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Eating moderates the link between body mass index and perceived social connection

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ABSTRACT

Some studies have demonstrated that heavier people perceive themselves as lacking social connections, whereas others have not. The current study investigated whether eating alters the link between body mass index (BMI) and perceived social connection, providing one explanation for inconsistencies across previous studies. Participants were instructed to refrain from eating or drinking anything except water after 9 p.m. the prior night. Upon arrival at the lab, participants were assigned to the food ($n = 63$) or no food ($n = 110$) condition. They also provided a saliva sample that was assayed for ghrelin (an appetite-relevant hormone), and completed a series of questionnaires about their relationships. Participants with a higher BMI felt more socially disconnected than people with a lower BMI, but only among those who had not recently eaten. BMI and perceived social disconnection were unrelated among people who had recently eaten. These results were consistent across multiple measures of perceived social disconnection, and also across the experimental manipulation and continuously measured ghrelin.

1. Introduction

A life devoid of social connection is stereotypically associated with overweight and obese people. For example, overweight people were viewed as having fewer friends than thin people (Harris & Smith, 1983), and this stereotype even existed among grade school children (Harrison, 2000). Furthermore, people rated overweight men as lonelier than non-overweight men (Swami et al., 2008).

Theoretically, people who are overweight or obese may also perceive themselves as lacking social connection. For instance, overweight and obese individuals are regularly stigmatized by friends, family members, and the media (Puhl & Heuer, 2009). Furthermore, weight-based discrimination rose by 66% from 1995 to 1996 to 2004–2006 (Andreyeva, Puhl, & Brownell, 2008). Thus, the social stigma surrounding obesity may lead obese people to feel disconnected from their social circles and from society more broadly. Although this argument is compelling, it is also possible that weight increases are a possible mechanism linking perceived social disconnection (e.g., loneliness) to poor health (Hawkley & Cacioppo, 2007; Lauder, Mummery, Jones, & Caperchione, 2006). From this perspective, feeling socially disconnected leads to weight gain, which ultimately negatively impacts health and mortality. Thus, the relationship between body mass index (BMI) and perceived social connection may be bi-directional, whereby being overweight or obese makes people feel socially disconnected, which further fuels weight gain.

Although there are clear theoretical arguments supporting a bi-directional link between BMI and social disconnection, empirical evidence is mixed. On the one hand, undergraduate students with a higher BMI felt lonelier than those with a lower BMI (Hawkley & Cacioppo, 2007). Loneliness and BMI were also linked among middle-aged adults (Lauder et al., 2006; Schumaker, Krejci, Small, & Sargent, 1985). On the other hand, BMI was unrelated to loneliness in another sample (Sarlio-Lähteenkorva, 2001). Furthermore, there were no differences in relationship quality, perceived social support, or social network size for heavier versus thinner adults in several other studies (Carr & Friedman, 2006; Dierk et al., 2006; Miller, Rothblum, Brand, & Felicio, 1995). Contradictory findings, like those described above, remain unexplained and led to a call for more research about differences in social connection between heavier and thinner people (Puhl & Heuer, 2009).

There are many potential explanations for inconsistent findings. One conventional candidate is “hidden moderators”, contextual differences that systematically explain discrepant results (van Bavel, Mende-Siedlecki, Brady, & Reinero, 2016). The conceptual assertions behind hidden moderators suggest that behaviors are

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contextually bound and are explained via person by situation interactions. Extending this argument suggests that attempts to reproduce contextually sensitive results (i.e., outcomes that depend on the context of the study) in a different setting should lead to replication failures. Indeed, a recent review concluded that replication success was more likely when the result in question had relatively low contextual sensitivity (van Bavel et al., 2016). The thrust of the current paper is that the link between BMI and perceived social connection is contextually sensitive. Based on this argument, the present study investigated whether having recently eaten is one hidden moderator that alters the link between BMI and perceived social connection.

Researchers have theorized that eating reminds people of their emotional bonds with significant others (Locher, Yoels, Maurer, & van Ells, 2005). From this perspective, eating invokes positive nostalgic memories of preparing and eating food with family, friends, and romantic partners, thus instilling emotional warmth and a sense of security. Others have made similar arguments, proposing that initial positive experiences eating food with close relationship partners leads people to subsequently remember those relationships when eating the same foods (Troisi & Gabriel, 2011). In support of these perspectives, eating comfort food (i.e., food that satisfies both physical and emotional needs) caused people to spontaneously think about their relationships, and thinking about comfort food decreased loneliness (Troisi & Gabriel, 2011). Theoretically, eating may exert these and other social benefits in one of two ways. On the one hand, researchers have theorized that eating has positive social consequences because it creates a sense of relative fullness and decreases a person's appetite (Locher et al., 2005). From this perspective, any food that decreases a person's appetite should have the same social effects, regardless of the nutrient content of those foods. On the other hand, others have suggested that palatable foods high in fat and sugar may be particularly emotionally rewarding relative to other foods (Gibson, 2006). Indeed, high fat and high sugar foods cause the release of endogenous opioids, neuropeptides that are strongly implicated in social bonding (Chang et al., 2007; Dum, Gramsch, & Herz, 1983; Machin & Dunbar, 2011; Mizushige et al., 2009; Way, 2013). From this perspective, only foods relatively high in fat and/or sugar would impact perceived social connection. These two competing possibilities were tested in the current study.

