
# Internal States and Interoception Along a Spectrum of Eating Disorder Symptomology

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Running head: INTEROCEPTION IN SUBCLINICAL EATING DISORDER SYMPTOMOLOGY

## Highlights

- At higher levels of eating concern and restraint, a college sample blinded to receiving a high or low calorie lunch shake showed difficulty in both the subjective sensing and interpretation of gastric cues, respectively.
- Self-reported happiness increased in those with elevated eating concerns after they had had a higher calorie shake relative to a lower calorie shake.
- This study provides preliminary data characterizing the influence of eating concern and restraint on affective and gastric domains of interoceptive capabilities.

# Internal States and Interoception Along a Spectrum of Eating Disorder Symptomology

Nandini Datta, PhD[a,1], Tatyana Bidopia, BS[a], Samir Datta, MS, Gauri Mittal, BS[a], Franca Alphin, MPH, RDN, LDN, CSSD, CEDRD[b], Beate M. Herbert, Ph.D[c]., Elizabeth J. Marsh, PhD[a], Gavan J. Fitzsimons, PhD[d], Timothy J Strauman, PhD[a], Nancy L. Zucker, PhD[a,e]

[a] Duke University Department of Psychology and Neuroscience, Durham NC, USA

[b] Duke University Department of Family Medicine and Community Health, Durham NC, USA

[c]University of Tuebingen, Clinical Psychology & Psychotherapy, Tuebingen, Germany

[d]Duke University Fuqua School of Business, Durham NC, USA

[e]Duke University School of Medicine, Department of Psychiatry & Behavioral Sciences Durham NC, USA

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[1]Corresponding Author: Nandini Datta

Declaration of interests: none

Email: nandinid@stanford.edu Phone: 408.705.0019

Present Address: Department of Psychiatry and Behavioral Sciences

Stanford University School of Medicine

401 Quarry Rd

Stanford CA 94305-5719

INTEROCEPTIVE PROCESSES MODERATED BY EATING PSYCHOPATHOLOGY

Abstract

**Objective.** Recent studies on atypical interoceptive capabilities have focused on clinical populations, including anorexia nervosa[1,2]. The present exploratory study aims to characterize the influence of disordered eating symptomology on interoceptive capabilities in college students, a population for which dangerous dieting behaviors may emerge. **Method.** Ninety-nine participants were randomized to consume a blinded high calorie or low calorie midday shake. Participants reported frequency of eating disorder cognitions and behaviors; indicated changes in satiety, happiness, and energy pre- and post-consumption; and guessed the calories in their shake. Outcomes (perceived satiety, changes in mood, and caloric guess) were regressed on eating disorder symptoms scores, the high/low calorie shake condition, and the interaction between these predictors. **Results.** Those randomized to receive the high calorie shake reported feeling fuller, but only when endorsing lower levels of eating concern. Those randomized to the high calorie shake reported greater post-meal happiness, but only at greater levels of eating concerns. Lastly, those with lower levels of eating restraint reported an expected positive association between level of fullness and calorie guess, but those with higher levels of eating restraint did not exhibit any relationship between perceived fullness and calorie guess. **Discussion.** Results of this exploratory suggest that irregular eating habits (e.g., not eating a sufficient amount for lunch) may have direct consequences on interoceptive capabilities. Further, these capacities may be impacted by individual differences in eating concern and restraint. Preliminary findings suggest that impairment in deciphering visceral signals may be associated with the degree of eating disorder symptomology; such impairment may occur at lower levels of symptomatology than normative data would indicate.

*Keywords:* satiety; mood; subclinical; appetite; interoception; eating concern

## Introduction

Interoception broadly refers to the perception, interpretation, and integration of internal somatic sensations, such as the physiological constituents of emotional experience, hunger, and fatigue [3]. Relative weaknesses in interoceptive capabilities (e.g., perceptions of appetitive signals of hunger and fullness) have been associated with various forms of psychopathology, including eating disorders [3-5]. Yet, investigations of the potential impact of eating disorder symptoms on interoceptive capacities is limited. For example, both intentional food restriction and preoccupation with guilt/concerns around eating may be associated with dismissing appetitive signals of hunger rather than responding with food consumption. It is conceivable that over time, ignoring hunger signals may contribute to weakened abilities to sense hunger. To date, there have been limited investigation of these associations, or, if related, the duration of eating disordered behaviors needed for such disruptions to occur.

Interoception is comprised of a variety of dimensions and associated terms and measurements[3]. For the purposes of this paper, we will be focusing on the constructs interoceptive attention and magnitude. Interoceptive attention refers to the process of observing sensations within the body whereby detection is driven by the presence or absence of interoceptive stimuli (e.g., a growling stomach to reflect hunger). This component of interoception can be measured continuously, using individual rating scales. Interoceptive magnitude is a less commonly used term in the literature; it has been described by Khalsa et al., (2018) to reflect to one's perceived intensity of a specific interoceptive signal (for example, *how* full, or *how* fatigued someone feels). This component of interoception may also be measured continuously, using individual rating scales. Current literature on interoception most often

assesses interoceptive accuracy, or one's objective ability to accurately sense internal body sensations, frequently measured by behavioral tasks such as heart beat detection.

There has been an increased emphasis on the importance of investigating interoceptive capacities in response to a provocation rather than at rest: what may be essential about interoceptive capacities is the ability to assess change. One such provocation that is particularly relevant for those with eating disorders is the consumption of food. Investigations of the effects of meal consumption on subsequent perceptions of satiety and mood in healthy participants is thus far limited but informative. Relative to those skipping meals or eating at irregular intervals, individuals who consume meals more regularly have reported normative increases in feelings of satiety and fullness as well as improved mood and energy levels [6-8]. In a sample of sixteen adults randomized to a no-breakfast versus low or high glycemic index breakfast, those randomized to the breakfast condition reported increased happiness, less dysphoria, and less fatigue[8]. This finding was replicated in children who were randomized to a breakfast or no-breakfast condition in a crossover design[6]. Jointly, findings suggest meal consumption contributes to improved affect, energy level, and satiety across development.

One symptom of individuals with anorexia nervosa (AN) is sustained food restriction; thus, findings of relative weaknesses or strengths in interoceptive capacities in individuals with AN may be informative for formulating hypotheses on the sustained effects of skipping meals on somatic sensing. People with AN report increased post-prandial feelings of fullness relative to healthy controls [9-11]. Critically, post-prandial gastric emptying is slower in individuals with AN, and this biological factor may influence subjective sensing. However, even when controlling for actual gastric content, self-reported sensations of satiety in individuals with AN was greater than in healthy controls [9]. Individuals with AN have reported experiencing less hunger before eating

relative to controls, suggesting a lack of expected interoceptive signaling [12,13]. In interoceptive tasks assessing cardiac accuracy, studies of people with AN have yielded inconsistent results: while some studies have provided evidence supporting poorer interoceptive accuracy in people with AN [14,15], other more recent data reflect no differences in interoceptive accuracy between people with AN and healthy controls [16-19]. Additional clarification is needed to gather putative support for altered interoceptive processes in AN.

Investigations of interoceptive impairment have been predominately explored in actively ill populations, as described above. However, it is interesting to consider the learning that occurs when individuals first initiate unhealthy eating practices or have unhealthy preoccupations around eating. In somewhat of a causality dilemma, it is unclear whether one's prior lack of sensitivity to interoceptive cues may predispose them to the development of an eating disorder, or whether eating disorder symptomology leads to dysregulation of interoceptive cues to maintain the disorder. If the latter, the degree of eating disorder symptoms needed for maladaptive conditioning to occur is unknown; those beginning to demonstrate disordered eating psychopathology may also experience altered interoceptive capabilities, specifically around processing cues of hunger and fullness, yielding an important group that may benefit from preventative interventions. The present pilot study administered blinded high/low calorie shakes to allow for a controlled observation of how varying report of eating disorder symptoms are associated with perceptions of hunger/satiety using visual analog scales[20,21]. In exploratory analyses, measurements of interoceptive capabilities provided preliminary evidence around the impact of eating disorder symptoms on assessment of interoception capabilities. Results are meant to be hypothesis generating in lieu of the preliminary nature of the study.

