves) in Study 2.

tasks. This is particularly relevant in Study 2, where hunger threshold was likely reported amidst a multitude of environmental distractions. Furthermore, in Study 1, some participants might have been more aversive than others to thirst, and, therefore, more strongly inclined to report the onset of satiation with delay because this would allow them to drink more water. In turn, in Study 2, some participants might have been more strongly inclined to rush the reporting of hunger onset because this would give them quicker access to food.

The lack of association between self-reported traits and incidental indicators of behaviour did not specifically concern SS and SH, but also escalated to the generic self-report of interoceptive awareness (MAIA). This phenomenon has also been observed in other studies. For example, gastric sensitivity, as measured with the WLT, was not associated neither with self-reported body awareness (Ferentzi et al., 2019) nor with self-reported private body consciousness (van Dyck et al., 2016) in studies employing healthy subjects. Similar results have been documented with measures of eating behaviour. For example, self-reported external eating was found to be positively associated with self-reported food reactivity but not associated with food intake after food cue exposure (Jansen et al., 2011). Similarly, Stice et al. (2010) found that four self-report measures of restrained eating were not correlated with an objective measure of caloric intake over a 2-week period. It is possible, therefore, that our results tap into a broader phenomenon. According to the principle of correspondence, general dispositions/traits are not always associated with specific behaviours but are more likely to associate with aggregate measures of behaviour (multi-act indices) (Ajzen, 1987). Our results confirm and further extend this assertion, as we have shown that neither competences manifest themselves in momentary challenge tasks.

Although the present studies failed to confirm the main hypotheses, several findings in this research comprise preliminary evidence for the construct validity of SS and SH. First, it was evident that trait sensitivity to bodily signals of satiation or hunger was positively associated with trait interoceptive awareness, which indicates that SS and SH tap into the broader theoretical construct they are intended to measure. Additionally, SS was associated with stronger perception of early sensations of satiation at the onset of satiation and SH was associated with weaker perception of late sensations of hunger at the onset of hunger, indicating a trend towards subtle signal perception at higher sensitivity levels. Yet, these pieces of evidence should be treated with caution because they are based on exploratory analysis of the data.

The following limitations should be acknowledged for the present research. As discussed earlier, in this research we did not control for a series of cognitive factors that could influence the satiation and hunger thresholds. Furthermore, as explained earlier, the use of water in Study 1 might have introduced bias in the satiation threshold of individuals who were particularly sensitive to early signals of satiation. In turn, in Study 2 hunger threshold was reported under ecologically valid conditions and might have been influenced by several uncontrolled factors (e.g., physical activity, environmental distractions). More importantly, in this study we did not control for rate of gastric emptying or the hormonal response to the preload. These factors could potentially explain a large amount of variation in hunger threshold.

Despite these limitations, the following theoretical and practical implications can be drawn from this research. One issue that emerges is that, with regard to eating-related interoceptive abilities, there should be caution when using self-reports to predict incidental behaviours and vice versa. In relation to that, researchers should be careful when reviewing evidence from studies that employ different methodologies of assessing interoceptive processes in the eating domain. On a more practical note, it became evident that the WLT is perhaps less ideal for studying perception of early signals of satiation because these are elicited to a lesser extent with water than with food.

More research is needed to assess the validity of SS and SH. Future studies could measure satiation threshold using a caloric load test, thereby allowing the full spectrum of physical sensations of satiation to emerge. If the caloric preload is ingested orally, cognitive factors (e.g., satiation expectations) should be controlled for. Alternatively, infusion of the caloric load directly in the stomach would surpass oral exposure and the accompanying cognitive effects. Ideally, several measurements of satiation or hunger threshold should be taken to calculate aggregate and more representative indicators of competence. Furthermore, neuroimaging studies could be employed to assess the association of trait sensitivity to bodily signals of satiation and hunger with patterns of neural activation in the brain during behavioural tasks. For example, Beaver et al. (2006) showed that trait reward sensitivity (as measured with the Behavioural Activation Scale - BAS) was highly correlated with activation in relevant brain regions as a response to images of palatable food (Beaver et al., 2006). This finding supports the construct validity of the BAS scale and elucidates a possible explanation for individual differences in reward sensitivity. Sensitivity to bodily signals of satiation and hunger may be mapped in the brain in a similar way. Finally, future studies could try to disentangle the visceral processes that generate peripheral signals of satiation and hunger (i.e., neural or hormonal signals that are transmitted to the brain) from the corresponding neural activation processes that take place in the brain. This might help understand the relative contribution of the various signalling processes in determining one's level of sensitivity and to explain more accurately individual differences in this domain. To study these associations, measures of brain activity should be complemented with physiological measures of gastric wall tension, gastric emptying rate, and hormonal response to nutrients.