Taken together, past theoretical and empirical work suggest that whether people have recently eaten, and potentially whether they ate foods high in fat and/or sugar, may modify perceived social connection. As outlined above, prior theorizing also suggests that people with a higher BMI feel relatively socially disconnected for a variety of reasons. In other words, people with a higher BMI have relatively negative thoughts about their relationships than those with a lower BMI. Eating may eliminate this discrepancy by instilling a relatively positive (perhaps nostalgic) social mindset for those with a higher BMI. In other words, eating may equate people with a higher and lower BMI in terms of how socially connected they feel. Therefore, the primary aim of the current study was to examine whether having recently eaten modified the link between BMI and perceived social connection.

Based on the arguments outlined above, the current study had three goals and three sets of corresponding hypotheses:

Goal 1. The first goal was to investigate whether having recently eaten versus not moderated the relationship between BMI and perceived social disconnection. To accomplish this goal, participants arrived after fasting and were assigned to either consume food (the food condition) or not (the no food condition). *Hypothesis 1*. We hypothesized that participants with a higher BMI would feel less socially connected than participants with a lower BMI, but only among those in the no food condition (who had not recently eaten). We expected the relationship between BMI and perceived social connection to attenuate among participants in the food condition (who recently ate).

Goal 2. The experimental manipulation controlled whether participants recently ate or not. One of the conceptual arguments underlying this manipulation asserts that eating has social consequences because it decreases appetite and creates a sense of relative fullness (Locher et al., 2005). Accordingly, the second goal of this study was to examine whether appetite-relevant hormones mirrored the effects of having recently eaten versus not. To accomplish this goal, participants provided a saliva sample after the eating manipulation that was later assayed for ghrelin, a hormone that is implicated in appetite regulation and plays a major role in regulating energy balance (Klok, Jakobsdottir, & Drent, 2007). Ghrelin consistently increases before eating and drops after a meal, and it also plays a key role in meal initiation (Cummings et al., 2001; Klok et al., 2007). Because ghrelin levels largely operate outside of conscious awareness, the ghrelin measurements were virtually free from subjective biases and were unaffected by any demand characteristics present in the study. Thus, the post-manipulation ghrelin samples provided a unique glimpse into appetite-regulation and allowed us to investigate whether ghrelin, measured continuously, moderated the effects of BMI.[1] *Hypothesis 2*. We predicted that participants with a higher BMI would feel less socially connected than participants with a lower BMI, but only among those with higher ghrelin. We expected the relationship between BMI and perceived social connection to attenuate among participants with lower ghrelin.

Goal 3. The final goal was to examine whether the type of food consumed mattered; in other words, whether different foods had different moderating effects. To achieve this goal, those in the food condition were assigned to eat a food that was relatively higher or lower in fat and/or sugar content. This goal encompassed two competing hypotheses. *Hypothesis 3a*. One possibility is that the relationship between BMI and perceived social connection would attenuate only among participants in the higher-fat higher-sugar condition, and not among those in the other two food conditions. This hypothesis would support prior research suggesting that palatable foods high in fat and sugar may be particularly emotionally rewarding (Gibson, 2006). *Hypothesis 3b*. A competing possibility is that there would be no differences between food types. In others words, the relationship between BMI and perceived social connection would be consistent among foods both higher and lower in sugar and/or fat. This hypothesis would support the argument that feelings of relative fullness and a decreased appetite are driving the social benefits of eating (Locher et al., 2005); any food that decreases appetite should have the same consequences.