Informed by current research, we predict that at lower levels of eating disorder symptomology, participants randomized to have a high calorie midday shake will report **increases in interoceptive magnitude**: e.g., higher scores on change in fatigue and satiety, relative to those receiving the low calorie lunch shake. In addition, we hypothesize that individuals lower in eating disorder symptomatology will experience increases in positive mood (happiness) following a high-calorie shake. As self-reported eating disordered behaviors increase, we expect participants will report **decreases in interoceptive magnitude**: e.g., lower scores on change in fatigue, and no difference in change of fullness. We further hypothesize that individuals with greater eating disorder symptoms will report decreases in positive mood (i.e., happiness) following a meal. These hypotheses are exploratory since prior literature have not studied changes in interoception capabilities in individuals with subclinical eating disorder symptomology.

To assess the impact of the meal manipulation on **interoceptive attention,** participants guessed the calorie content in their shake two hours after consumption. Of note, participants were asked to guess the calorie content of the shake predominately to assess whether or not deception was successfully implemented. Given the relevance of this data to the current exploratory hypotheses, analyses incorporated calorie guess data to assess possible changes in interoceptive attention, a term that was applied retroactively to capture differences in assessment of calorie guess. We anticipated that on the lower end of eating disorder symptomology, participants' guess for the caloric load of their shake will be positively associated with self-reported levels of fullness, indicating an understandable relationship between one's assessment of their own level of satiety and subsequent guesses of how much they might have consumed.

Contrarily, we expected that at higher levels of eating disorder symptomology, the relationship between fullness and perception of calories consumed would be attenuated.

Perception is central to the construct of interoception, and with that, any biases or subjective states that could impact that perception are important to consider in interpreting interoceptive capacities regardless of an individual's state of health or diagnosis. As such, classic laboratory preload studies such as those by Herman and Polivy (1983) are interesting to consider in terms of what they can tell us about interoceptive capabilities when deception is employed. The essence of such manipulations is informing a participant that an interoceptive load (e.g., the energy content of a shake) is different than it is, and seeing how that knowledge, versus the actual interoceptive experience, differentially impact behavior. Likewise, the present study assessed interoceptive attention and magnitude while participants were blinded to their caloric load and the study purpose. Participants were told that everyone would receive a "meal replacement" shake, when, in fact, half were blindly randomized to a shake of limited caloric content. By using incomplete disclosure, the present study aims to assess unbiased interpretations of interoception after implementation of high calorie/low calorie manipulation.

## 2 Methods

Participants were recruited for a study that employed incomplete disclosure in advertising the study purpose. The study was framed as an investigation of the effectiveness of a meal replacement shake on food preoccupation when in fact, participants were blindly randomized to receive a high calorie shake, or a low calorie shake (See Table 1 for an outline of what the study visit entailed). All study procedures were approved by the Duke University Campus Institutional Review Board (IRB), protocol number C0873. Caloric load for each shake was discussed with a registered dietician and head of the university nutrition services (Franca Alphin, MPH, RDN, LDN, CSSD, CEDRD. All shakes were prepared from scratch by the Refrectory Café, a supplier of Duke University nutrition options. Participants were told during the phone screen (and reminded via email the day before the visit) to not eat any food or have any caffeine 2 hours prior to their appointment time. Participants did not receive any additional information regarding shake composition.

1

2 Table I: Participant Flow

| Time | Task | Measure/Assessment | Variables Assessed |
|---|---|---|---|
| 11:00 AM | Arrive | - | |
| | Affect/Satiety/Energy Questionnaire | Three 1-item self-report questions | Baseline affect/satiety/energy level |
| 11:10 AM | Consume Shake | - | |
| | Demographic Questionnaire | Qualtrics force-choice questions | Age, Sex, BMI, Race, Class status, Major, GPA, Eating disorder history/current diagnosis |
| 11:30 AM* | 2 hour wait period | - | |
| 1:30 PM | Affect/Satiety/Energy Questionnaire | Three 1-item self-report questions | Baseline affect/satiety/energy level |
| 1:40 PM* | Neuropsychological Battery† | Wechsler Memory Scale (WMS) Spatial Addition, WMS Verbal Paired Associates Parts 1 & 2, Color Word Interference, Trail Making Test, Continuous Performance Task | Short-term, long-term, and working memory, processing speed, set shifting, and attention |
| 3:00 PM | Post-test Questionnaire | Eating Disorder Examination Questionnaire, Manipulation Check | Eating disorder symptomology & manipulation |

3 †The results from these outcome measures are presently undergoing revise and resubmission

4 procedures at Eating Behaviors.

### 2.1 Eligibility Criteria and Randomization

Participants were eligible if they were between 18 –25 years old with no dietary restrictions that interfered with shake consumption. Participants could choose to participate for credit or monetary compensation (twenty dollars/hour).

Study participants were (unbeknownst to them) randomized into one of two study conditions after successful completion of the telephone screen. Condition placement was determined by using www.random.org, a random number generating site. Minimum and maximum numbers (0 and 1) were specified, where a generation of 0 indicated placement into the high calorie condition, and a generation of 1 indicated placement into the low calorie condition. Research personnel were informed of the randomization prior to running study participants.

### 2.2 Procedures

#### 2.2.1 High calorie condition: 638-calorie shake

In this condition, participants consumed a pink 638-calorie shake per 16-ounce serving. The ingredients were: Strawberries, coconut milk, banana, non-fat Greek yogurt, vanilla extract, and hemp protein powder. This shake had 35% of calories from carbohydrates, 6% from protein, and 59% from fat.

#### 2.2.2 Low calorie condition: 48-calorie shake

In this condition, participants consumed a green 48-calorie shake per 16-ounce serving. The ingredients were: Spinach, water, xanthan gum, ground cinnamon, and natural peanut butter powder (allergies and dietary restrictions were assessed during screening). This shake had 50% of calories from carbohydrates, 33% from protein, and 17% from fat.

While the two shakes administered have different sensory properties, the use of xanthan gum helped create similar consistency and texture between both shakes, despite differences in hue and caloric properties. The palatability differences between shakes can be found below.