## 5. Conclusions

Self-reports of trait sensitivity to physiological signals of satiation (SS) and hunger (SH) were positively associated with a generic self-report of trait interoceptive awareness (MAIA) but not with behavioural indicators of the incidental (state) ability to perceive the onset of satiation and hunger, thereby showing only preliminary evidence of construct validity. This research contributes to the scarce literature that has examined the convergence between self-reported (trait) and behavioural (state) responses in the eating domain.


## Funding statement

This research was part of the PhD project of A.P., which was funded by the Wageningen School of Social Sciences (WASS). The funding source had no involvement in the conduct of this research or in the preparation of this article.


## CRediT authorship contribution statement

**Aikaterini Palascha:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Ellen van Kleef:** Writing – review & editing, Supervision. **Emely de Vet:** Writing – review & editing, Supervision. **Hans C. M. van Trijp:** Writing – review & editing, Supervision.

## Declaration of competing interest

None.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.paid.2021.111054.

## References


Ajzen, I. (1987). Attitudes, traits, and actions: Dispositional prediction of behavior in personality and social psychology. In L. Berkowitz (Ed.), *20. Advances in experimental social psychology* (pp. 1–63). Academic Press. https://doi.org/10.1016/S0065-2601(08)60411-6.

Beaver, J. D., Lawrence, A. D., van Ditzhuijzen, J., Davis, M. H., Woods, A., & Calder, A. J. (2006). Individual Differences in Reward Drive Predict Neural Responses to Images of Food. *Journal of Neuroscience, 26*(19), 5160–5166. https://doi.org/10.1523/JNEUROSCI.0350-06.2006.

Blundell, J., de Graaf, C., Hulshof, T., Jebb, S., Livingstone, B., Lluch, A., … Westerterp, M. (2010). Appetite control: Methodological aspects of the evaluation of foods. *Obesity Reviews, 11*(3), 251–270. https://doi.org/10.1111/j.1467-789X.2010.00714.x.

Boeckxstaens, G. E., Hirsch, D. P., Van den Elzen, B. D. J., Heisterkamp, S. H., & Tytgat, G. N. J. (2001). Impaired drinking capacity in patients with functional dyspepsia: Relationship with proximal stomach function. *Gastroenterology, 121*(5), 1054–1063. https://doi.org/10.1053/gast.2001.28656.

Booth, D. A. (2009). The basics of quantitative judgment. How to rate the strength of appetite for food and its sating. *Appetite, 53*(3), 438–441. https://doi.org/10.1016/j.appet.2009.08.003.

Cebolla, A., Barrada, J. R., van Strien, T., Oliver, E., & Baños, R. (2014). Validation of the Dutch Eating Behavior Questionnaire (DEBQ) in a sample of Spanish women. *Appetite, 73*, 58–64. https://doi.org/10.1016/j.appet.2013.10.014.

Costa, R. J. S., Snipe, R. M. J., Kitic, C. M., & Gibson, P. R. (2017). Systematic review: Exercise-induced gastrointestinal syndrome-implications for health and intestinal disease. *Alimentary Pharmacology & Therapeutics, 46*(3), 246–265. https://doi.org/10.1111/apt.14157.

Ferentzi, E., Horváth, Á., & Köteles, F. (2019). Do body-related sensations make feel us better? Subjective well-being is associated only with the subjective aspect of interoception. *Psychophysiology, 56*(4), Article e13319. https://doi.org/10.1111/psyp.13319.

Goetze, O., Steingoetter, A., Menne, D., van der Voort, I. R., Kwiatek, M. A., Boesiger, P., … Schwizer, W. (2007). The effect of macronutrients on gastric volume responses and gastric emptying in humans: A magnetic resonance imaging study. *American Journal of Physiology - Gastrointestinal and Liver Physiology, 292*(1), G11–G17. https://doi.org/10.1152/ajpgi.00498.2005.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. Peninsula Publishing.

Greenleaf, E. A. (1992). Measuring extreme response style. *Public Opinion Quarterly, 56*(3), 328–351.

Higgs, S., Dolmans, D., Humphreys, G. W., & Rutters, F. (2015). Dietary self-control influences top–down guidance of attention to food cues. *Frontiers in Psychology, 6*, 427. https://doi.org/10.3389/fpsyg.2015.00427.

Jansen, A., Nederkoorn, C., Roefs, A., Bongers, P., Teugels, T., & Havermans, R. (2011). The proof of the pudding is in the eating: Is the DEBQ - external eating scale a valid measure of external eating? *International Journal of Eating Disorders, 44*(2), 164–168. https://doi.org/10.1002/eat.20799.