2. Methods

2.1. Participants

Participants were recruited through the introductory research participation pool at a large public university. Prior to their lab visit, all participants were screened via an online questionnaire. Students were deemed eligible if they were not on a strict diet (e.g., weight watchers program, paleo diet), did not smoke cigarettes, and did

[1] We focused on ghrelin rather than self-reported hunger due to concerns over potential demand characteristics that could influence self-reported hunger. Please refer to the online supplemental material for a set of analyses examining the interaction between BMI and post-manipulation self-reported hunger predicting each outcome. The supplemental material also includes a discussion of differences and similarities between ghrelin and self-reported hunger.

not have any medical conditions or were taking related medications that had significant effects on appetite or eating behavior (e.g., diabetes). These eligibility criteria were selected *a priori* due to their influence on a person's appetite and eating habits (e.g., Chen et al., 2004). Due to the procedures employed in this study, participants also had to indicate that they would be willing to fast the night prior to their appointment. A total of 192 people passed this initial screening stage and completed the in-person lab visit. This sample size was determined by logistic constraints in the lab, particularly in terms of money available for the ghrelin assay and the time we had available to conduct the study. During data collection, 19 people (9 from the no food condition and 10 from the food condition) were subsequently deemed ineligible when they revealed during their in-person visit that they were taking appetite-relevant medications. The most common medication exclusions during both the initial and second stage of screening were stimulants (e.g., Vyvanse) and anti-depressants; the warning labels for these medications list appetite dysregulation as a side effect. The final sample consisted of 173 participants. Their average age was 18.85 years ($SD = 1.16$) and the majority of participants were female ($n = 113$). The range of BMI went from 16.68 to 42.41 ($M = 23.39$, $SD = 3.88$); 15% of participants were underweight, 57.8% were healthy weight, 22% were overweight, and 5.2% were obese. Due to a computer malfunction, we were missing racial data for all participants. However, the majority of students at the university from which this data was collected are white, which was likely reflected in this sample.

2.2. Procedure

Participants were instructed to refrain from eating or drinking anything except water after 9 p.m. the prior night. All visits started at 9 a.m., further reducing individual variability in people's appetite. After completing a written informed consent along with demographic and other background questionnaires, participants were assigned to the no food ($n = 63$) or food ($n = 110$) condition. Those in the food condition were assigned to eat one of the following three foods: an Ensure nutritional drink in the milk chocolate flavor ($n = 40$); a Jimmy Dean sausage, egg, and cheese muffin breakfast sandwich ($n = 33$); or a Little Debbie individually packaged cheese danish ($n = 37$). These food options were chosen because they varied in their fat and sugar content (see the standardized food item section for details). All participants in the food condition had 5 min to consume their food item, and those in the no food condition waited for 5 min before beginning the next task. All participants ate the entire item they were served. After the food manipulation, participants completed a series of dependent measures, described in the materials section. They also provided a saliva sample 20 min after the manipulation. At the end of the study, participants had their height and weight measured. In preparation for these measurements, participants were asked to remove their shoes and bulky clothing or jackets. Participants stood against the wall with their head, shoulders, buttocks, and heels touching a wall-based height measurement decal. Their height was recorded to the nearest quarter inch and their weight was recorded to the nearest decimal in pounds. All participants were informed about the purpose of the study and thanked for their participation.

2.3. Standardized food items

Three food items were chosen to reflect breakfast food options that were relatively higher versus lower in their fat and sugar content. The three food items (relatively higher-fat higher sugar, higher-fat lower sugar, and lower-fat lower sugar) were selected through a multi-step process. First, the first author and her undergraduate research assistants brainstormed a list of pre-packaged breakfast foods and typical foods that students ate for breakfast. Second, the first author narrowed down the list to items that were pre-packaged and readily available at local grocery stores, thus guaranteeing consistent nutritional content over time. Finally, the first author chose between the higher-fat lower-sugar and higher-fat higher-sugar options by matching their fat content and varying the sugar content as much as possible. This decision making process resulted in the selection of three foods (described below) that systematically varied in their relative sugar and fat content.

2.3.1. Lower-fat lower-sugar

Participants in the lower-fat lower-sugar condition drank an "Ensure Original" nutritional shake in the milk chocolate flavor. The shake had 220 calories, 6 g of total fat, 190 mg of sodium, and 15 g of sugar. The Ensure drink was served chilled.

2.3.2. Higher-fat lower-sugar

Participants in the higher-fat lower-sugar condition ate a Jimmy Dean sausage, egg, and cheese muffin sandwich. This breakfast sandwich had 350 calories, 21 g of total fat, 700 mg of sodium, and 2 g of sugar. The breakfast sandwich was heated in the microwave according to instructions before serving.

2.3.3. Higher-fat higher-sugar

Participants in the higher-fat higher-sugar condition ate a pre-packaged Little Debbie cheese danish. The danish had 430 calories, 18 g of total fat, 370 mg of sodium, and 36 g of sugar. The danish was served at room temperature.

2.4. Measures

Perceived social connection was measured via an array of scales assessing both the presence and absence of companions, along with the degree of connection within those relationships. To investigate whether the results were specific to perceived social connection, participants also completed a measure of general affect and depressive symptomology.

A state social disconnection scale created for the purposes of the first author's research assessed momentary feelings of social disconnection ($\alpha = 0.91$). Participants were given the prompt "Right now I feel" and then responded to 8 items, including "disconnected from other people", "loved by other people" (reverse scored), "cared for by other people" (reverse scored), and "lonely".