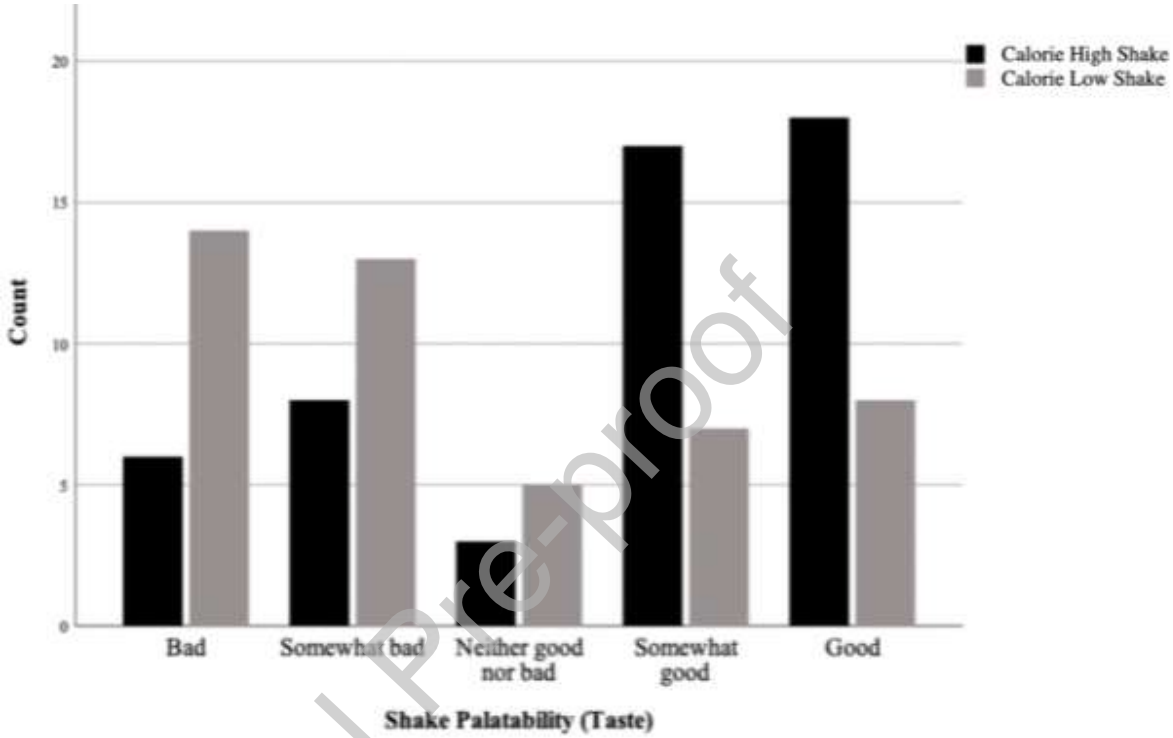


**Figure 1. Palatability Differences by Condition**

## 2.3 Study Measures

### 2.3.1 Perception of Calories

Item 4 of the manipulation check (see 2.3.7 Manipulation Check) (i.e., "Guess to the best of your ability how many calories was in the shake you consumed earlier (0-800)") was used to assess individual differences in the relationship between self-assessment of hunger/fullness and how many calories participants believed they had consumed. See section 3.5 Calorie Guess for additional information, and section 4.4 Limitations for comments addressing the use of this construct to assess interoceptive attention.

### 2.3.2 Satiety scale

A hunger/satiety scale was used to assess level of hunger and fullness prior to and after shake consumption. This 1-item slider-scale asked participants to "rate their hunger/satiety level by using the scale from 0 - 10." This scale was anchored at 0 = starving and 10 = uncomfortably full. This scale was administered twice: once immediately before shake consumption, and again after a two-hour wait period. This self-report slider scale allows participants to assess and rate their subjective perception and magnitude of how hungry or full they feel.

### 2.3.3 Mood and energy items

The assessment of affect and fatigue used a 0-10 Likert scale to assess participant's self-reported levels of happiness and tiredness prior to and after consumption of the shake. These two scales were anchored at 0 = "not at all tired or happy (respectively)", and 10 = "extremely tired or happy". These two scales were administered twice once immediately before shake consumption, and again after a two-hour wait period. These self-report items allow participants to assess and rate their subjective perception and magnitude of how happy or energetic they feel.

1

2 **2.3.4 Eating Disorders Examination-Questionnaire[22]**

3 The EDE-Q is a 32-item self-report questionnaire assessing eating disorder
4 symptomatology. The global EDE-Q score is comprised of 23 questions assessing the frequency
5 of eating disordered behavior over the past 28 days. Each item is rated on a 7-point forced
6 choice scale. The EDE-Q is broken down into a four-factor structure: Eating restraint (5
7 questions), eating concern (5 questions), shape concern (8 questions), and weight concern (5
8 questions). Global scores are generated by averaging the four factor scores. Scores greater than
9 *(M* = 4.02, *SD* =.28) are considered to be clinically significant[23,24]. In our sample, internal
10 consistency for the global score was (α = .92), eating restraint (α = .75), eating concern (α = .62),
11 shape concern (α =. 90), and weight concern (α = .86). For the purposes of this exploratory study,
12 continuous EDE-Q factor scores were entered in multiple regression models separately.

13 **2.3.7 Manipulation check**

14 Participants reported their impression of the study (to check for efficacy of blinding).
15 They were asked (1) whether any questions were answered randomly (yes/no); (2) recruitment
16 method used (free text entry); (3) what they thought the study's purpose was (free text entry); (4)
17 how many calories their shake was (0 – 800); (5) palatability of the shake (using a 1-5 Likert
18 Scale); (6) whether they would use their shake as a meal replacement (yes/no); and, (7) to
19 explain why they would not, if they had selected no to the previous question (free text entry).
20 Item 4 was used to assess interoceptive attention in the context of participant's self-reported
21 satiety.

22

1

2 **2.3.8 Cognitive measures**

3 The Wechsler Memory Scale spatial addition and verbal paired associates, Conner's
4 Continuous Performance Test, Delis-Kaplan Executive Function System color word interference
5 and trail making test were used to assess cognitive domains. The results from these outcome
6 measures are presently undergoing revise and resubmission procedures at Eating Behaviors.

7 **2.4 Data Analytic Strategy**

8 Data met assumptions of normality and no outliers were identified in the dataset using
9 visual examination of skewness and kurtosis and assessment of scatterplots to confirm the use of
10 a GLM model. The pattern of missing data were assessed prior to analyses and identified to be
11 missing completely at random (MCAR), by Little's MCAR test. Thus, listwise deletion was used
12 as the missing data approach used for scoring questionnaires and subsequent analyses.

13 **2.4.1 Moderation for interoceptive variables/condition**

14 Multiple linear regressions were conducted to assess whether the degree of eating
15 disordered behaviors moderated the relationship between interoceptive outcome variables and
16 the shake manipulation. The EDE-Q outlines a four-factor structure (eating restraint, shape
17 concern, weight concern, and eating concern). The reported analyses were exploratory in nature
18 since prior literature have not consistently reported associations between specific eating
19 behaviors and differences in interoceptive capabilities. Thus, each EDE-Q factor score was
20 entered in the model separately to assess distinct contributions to the relationship between
21 interoceptive outcome variables and the shake manipulation. The dependent variable in each
22 regression was entered as interoceptive domains assessed (change in satiety, happiness, and
23 tiredness), and the predictor variables were entered as condition, each EDE-subscale score, and

the interaction between each EDE-Q subscale score and condition type. Significant findings are reported both by group and separately for males and females, given the difference in sex in our sample, despite use of randomization.

Similarly, multiple linear regression analyses were used to assess whether the degree of eating disordered behaviors moderated the relationship between calorie guess and feelings of hunger/fullness when controlling for condition. The dependent variable was calorie guess, and the predictor variables were change in satiety, each EDE-subscale score, and the interaction between each EDE-Q subscale score and change in satiety.

For the above analyses, the Johnson-Neyman Floodlight technique was used to highlight the entire range of EDE-Q scores where the simple effect is significant; the border between these regions is known as the "Johnson-Neyman point"[25]. Values on one side of this point yield significant differences between groups, values on the other side of the point do not. This statistical technique highlights the range of values on the continuous predictor for which group differences are statistically significant. All analyses were conducted using SPSS® version 25, ($\alpha = 0.05$). Figures were produced using JMP® version 13. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Despite the use of random assignment, there was an observed difference in sex distribution between groups, although this difference was not significant ($p = .05$). Since such differences between group may impact both EDE-Q scores and interoceptive measures, results are reported both by sex and for the total group in which sex was entered as a covariate in the model. Similarly, as shown in Figure 1, participants reported that the palatability (taste of their shake) differed significantly by condition ($F(1, 97) = 12.23$, $p = .001$) with a medium effect size (Cohen's $d = .7$). Thus, palatability was also entered as a covariate in all the analyses reported.

Lastly, to account for variability in what participants may have eaten the two hours prior to their study appointment, baseline levels of satiety were assessed prior to analyses. Differences in baseline satiety were not statistically significant between groups ($p = .40$).