Marciani, L., Gowland, P. A., Spiller, R. C., Manoj, P., Moore, R. J., Young, P., & Fillery-Travis, A. J. (2001). Effect of meal viscosity and nutrients on satiety, intragastric dilution, and emptying assessed by MRI. *American Journal of Physiology - Gastrointestinal and Liver Physiology, 280*(6), G1227–G1233. https://doi.org/10.1152/ajpgi.2001.280.6.G1227.

McDonald, J. D. (2008). Measuring personality constructs: The advantages and disadvantages of self-reports, informant reports and behavioural assessments. *Enquire, 1*(1), 75–94.

Mehling, W. E., Price, C., Daubenmier, J. J., Acree, M., Bartmess, E., & Stewart, A. (2012). The multidimensional assessment of interoceptive awareness (MAIA). *PLoS One, 7*(11), Article e48230. https://doi.org/10.1371/journal.pone.0048230.

Monello, L. F., & Mayer, J. (1967). Hunger and satiety sensations in men, women, boys, and girls. *The American Journal of Clinical Nutrition, 20*(3), 253–261. https://doi.org/10.1093/ajcn/20.3.253.

Murphy, J., Brewer, R., Catmur, C., & Bird, G. (2017). Interoception and psychopathology: A developmental neuroscience perspective. *Developmental Cognitive Neuroscience, 23*, 45–56. https://doi.org/10.1016/j.dcn.2016.12.006.

Murray, M., & Vickers, Z. (2009). Consumer views of hunger and fullness. A qualitative approach. *Appetite, 53*(2), 174–182. https://doi.org/10.1016/j.appet.2009.06.003.

Palascha, A., van Kleef, E., de Vet, E., & van Trijp, H. C. M. (2020a). Internally regulated eating style: A comprehensive theoretical framework. *British Journal of Nutrition*, 1–13. https://doi.org/10.1017/S0007114520003840.

Palascha, A., van Kleef, E., de Vet, E., & van Trijp, H. C. M. (2020b). Development and validation of the Multidimensional Internally Regulated Eating Scale (MIRES). *PLoS One, 15*(10), Article e0239904. https://doi.org/10.1371/journal.pone.0239904.

Rolls, B. J., Bell, E.a., & Waugh, B.a. (2000). Increasing the volume of a food by incorporating air affects satiety in men. *The American Journal of Clinical Nutrition, 72*(2), 361–368. https://doi.org/10.1093/ajcn/72.2.361.

Sepple, C. P., & Read, N. W. (1989). Gastrointestinal correlates of the development of hunger in man. *Appetite, 13*(3), 183–191. https://doi.org/10.1016/0195-6663(89)90011-1.

Stephan, E., Pardo, J. V., Faris, P. L., Hartman, B. K., Kim, S. W., Ivanov, E. H., … Goodale, R. L. (2003). Functional neuroimaging of gastric distention. *Journal of Gastrointestinal Surgery, 7*(6), 740–749. https://doi.org/10.1016/S1091-255X(03)00071-4.

Stevenson, R. J., Mahmut, M., & Rooney, K. (2015). Individual differences in the interoceptive states of hunger, fullness and thirst. *Appetite, 95*, 44–57. https://doi.org/10.1016/j.appet.2015.06.008.

Stice, E., Sysko, R., Roberto, C. A., & Allison, S. (2010). Are dietary restraint scales valid measures of dietary restriction? Additional objective behavioral and biological data suggest not. *Appetite, 54*(2), 331–339. https://doi.org/10.1016/j.appet.2009.12.009.

Tuomisto, T., Tuomisto, M. T., Hetherington, M., & Lappalainen, R. (1998). Reasons for initiation and cessation of eating in obese men and women and the affective consequences of eating in everyday situations. *Appetite, 30*(2), 211–222. https://doi.org/10.1006/appe.1997.0142.

van Dyck, Z., Vögele, C., Blechert, J., Lutz, A. P. C., Schulz, A., & Herbert, B. M. (2016). The water load test as a measure of gastric interoception: Development of a two-stage protocol and application to a healthy female population. *PLoS One, 11*(9), Article e0163574. https://doi.org/10.1371/journal.pone.0163574.

van Strien, T., Frijters, J. E. R., Bergers, G. P. A., & Defares, P. B. (1986). The Dutch Eating Behavior Questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behavior. *International Journal of Eating Disorders, 5*(2), 295–315. https://doi.org/10.1002/1098-108X(198602)5:2<295::AID-EAT2260050209>3.0.CO;2-T.