Perceived emotional support was measured with a scale developed in conjunction with the National Institutes of Health (NIH) as part of the Patient-Reported Outcomes Measurement System (PROMIS; Cella et al., 2010; Liu et al., 2010; Rothrock et al., 2010). Example items include "I have someone who will listen to me when I need to talk" and "I have someone to confide in or talk to about myself or my problems". The 8-item short form demonstrated excellent reliability in this sample ($\alpha = 0.97$).

Perceived informational support was also assessed using a PROMIS scale. Example items include "I can get helpful advice from others when dealing with a problem" and "I have someone to give me good advice about a crisis if I need it". The 8-item short form had excellent reliability in the current sample ($\alpha = 0.95$).

The 8-item short form of the PROMIS social isolation scale measured perceived social isolation. Example items include "I feel that people barely know me" and "I feel isolated from others". Similar to the other PROMIS scales, the measure had excellent reliability in this sample ($\alpha = 0.93$).

The 6-item short form of the PROMIS companionship questionnaire assessed the degree to which participants had someone

to spend time with in different circumstances. This scale differed from the other 3 PROMIS scales because it assessed the physical presence of other people rather than the degree of social connection that existed within those relationships. Example items include "Do you have someone to go with you to an event?" and "Do you have someone to keep you company at home?" This scale demonstrated good reliability in the current sample ($\alpha = 0.88$).

The Center for Epidemiological Studies Depression (CES-D) Scale is one of the most commonly used measures of depressive symptoms ($\alpha = 0.88$; Radloff, 1977). The CES-D has good discriminant validity, construct validity, and test-retest reliability. An adapted version of the CES-D was used for this study; rather than reporting their depressive symptoms in the past week, participants were asked to report how they were feeling that day.[2]

The self-assessment MANIKIN (SAM) has a single item assessing positive/negative affect (Bradley & Lang, 1994). Participants saw a 9-point scale with 5 pictorial representations of figures displaying sad or happy faces and they were asked to pick the picture that best represented how they currently felt. On the low end of the scale participants saw the words "unhappy, annoyed, unsatisfied, and bored" and on the high end they saw "happy, pleased, satisfied, and hopeful".

2.5. Ghrelin assay

Blood and saliva ghrelin levels are significantly correlated (e.g., Aydin et al., 2005; Dag et al., 2010; Li et al., 2011). Accordingly, saliva samples were collected via a passive drool technique and frozen at −80 °C after collection. Determinations for total ghrelin were made using the RIA kit per kit instructions, supplementing salivary samples in place of blood samples (EMD Millipore Billerica, MA). The intra-assay coefficient of variation was 7.91% and inter-assay coefficient of variation was 10.32%; sensitivity was 93 pg/ml. An intra-assay coefficient of variation below 10 and an inter-assay coefficient of below 15 is desirable (Salimetrics, 2013). Accordingly, our total ghrelin assays met criteria for an acceptable amount of consistency both between and within assays.

2.6. Data analytic strategy

A total of 15 participants did not have ghrelin data, either because they did not provide enough saliva for the assay, or their ghrelin levels could not be calculated from the RIA assay (e.g., it was below detectable limits). The distributions of the ghrelin data were checked for normality and the presence of outliers. After removing a single outlier that was >6 standard deviations above the sample mean, 3 additional samples whose values were more than 4 standard deviations from the new sample mean were dropped from the ghrelin analyses. The remaining ghrelin values were moderately skewed and were thus square root transformed prior to analyses.

As described in the measures section, we included 4 scales (state social connection, perceived emotional support, perceived informational support, perceived social isolation) that conceptually reflected the same construct. However, there was a wide range of shared variance among the scales (30–69%). In addition, the PROMIS scales were partially developed to encourage cross-study comparisons of different findings using the same measures. In other words, using standardized scales in different studies allows researchers to directly compare findings from one study to the next, one big advantages of using these measures ("PROMIS," 2016). Accordingly, the perceived social disconnection scales were investigated as distinct outcomes in separate models.

We performed three sets of linear regressions using SPSS 22.0 with BMI calculated from objectively measured height and weight.[3] These sets of analyses mirrored the three goals of the study, described earlier. The first set (Goal 1) examined whether the experimental food vs. no food manipulation moderated the effects of BMI on both the social (state social connection, perceived emotional support, perceived informational support, perceived social isolation, and companionship) and non-social (current affect and depressive symptoms) outcomes. Every model included the main effect of condition (food vs. no food), the main effect of BMI (centered), and the two-way condition by BMI interaction predicting each outcome.[4] We added season as a covariate (to these and all subsequent analyses) because it significantly predicted multiple dependent measures, including depressive symptoms, likely because data collection spanned both academic semesters and breaks (see also Harmatz et al., 2000). Significant two-way interactions were decomposed by examining the simple slope of BMI separately for the food vs. no food conditions (Aiken & West, 1991).