All EDE-Q scores were examined on a continuous scale. No mathematical corrections were made for multiple comparisons[26]. Given that these reported data are from a pilot study, interpretations of the results should be considered liberally and in light of the exploratory nature of this project. Full results of the regression models can be found in Supplementary Table 1.

## 3. Results

### 3.1 Participants Demographics

Sample characteristics of the present study ($n = 99$; 52 in the high calorie condition, 47 in the low calorie condition) are presented below.

1

2 Table 2: Sample Demographics[†]

| | High Calorie (n=52) | Low Calorie (n=47) |
|---|---|---|
| Variable: Mean (Standard Deviation) | | |
| Age | 19.60 (1.52) | 19.78 (1.61) |
| BMI | 23.04 (2.82) | 23.00(3.74) |
| Sex: # (%) | | |
| Male | 13 (13.13%) | 20 (20.2%) |
| Female | 39 (39.39%) | 27 (27.27%) |
| Race: # (%) | | |
| Caucasian | 24 (24.24%) | 21 (21.21%) |
| African American | 7 (7.07%) | 5 (5.05%) |
| Asian/Pacific Islander | 17 (17.17%) | 15 (15.15%) |
| Hispanic/Latino | 1 (1.01%) | 4 (4.04%) |
| Native American | 0 (0%) | 1 (1.01%) |
| Multiracial | 1 (1.01%) | 0 (0%) |
| Other | 2 (2.02%) | 1 (1.01%) |
| EDE-Q: Mean (Standard Deviation) | | |
| Weight | 2.68 (1.58) | 2.14 (1.95) |
| Shape | 2.89 (1.54) | 2.63 (1.38) |
| Eating Concern | 1.56 (.68) | 1.47 (.63) |
| Restraint | 2.33 (1.34) | 2.08 (1.16) |
| Global | 2.35 (1.13) | 2.08 (1.00) |

3 [†]None of the variables reported differed significantly between conditions, ($p > .05$) in all cases.

4

### 3.2 Manipulation Check

Analysis of free text entry responses from the manipulation check revealed that when asked about the study's purpose at the end of testing, 80 (80.81%) participants reported reasons consistent with the purported intention of the study ("To test the effectiveness of a meal replacement shake"); 12 (12.12%) incorporated the involvement of eating disorders into the study purpose ("To evaluate anorexia/mental health associated with eating"); and 7 (7.07%) reported being unsure about the study purpose. These data of study intent did not interact with any of the findings reported below.

Participants' estimated calorie content differed significantly by high calorie condition ($F(1, 97) = 5.64$, $p < .05$) with a small effect size (Cohen's $d = .27$, $r = .13$). Individuals in the high calorie condition estimated their shake to be ($M = 354$, $SD = 140$) calories, while individuals in the low calorie condition estimated their shake to be ($M = 315$, $SD = 139$) calories. Despite this approximately 40-calorie difference and relatively large standard deviations, individuals in the low calorie condition believed their shake was 267 calories more than its actual value (overestimating) and individuals in the high calorie condition believed their shake was 284 calories less than its actual value (underestimating). When broken down by sex, males in the high calorie condition estimated their shake to be ($M = 415$, $SD = 121$) calories, while males in the low calorie condition estimated their shake to be ($M = 305$, $SD = 128$) calories, amounting to an approximate 110 calorie difference between shakes. Females in the high calorie condition estimated their shake to be ($M = 381$ $SD = 139$) calories, while females in the low calorie condition estimated their shake to be ($M = 325$, $SD = 148$) calories, amounting to an approximate 56 calorie difference between shakes. Given this discrepancy in male/female report of calorie

guess, analyses including calorie guess as a predictor variable are reported by sex and with sex entered in the model as a covariate.

While the color of the drink (green versus pink) may have undue influences on participant perceptions of the "healthiness" or caloric content of the shake, it appears that given the data reported above in conjunction with participant's beliefs on the study purpose, incomplete disclosure was successful. Notwithstanding, this is discussed further in the limitations section.

**3.3 Satiety (Group)**

Regressing change in satiety on the predictor variables (EDE-Q 4 factor scores, condition) revealed a significant interaction between EDE-Q eating concern and condition, ($F$ (3, 94) = 2.22, $p$ =.02), with a large effect size, Cohen's $f^2$ = .47 (Table 3, Figure 2) while controlling for palatability and sex. To decompose this interaction, the Johnson-Neyman Floodlight technique revealed that individuals in the high calorie shake condition reported feeling fuller relative to individuals in the low calorie shake condition, but this only held for individuals with EDE-Q eating concern scores of less than or equal to 1.46. To clarify, EDE-Q eating concern scores ≥ 1.5[1] reflects endorsement of eating concern on at least 1 – 5 days over the past month (4% - 18%), including guilt around eating and worry about eating in public at least "slightly." 64.29% of the sample had EDE-Q eating concern scores below the cut-off, and 35.71% of the sample had scores above this cut-off.

[1] The EDE-Q is typically scored on a 0-6 scale, however, the scoring program applied in this manuscript employed 1-7, thus the interpretation of a 2 (a 1 in the typical version) is 0-5 days.

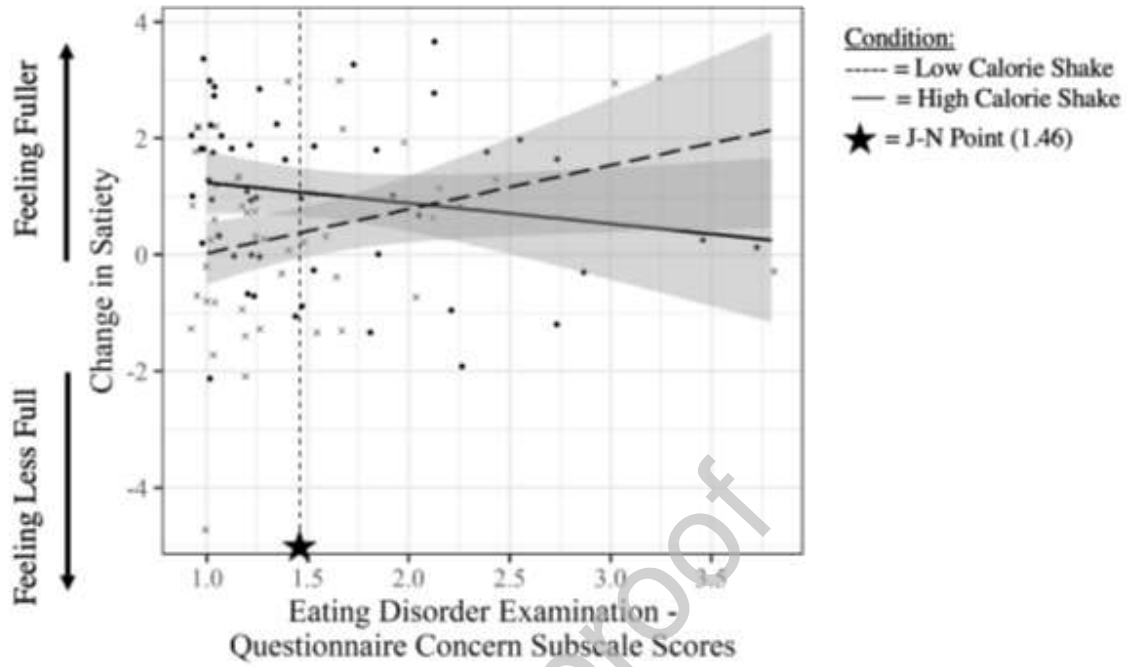


**Figure 2. Group Satiety Interaction Plot**

The vertical dashed line indicates the region of Eating Concern scores beyond which the expected values of change in satiety are no longer significant. In other words, there was a significant positive effect of self-reported fullness and low/high calorie shake for any participant with eating concern scores less than 1.46, but not for any participant with scores higher than 1.46

***3.3.1 Males***

For males, regressing change in satiety on condition and eating concern revealed the following: F (4, 29) = 2.02, p = .08, with a medium-large effect size, Cohen's $f^2$ = .3 while controlling for palatability.

***3.3.2 Females***

For females, regressing change in satiety on condition and eating concern revealed the following: F (4, 62) = .9 p = .1, with a small-medium effect size, Cohen's $f^2$ = .05 while controlling for palatability.

**3.4 Mood (Group)**

Regressing change in happiness on the predictor variables (EDE-Q 4 factor scores, condition) revealed a significant interaction term for EDE-Q eating concern and condition, ($F$ (3, 92) = 2.34, $p$ =.01), with a large effect size, Cohen's $f^2$ = .38 (Table 3, Figure 3) while controlling for palatability and sex. The Johnson-Neyman "Floodlight" technique revealed that individuals in the high calorie shake condition felt significantly happier two hours after consuming their shake relative to when they arrived for the study compared to the low calorie shake group, but only at greater levels of eating concern; specifically, when EDE-Q eating concern scores were greater than or equal to 2.10. In other words, as eating concern increased, consumption of a higher calorie shake appeared to positively impact subjective levels of happiness - even after a two hour wait - relative to those who received a low calorie shake.

81.25% of the sample had EDE-Q eating concern scores below the cut-off, and 18.75% of the sample had scores above this cut-off.

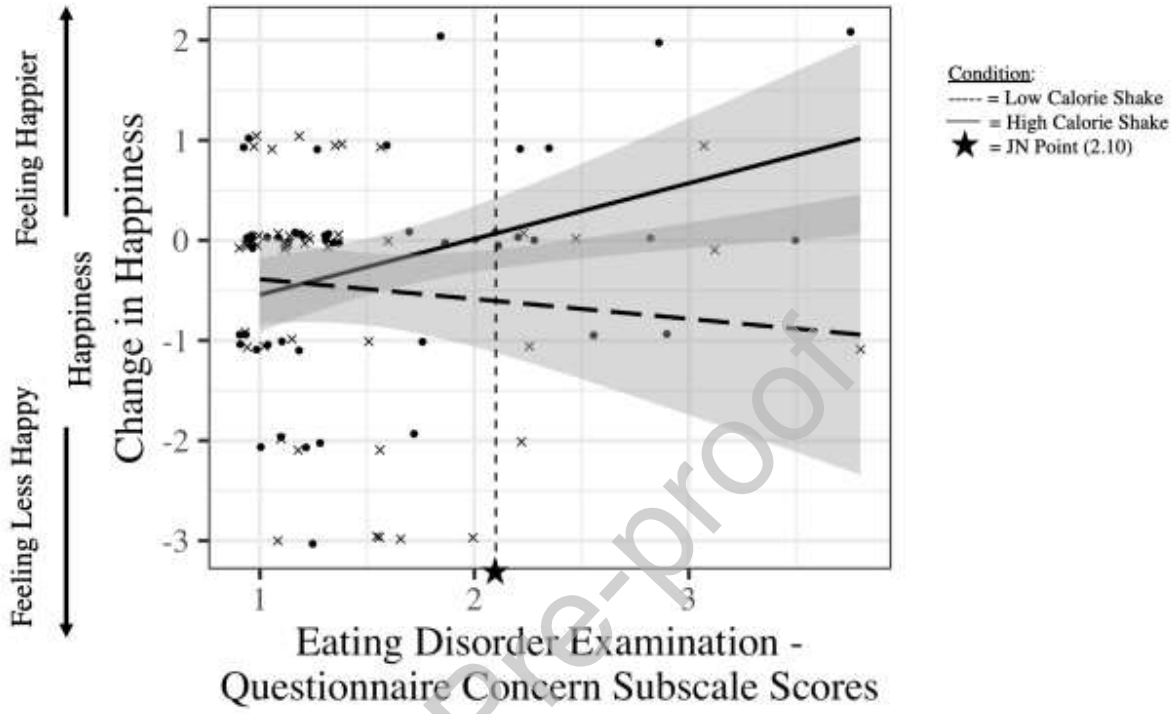


**Figure 3. Group Happiness Interaction Plot**

The vertical dashed line indicates the region of Eating Concern scores beyond which the expected values of change in happiness are no longer significant. In other words, there was a significant positive effect of self-reported happiness and low/high calorie shake for any participant with eating concern scores greater than 2.10, but not for any participant with scores lower than 2.10

***3.4.1 Males***

For males (n = 33), regressing change in happiness on condition and eating concern revealed the following: F (4, 29) = 1.7, p = .1, with a medium-large effect size, Cohen's $f^2$ = .3 while controlling for palatability.

***3.4.2 Females***

For females (n = 66), regressing change in happiness on condition and eating concern revealed: F (4, 62) = 2.04, p = .04, with a medium effect size, Cohen's $f^2$ = .14 while controlling for palatability, Figure 4. The Johnson-Neyman "Floodlight" technique revealed that females in the high calorie shake condition felt significantly happier two hours after consuming their shake relative to when they arrived for the study compared to the low calorie shake female participants, but only at greater levels of eating concern; specifically, when EDE-Q eating concern scores were greater than or equal to 2. In other words, as eating concern increased, consumption of a higher calorie shake appeared to positively impact subjective levels of happiness - even after a two hour wait - relative to those who received a low calorie shake. 79.69% of the females in the sample had EDE-Q eating concern scores below the cut-off, and 20.31% of females in the

sample had scores above this cut-off.

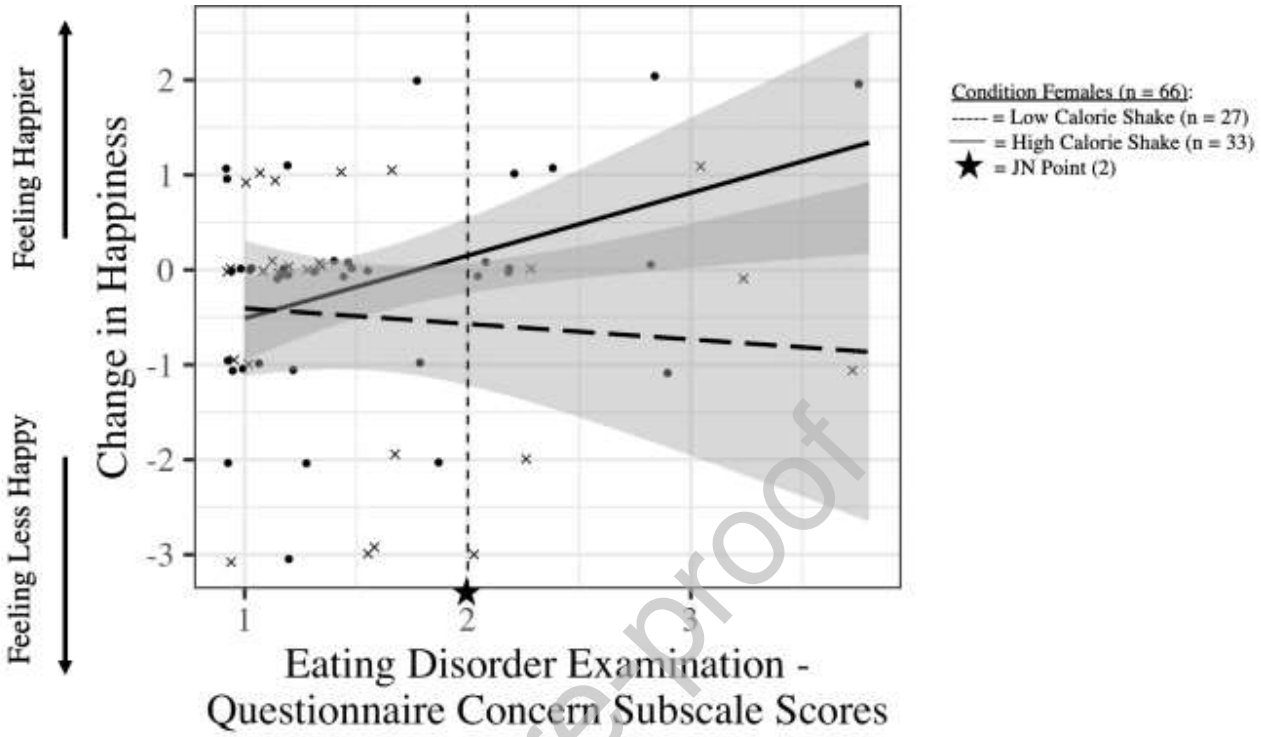


**Figure 4. Female Happiness Interaction Plot**

The vertical dashed line indicates the region of Eating Concern scores beyond which the expected values of change in happiness are no longer significant for females in our sample. In other words, there was a significant positive effect of self-reported happiness and low/high calorie shake for any female with eating concern scores greater than 2 but not for any participant with scores lower than 2.