The next set of linear regressions (Goal 2) examined whether the interaction between BMI and post-manipulation ghrelin levels predicted both the social and non-social outcomes. Every model included the main effect of post-manipulation ghrelin (centered), the main effect of BMI (centered), and the two-way ghrelin by BMI interaction predicting each outcome (along with season as a covariate, as in the Goal 1 analyses). Significant two-way interactions were decomposed by examining the simple slope of BMI separately for people with lower vs. higher ghrelin (±1 SD; Aiken & West, 1991).

The final set of analyses (Goal 3) investigated whether the type of food differentially moderated the effects of BMI. These models were structured identical to the analyses for Goal 1, except the main effect of condition (food vs. no food) was replaced with the main effect of type of food (lower-fat lower-sugar vs. higher-fat lower-sugar vs. higher-fat higher-sugar). The corresponding two-way interaction was also changed accordingly.

3. Results

3.1. Preliminary results

Levene's test comparing the food and no food conditions was non-significant for both the social and non-social outcomes, all p values > 0.276, indicating homogeneity of variance across conditions. BMI did not differ between the food and no food conditions, $F(1,168) = 0.20$, $p = 0.654$. As expected, people in the food condition ($M = 0.98$, $SD = 0.29$) had lower ghrelin after the eating manipulation compared with those in the no food condition ($M = 1.12$. $SD = 0.41$), $F(1,152) = 7.27$, $p = 0.008$.

[2] Due to a programming error, some participants (n = 79) mistakenly received a version that asked them to report their symptoms during the prior week. Importantly, the results were the same as those reported in the text if we separated out people who reported on last week versus today (see online supplemental material for details about these analyses).

[3] We also report results for BMI via participants' self-reported height and weight in online supplemental material. A recent meta-analysis concluded that people often under-estimate their weight and over-estimate their height (Gorber, Tremblay, Moher, & Gorber, 2007). However, the predictive validity associated with both types of measurements are virtually identical for health outcomes (Stommel & Schoenborn, 2009). Accordingly, the self-report BMI data adds this literature by examining the predictive validity of both self-reported and measured BMI within the social domain. Similar to the health literature, we expected consistent effects for both measured and self-reported BMI.

[4] Across all analyses, we tested the three-way gender by condition by BMI interaction to examine whether the effects of interest differed for men and women. None of the three-way interactions were significant (all p values > 0.145), and thus gender was dropped from the analyses.

3.2. Goal 1: did the food manipulation moderate the relationship between BMI and perceived social disconnection?

The patterns of results across the different perceived social connection measures were consistent. Specifically, the 2-way condition by BMI interaction predicting state social disconnection and perceived informational support was significant, $F(1,166) = 4.17$, $p = 0.043$, $\Delta R^2 = 0.024$ and $F(1,166) = 4.25$, $p = 0.041$, $\Delta R^2 = 0.024$ respectively. There was also a marginally significant 2-way condition by BMI interaction predicting perceived emotional support, $F(1,166) = 3.77$, $p = 0.054$, $\Delta R^2 = 0.021$. However, the 2-way interaction between condition and BMI predicting perceived social isolation was not significant, $F(1,166) = 2.02$, $p = 0.157$, $\Delta R^2 = 0.012$.

As shown in Figs. 1–4, among participants in the no food condition, those with a higher BMI felt more socially disconnected, perceived less informational support availability, felt less emotionally supported, and felt more socially isolated than those who with a lower BMI, $\beta = 0.34$, $t(166) = 2.95$, $p = 0.004$; $\beta = -0.32$, $t(166) = -2.73$, $p = 0.007$; $\beta = -0.33$, $t(166) = -2.88$, $p = 0.005$; and $\beta = 0.30$, $t(166) = 2.59$, $p = 0.010$ respectively. On the other hand, BMI was unrelated to state social disconnection, perceived informational support, perceived emotional support, and perceived social isolation among people in the food condition, $\beta = 0.03$, $t(166) = 0.30$, $p = 0.765$; $\beta = -0.002$, $t(166) = -0.02$, $p = 0.987$; $\beta = -0.04$, $t(166) = -0.37$, $p = 0.712$; and $\beta = 0.08$, $t(166) = 0.84$, $p = 0.405$ respectively.

The 2-way condition by BMI interaction was unrelated to companionship (indexing the presence/absence of relationship partners) and depressive symptoms, $F(1,166) = 0.25$, $p = 0.621$, $\Delta R^2 = 0.001$ and $F(1,166) = 0.06$, $p = 0.801$, $\Delta R^2 < 0.001$. The 2-way condition by BMI interaction also did not predict affect, $F(1,166) = 0.89$, $p = 0.346$, $\Delta R^2 = 0.005$.