**3.5 Energy**

There were no significant interactions between condition and the EDE-Q 4 factor scores for change in tiredness (p = .16) at the group level and by sex (Supplementary Table 1).

**3.6 Calorie Guess**

Regressing calorie guess (how many calories people guessed was in their drink) on the predictor variables (EDE-Q 4 factor scores, change in satiety) revealed a significant interaction term for participants' change in satiety and level of EDE-Q eating restraint factor scores (Table 3, Figure 5). Examination of this interaction effect while controlling for condition, palatability and sex revealed that at lower levels of eating restraint, there was a significant positive relationship between changes in satiety and calorie guess ($F$ (4, 91) = 2.40, $p$ = .01), with a large effect size, Cohen's $f^2$ = .38). The Johnson-Neyman procedure was used to determine the "cut-off" for eating restraint at which this relationship was no longer significantly different from 0, which was found to be 1.42 (Spiller, Fitzsimons, Lynch, & McClelland, 2013). Thus, when individuals with lower levels of eating restraint (EDE-Q restraint scores<1.42, 36% of the sample) reported feeling fuller, they guessed their shake had more calories. For individuals with higher levels of eating restraint (64% of the sample had eating restraint scores>1.42), there was no significant relationship between subjective levels of satiety and calorie guess.

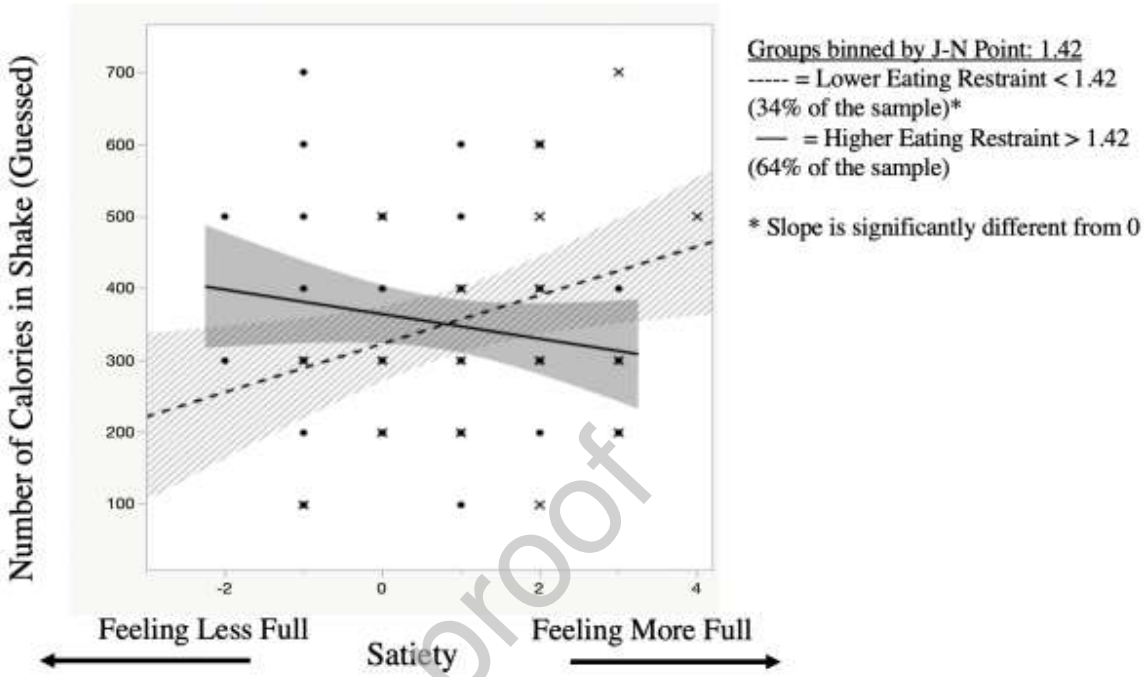


**Figure 5. Group Calorie Guess Interaction Plot**

Participants were binned by their level of EDE-Q Restraint subscale scores according to the Johnson-Neyman cut off for data visualization purposes. The group cut-off was 1.42, beyond which the expected values of calorie guess were no longer significant. Participants with scores below 1.42 (36% of the sample) had a positive relationship between their change of satiety and the numbers of calories they guessed was in their shake (positive regression slope on the dotted line). Participants with scores above 1.42 (64% of the sample) had no relationship between change in satiety and calories guessed.

### *3.6.1 Males*

For males, regressing calorie guess (how many calories people guessed was in their drink) on the predictor variables (eating restraint and change in satiety) revealed a significant interaction term: $F(5, 28) = 3.6$, $p = .02$, with a large effect size Cohen's $f^2 = .7$, controlling for shake palatability and condition, Figure 6. The Johnson-Neyman procedure was used to determine the "cut off" for eating restraint at which this relationship was no longer significantly different from zero, which was found to be 1.38 (Spiller, Fitzsimons, Lynch, & McClelland, 2013). Thus, when male participants with lower levels of eating restraint (EDE-Q restraint scores<1.38, 34% of males in the sample) reported feeling fuller, they guessed their shake had more calories. For male participants with higher levels of eating restraint (66% of males in the sample had EDE-Q restraint scores>1.38), there was no significant relationship between subjective levels of satiety and calorie guess.