3.3. Goal 2: did the effects of ghrelin (an appetite-relevant hormone) mirror the effects of having recently eaten versus not?

The analyses using the BMI by ghrelin interaction largely paralleled those using the BMI by condition interaction. Although the 2-way ghrelin by BMI interaction predicting state social disconnection was non-significant, the interaction significantly predicted perceived informational support, $F(1,151) = 1.96$, $p = 0.164$, $\Delta R^2 = 0.012$ and $F(1,151) = 4.04$, $p = 0.046$, $\Delta R^2 = 0.025$ respectively. The 2-way ghrelin by BMI interaction was also a marginally significant predictor of perceived emotional support and perceived social isolation, $F(1,151) = 3.80$, $p = 0.053$, $\Delta R^2 = 0.023$ and $F(1,151) = 3.17$, $p = 0.077$, $\Delta R^2 = 0.020$ respectively.

Consistent with the Goal 1 analyses, among participants with higher ghrelin, those with a higher BMI felt more socially disconnected, perceived less informational support availability, felt less emotionally supported, and felt more socially isolated than those who with a lower BMI, $\beta = 0.33$, $t\ (151) = 2.63$, $p = 0.009$;, $\beta = -0.35$, $t\ (151) = -2.83$, $p = 0.005$; $\beta = -0.37$, $t\ (151) = -3.01$, $p = 0.003$; and $\beta = 0.38$, $t\ (151) = 3.10$, $p = 0.002$; see Table 1. On the other hand, BMI was unrelated to state social disconnection, perceived informational support, perceived emotional support, and perceived social isolation among people with lower ghrelin, $\beta = 0.03$, $t\ (151) = 0.23$, $p = 0.815$; $\beta = 0.07$, $t\ (151) = 0.51$, $p = 0.612$; $\beta = 0.04$, $t\ (151) = 0.26$, $p = 0.793$; and $\beta = 0.01$, $t\ (151) = 0.08$, $p = 0.938$.

The 2-way ghrelin by BMI interaction was unrelated to companionship and depressive symptoms, $F\ (1,151) = 1.69$, $p = 0.196$, $\Delta R^2 = 0.011$ and $F\ (1,151) = 2.45$, $p = 0.117$, $\Delta R^2 = 0.015$. In contrast to the Goal 1 analyses, the 2-way interaction between ghrelin and BMI predicting current affect was significant, $F\ (1,151) = 4.76$, $p = 0.031$, $\Delta R^2 = 0.029$. Among participants with higher ghrelin, those with a lower BMI felt happier than those who with a higher BMI, $\beta = -0.29$, $t\ (151) = -2.33$, $p = 0.021$. On the other hand, BMI was unrelated to affect among people with lower ghrelin, $\beta = 0.17$, $t\ (151) = 1.22$, $p = 0.226$.

3.4. Goal 3: did different foods have different moderating effects?

None of the 2-way type of food by BMI interactions were significant or marginally significant, all p values > 0.168, with the following exception. The 2-way type of food by BMI interaction predicting depressive symptoms was marginally significant, $F\ (2,101) = 2.37$, $p = 0.099$, $\Delta R^2 = 0.041$. However, the simple slopes of BMI predicting depressive symptoms were non-significant within each condition, all p values > 0.116.

4. Discussion

The current study demonstrated that people with a higher BMI felt more socially disconnected than people with a lower BMI, but only among those who had not recently eaten. BMI and perceived

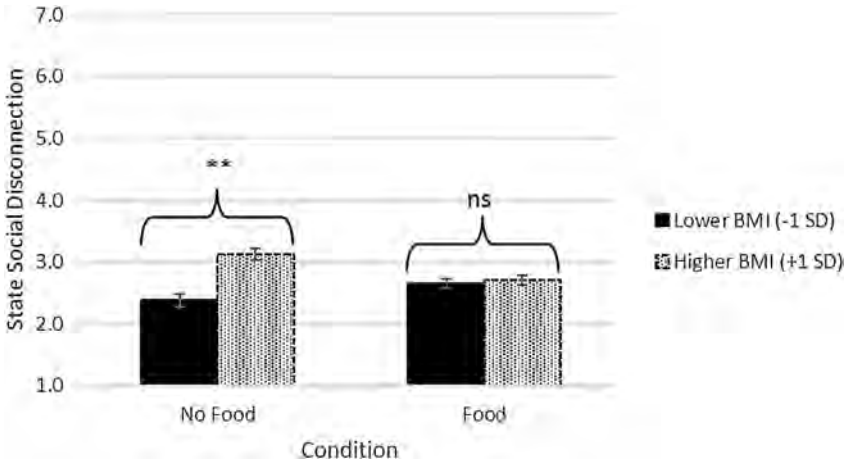

Fig. 1. Condition and measured BMI predicting state social disconnection. The values depicted are the estimated marginal means obtained from a model that included the main effect of condition, the main effect of BMI (continuous), and the condition by BMI interaction, along with season as a potential confound. The error bars reflect a standard error around the mean. $^{**}p < 0.01$, ns = not significant.

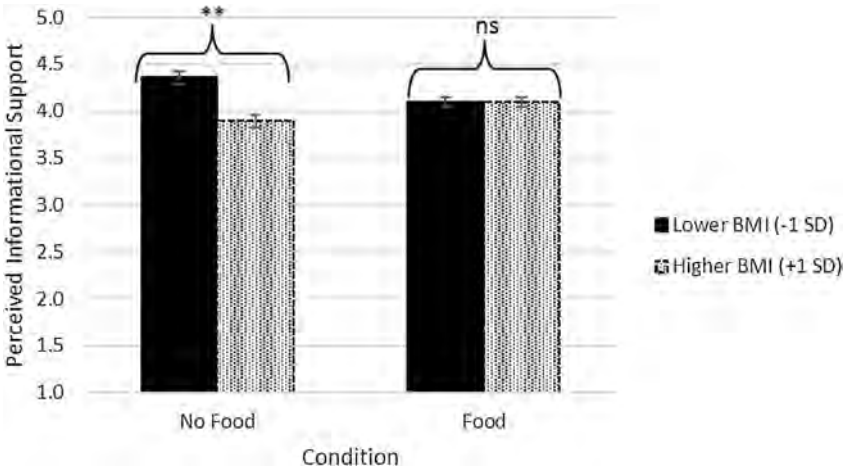

Fig. 2. Condition and meaured BMI predicting perceived informational support. The values depicted are the estimated marginal means obtained from a model that included the main effect of condition, the main effect of BMI (continuous), and the condition by BMI interaction, along with season as a potential confound. The error bars reflect a standard error around the mean. $^{**}p < 0.01$, ns = not significant.

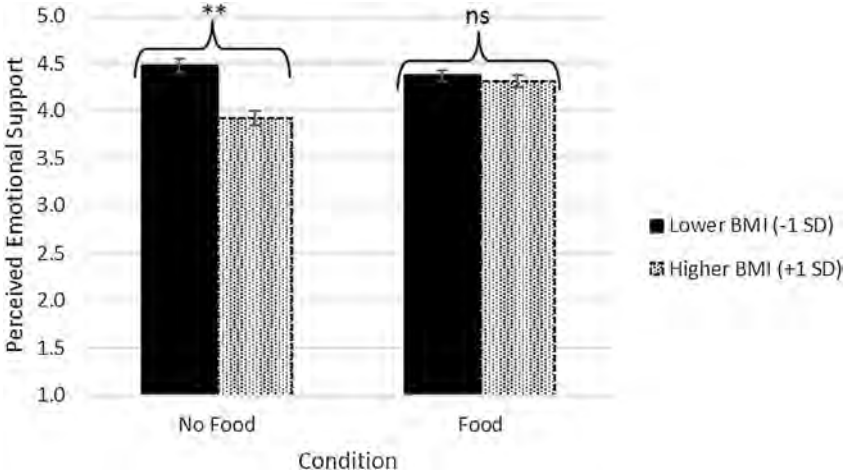

Fig. 3. Condition and measured BMI predicting perceived emotional support. The values depicted are the estimated marginal means obtained from a model that included the main effect of condition, the main effect of BMI (continuous), and the condition by BMI interaction, along with season as a potential confound. The error bars reflect a standard error around the mean. $^{**}p < 0.01$, ns = not significant.