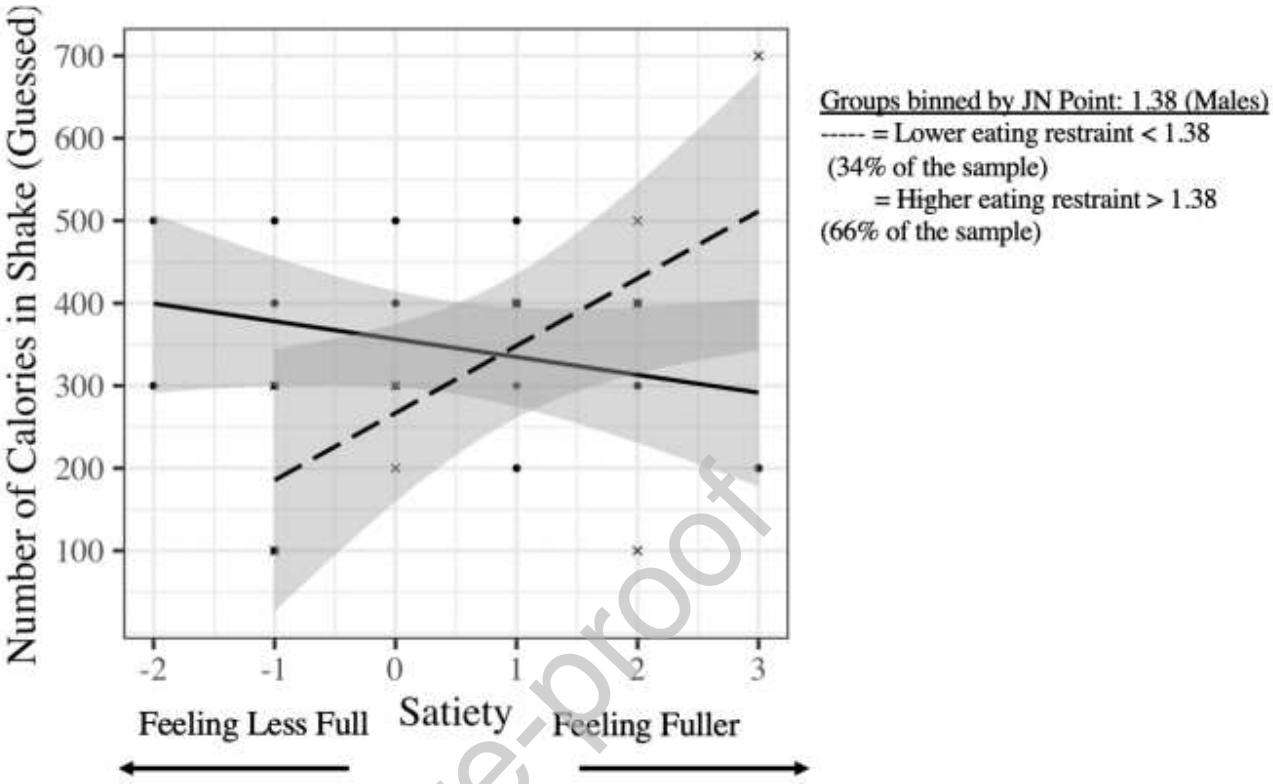


**Figure 6. Male Calorie Guess Interaction Plot**

Male participants were binned by their level of EDE-Q Restraint subscale scores according to the Johnson-Neyman cut off for data visualization purposes. The group cut-off was 1.38, beyond which the expected values of calorie guess were no longer significant. Male participants with scores below 1.38 (34% of the sample) had a positive relationship between their change of satiety and the numbers of calories they guessed was in their shake (positive regression slope on the dotted line). Participants with scores above 1.38 (66% of the sample) had no relationship between change in satiety and calories guessed.

### *3.6.1 Females*

For females, regressing calorie guess (how many calories people guessed was in their drink) on the predictor variables (eating restraint and change in satiety) revealed: $F(5, 61) = .09$, $p = .2$, with a small-medium effect size Cohen's $f^2 = .1$, controlling for shake palatability and condition.

Table 3. Significant Interactions

| | *F(df)* | $R^2$ | *Adjusted* $R^2$ | *p*(interaction) | Cohens *f* | Johnson Neyman |
|---|---|---|---|---|---|---|
| Satiety† (group) | 3.67(3, 94) | .32 | .08 | .02 | .47 | 1.46 |
| Happiness† (group) | 2.61(3, 92) | .28 | .05 | .03 | .38 | 2.10 |
| Happiness (females) | 2.03 (4, 62) | .12 | .06 | .04 | .10 | 2.00 |
| Calorie Guess‡ (group) | 2.54 (4, 91) | .28 | .05 | .01 | .38 | 1.42 |
| Calorie Guess (males) | 2.59 (5, 28) | .33 | .20 | .02 | .70 | 1.38 |

†Regressing change in happiness and change in satiety on predictor variables (EDE-Q factor scores and condition) revealed significant interaction terms for EDE-Q eating concern and condition. Change scores were scores were calculated by subtracting baseline (pre) ratings from post-shake consumption ratings. Higher scores indicate feeling fuller/happier, while lower scores indicate feeling hungrier/less happy.

‡Regressing calorie guess on predictor variables (EDE-Q subscale scores and change in satiety) revealed the following significant interaction term for change in satiety and EDE-Q Restraint.

## 4 Discussion

The goals of this paper included the use of a loading protocol, blinding participants to have a low or high calorie shake to assess subsequent impacts on interoceptive attention and magnitude at different levels of disordered eating behavior. The current findings suggest that as eating disorder symptoms increase, the relationship between somatic signals and the interpretation of these signals may become altered. As many formulations of eating disorders emphasize rigid rules that guide behaviors such as eating, it would not be surprising that as symptoms worsen or become prolonged, the connection between somatic signals, interpretation, and adaptive actions becomes increasingly disconnected. The primary take home from the current study is that disruption in these associations may emerge at lower levels of eating disorder symptoms than those seen in clinical samples. Targeted prevention efforts that focus on improving somatic sensing and interpretation may be an effective component of intervention strategies.

### 4.1 Satiety

Consistent with expectations, changes in fullness were greater in individuals who consumed the higher calorie shake, relative to those who received the low calorie shake. Aligned with our hypothesis, the difference in satiety between conditions decreased with increasing disordered eating cognitions, specifically, eating concern. Greater eating concern scores indicate a more frequent preoccupation with various aspects of eating, including concern about eating with others, concern over the caloric content of food, fear of losing control when eating, and significant guilt about eating. It is possible that people increasingly preoccupied with eating concerns may be eating in response to social expectations or dietary rules and may not be relying on signals of hunger and satiety to guide eating decisions. In individuals with lower levels of

eating concern, eating may more often occur as a response to biological hunger/fullness cues rather than cognitive dictates: for example, changes in blood sugar or related metabolic changes. In contrast, individuals who spend more time preoccupied by eating concerns may have difficulty sensing these biological signals[2,9,27].

Eating disorder symptomology has been found to be associated with poorer interoceptive capabilities and abnormal gastric sensitivity; indeed, our findings suggest that even at sub-clinical levels, eating concern may dampen the ability to discern hunger and fullness, an putative index of deficits in perceiving interoceptive magnitude[28]. Longitudinal studies have found that interoceptive disruption predicts vulnerability to the development of an eating disorder[29,30]. The present study provides preliminary findings that may be particularly important for college students, a population for whom information about eating choices might encourage the development of healthy eating habits[20,21,31].

**4.2 Mood**

In contrast to our hypothesis, happiness increased in individuals with elevated eating concerns who were randomized to receive the higher calorie shake - but only when eating concern scores were above 2.10. Thus, for participants with higher levels of eating concern, having a high calorie shake appeared to boost levels of happiness, after a two-hour wait. For those reporting lower levels of eating concern, having a low calorie midday shake did not differentially impact mood.

Implications of this finding suggest that those endorsing greater levels of eating concern may be susceptible to larger fluctuations in subjective levels of happiness based on intake. In a prior study using a national quota sampling procedure, Reba-Harrelson and colleagues[32] found that in 4,023 women, 74.5% reported that their concerns about the impact of eating reduced

subjective levels of happiness, irrespective of eating habits. However, levels of happiness were also found to be positively associated with the number of meals eaten daily, in a sample of 541 college students[33]. Taken together, these findings suggest that while increased concern around eating may negatively impact happiness, regular eating habits work to improve happiness. An alternative but complementary hypothesis is that when individuals are cognitively restrained or imposing dietary regulations that increase guilt around eating (as indexed by the eating concern scale), food becomes more valued and thus more tied to fluctuations in affect. This strengthened link of emotional experience to food may, in turn, increase vulnerability to the use food for functions other than satiety, for instance, as a way to influence affect.

In people with AN, eating has been found to be associated with guilt, fear, anger, and sadness[34]. Recent literature has suggested that those with AN have difficulty sensing affective changes overall; a feature that appears to remit in women who are weight-restored [35]. Taking this into consideration, it is possible that once eating concern becomes prolonged, regular eating does not function to improve subjective feelings of happiness; instead, eating becomes associated with negative emotionality. The present study's findings suggest with subclinical eating concern, having regular meals may help improve mood, though this is largely speculative in nature. This interpretation may be particularly valuable in informing preventative efforts targeting at-risk populations prior to the development of an eating disorder.

Of note, eating concern emerged as the only significant moderator between perceptions of happiness/satiety and condition. In the current data, preoccupation or shame related to eating was found to influence the relationship between intake (having a high calorie or low calorie shake) and subsequent perceptions of hunger/fullness and happiness more so than concern about shape, weight, or engagement in dietary and cognitive restraint. It is possible that in this non-

clinical sample, preoccupations or worries about consequences of eating may be more distracting that other domains of eating psychopathology, resulting in the altered assessments of happiness and satiety found in the current data.

**4.3 Calorie Guess**

This analysis aimed to discern whether or not there was a relationship between one's self-assessment of hunger/fullness and how many calories they guessed their shake had. By binning participants into "above" or "below" a subclinical cut-off identified by the Johnson-Neyman procedure (eating restraint subscale score = 1.42), those below the cut-off had an expected positive association between judgements of satiety and calorie guess, aligned with our hypothesis. For this group, when people felt hungrier, they reported that their shake consisted of less calories, and those who felt fuller reported their shake had more calories. At higher levels of eating restraint, there was no significant relationship between magnitude of satiety and calorie guess. One hypothesis to explain this finding is that people low in food restriction rely on interoceptive signals, such as the level of perceived hunger/fullness, to inform their knowledge of the energy provided by their meal: their calorie guess. In contrast, those higher in food restriction had more difficulty using interoceptive signaling adaptively to guess caloric load.

Aversiveness of interoceptive experiences have been found to contribute to differences in restrictive eating[5,36]. In a review article on interoception and mental health by Khalsa et al., (2018), individuals with AN reported having hunger insensitivity and gastrointestinal complaints after eating as a result of chronic food restriction and severe weight loss[1]. Chronic food restriction, thus, may dampen one's ability to accurately decipher interoceptive cues. Zucker and colleagues[37] found that individuals with AN and weight-restored AN both reported increased attempts to avoid sensory experiences, such as 'feeling full'. One possible reason that individuals

AN engage in restrictive eating behaviors might be to reduce subjective sensory experiences such as fullness or hunger[38]. Research on interoception in normative samples have found that even short-term fasts significantly influence dimensions of interoceptive experience[39-41], consistent with the findings in the current study.

**4.4 Limitations**

Study results should be considered in light of limitations. Insufficient statistical power, due to the sample size in the present study (n = 99), may have limited the significance of analyses. Currently, for interaction effects, the statistical power is ($1 - \beta = .74$). Future studies building off these results should ensure adequate sample sizes to have sufficiently powered moderation analyses. All participants were students (undergraduate or graduate level) enrolled at a private Southeastern US university. The majority of participants included were undergraduate students participating in the current research study in exchange for extra credit or class credit in psychology courses. This may limit generalizability of findings to students from other majors or adults outside of this setting. Additionally, there was an unequal distribution of males and females across conditions despite use of randomization. Participants were largely recruited from psychology courses, where there is a reported skew in the proportion of males to females in current literature[42]. We hypothesize this drove the overall difference in sex seen in the current manuscript, reflecting the composition of the population sampled. Group analyses reported should be interpreted with caution, though differences between shake condition were still detected in ratings of satiety, happiness, and calorie guess while controlling for sex differences, accompanied by robust effect sizes, suggesting that these results would replicate in a larger, more generalizable sample. That said, there may be some differences in interoceptive attention due to

sex that were not able to be assessed due to unequal cell sizes. Future research should specifically investigate sex-related differences in interoceptive capabilities.

Additionally, the inclusion of a clinical group for comparison to healthy individuals would be helpful in clarifying differences between conditions across a range of eating psychopathology. Since the present study evaluated a healthy sample, there is inadequate variability of eating disorder symptomology meeting clinical thresholds. Thus, the Johnson-Neyman point often has relatively few data points beyond what is established as the cutoff EDE-Q score in our preliminary sample. One needs to be cautious never to make claims outside the range of one's data, and to take care when the data may be "sparse" at the region the Johnson-Neyman point is computed. For the change in mood Johnson Neyman point, for instance, approximately 19% of the data occur above the EDE-Q score of the 2.10, which we believe warrants some caution in overinterpretation of the exact cutoff level of EDE. Future research might consider sampling participants with high levels of eating disorder symptomology endorsed for a more precise estimate, for example.

Additionally, future studies should include a measurement of consumption prior to the lab visit; participants in the present study were informed to not eat/drink 2 hours prior to their visit. The present study would have benefited from assessment of adherence to these parameters to control for any deviations from these guidelines. Of note, baseline satiety was not significantly different between groups.

The macronutrient composition and palatability of the two shakes were different; in creating the shakes authors prioritized matching the shakes on consistency and adherence to a high calorie versus a very low calorie shake. Future studies should keep the ratio of macronutrients or glycemic index in each shake as consistent as possible to minimize confounds.

Shakes in the present study were made to be similar in consistency and texture; thus, it is possible that the sensory properties (appearance and taste) of the shake may have impacted participants' perception of interoceptive signals. To attempt to address this limitation, authors controlled for palatability differences in all analyses reported. Analyses remained significant with and without adding palatability as a covariate, suggesting that the detected effects were not driven by differences in palatability. Further, palatability did not have any significant effect on the findings reported for satiety, mood, and calorie guess ( $p \geq .1$, accompanied by small effect sizes). This study's design was more focused on assessment of palatability to determine success in deception. We also acknowledge that the subjective perception of satiety may have been influenced by many factors (e.g., extrinsic food cues) not measured in the current study

The study of interoception is becoming increasingly more precise and such precision is essential to advance this field. As such, we attempted to map study tasks onto current definitions of interoceptive capacities; however, this study was designed and implemented prior to the publication of these definitions. While we had an objective measure in terms of caloric load, investigations of interoceptive capabilities would have been precise if we had an objective as well as subjective measure, such as blood glucose level. The current study is limited in only having subjective measures.

Relatedly, this study reports the use of Likert scales, which may not be sufficient for the parametric statistics used in this manuscript. However, following guidelines reported by Blunch [43] the Likert self-report scales reported in this study have more than 5 possible values and a normal distribution, allowing the use of these scales for this study's purposes. All Likert reports have been rounded to 1 in the manuscript for measurement accuracy.

1

2 **4.5 Conclusions**

3 The present study sought to clarify the nature of interoceptive attention and magnitude
4 dimensionally, using a novel paradigm to investigate how these features may be differentially
5 impacted by eating disorder symptomology. By blinding participants to the caloric content of
6 their high or low calorie shake and the study aims, this study offers unbiased associations
7 between having a low calorie versus high calorie "meal" and interoception in a sample of college
8 students, for whom the development of healthy eating habits and practices are particularly
9 valuable[44,45]. With increasing levels of eating concern and eating restraint, the present sample
10 showed difficulty in both the subjective sensing and interpretation of gastric cues, respectively.
11 Additionally, results highlight the importance of regular meals on self-perceived mood at
12 increasing levels of eating concern. Taken together, the current exploratory study begins to
13 characterize the influence of eating concern and restraint on gastric and affective interoceptive
14 capabilities. While replication and additional research are needed to increase the robustness of
15 these preliminary conclusions, results have direct implications on the importance of regular
16 eating habits, highlighting sub-clinical levels of eating disordered psychopathology in a
17 population particularly vulnerable to the development of eating disorders[21].

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## Disclosures

All study procedures received ethics approval by the Duke University Campus Institutional Review Board (IRB), protocol number C0873. All participants gave informed consent (both written and verbal) before taking part in the study. The material reported in the manuscript is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE-1644868. Any opinion, findings, and conclusions or recommendations expressed in this manuscript are those of the authors and do not necessarily reflect the views of the National Science Foundation. This project was also funded in part by the Duke University Bass Connections Initiative (Zucker/Fitzsimons). All authors have approved the final manuscript and contributed to the preparation of the manuscript.

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