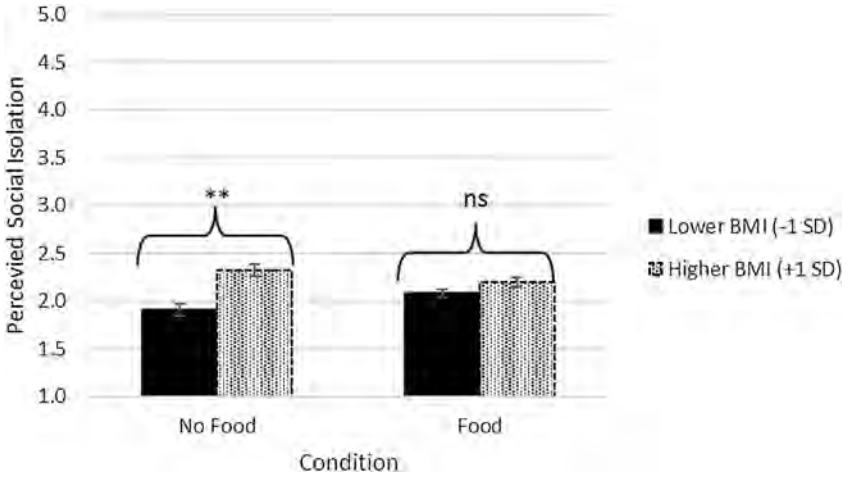

Fig. 4. Condition and measured BMI predicting perceived social isolation. The values depicted are the estimated marginal means obtained from a model that included the main effect of condition, the main effect of BMI (continuous), and the condition by BMI interaction, along with season as a potential confound. The error bars reflect a standard error around the mean. $^{**}p < 0.01$, ns = not significant.

Table 1
Summary of the Simple Slope of Measured BMI for People with Higher vs. Lower Ghrelin.

Outcome Category	Outcome	Predictor: Simple slope of BMI			
		Higher ghrelin (+1 *SD*)		Lower ghrelin (−1 *SD*)	
		standardized beta coefficient	*p* value	standardized beta coefficient	*p* value
a	State social disconnection	0.33	0.009	0.03	0.815
a	Perceived informational support	−0.35	0.005	0.07	0.612
a	Perceived emotional support	−0.37	0.003	0.04	0.793
a	Perceived social isolation	0.38	0.002	0.01	0.938
b	Current affect	−0.29	0.021	0.17	0.226

Note. $N = 158$ participants. a = social outcome focused on quality of social bonds, b = non-social outcome.

social disconnection were unrelated among people who had recently eaten. These results were consistent across multiple measures of perceived social disconnection, and also across an experimental manipulation of food intake and continuously measured ghrelin, a hormone that is implicated in appetite regulation. The specific measures of social disconnection all varied slightly from each other. In addition, some results were significant whereas others were marginally significant. However, the *pattern* of results throughout the paper was clear; whether people had recently eaten differentially affected the degree of association between BMI and perceived social connection.

Interestingly, the interaction between condition and BMI was unrelated to depressive symptoms and was inconsistently related to current affect. These results support the argument that the BMI by eating interaction is relevant when considering social and not non-social outcomes. However, since the depression measure was incorrectly programmed for a subset of participants (see footnote 2 and the online supplemental material), the differentiation between social and non-social outcomes needs further investigation. Importantly, the condition by BMI interaction was consistently related to perceptions of social connection, and not the mere presence or absence of companions. Accordingly, having recently eaten versus being fasted may only be relevant to how people perceive the *quality* of their relationships. An important next step is further exploring whether eating has additional differential impacts within the social domain. For example, researchers could investigate whether eating moderates the relationship between BMI and how people are actually behaving during real social interactions.

The current study included three types of foods, lower-fat lower-sugar (Ensure drink), higher-fat lower-sugar (Jimmy Dean breakfast sandwich), and higher-fat higher-sugar (cheese danish). The relationship between BMI and perceived social connection was the same across the three food types. Accordingly, the type of food a person ate did not matter in this context. The key moderator of the BMI-social connection link was whether people had recently eaten or were fasted. These data raise the possibility that eating any food will eliminate the relationship between BMI and perceived social connection. However, although the three food items had *relatively* more or less sugar and fat than the others, all three foods contained at least a moderate amount of sugar, one limitation of the current study. In addition, two of the three food items in this study were solid foods whereas the other was a liquid, a second limitation. Future research that systematically varies solid versus liquid foods with different nutrients (particularly including foods with little to no sugar) is needed to conclusively establish the role of specific nutrients versus appetite more broadly. In addition, systematically varying the time participants spend fasting will help delineate the boundary conditions of these effects.

Ghrelin consistently increases before eating and drops after a meal (Cummings et al., 2001). The post-manipulation ghrelin samples thus provided a way to assess appetite-relevant hormones, capturing individual differences within each experimentally manipulated condition. The ghrelin analyses largely mirrored the experimental data. Specifically, participants with a higher BMI felt more socially disconnected than their counterparts with a lower BMI, but only among those with higher ghrelin. For those with lower ghrelin, BMI and perceived social disconnection were unrelated. Similar to the experimental data, the individual significance levels varied across measures, but the patterns were identical and painted a consistent picture. The moderating role of ghrelin suggests that appetite may play a key role in the BMI-social connection link. These data thus support previously untested theoretical arguments that eating exerts it's social benefits by creating a sense of relative fullness and decreasing appetite (Locher et al., 2005). To fully investigate this possibility, future studies should manipulate whether a person is fasted, eats a small amount of food, or eats a large amount of the same food item. This type of design would allow researchers to assess the relative importance of eating versus appetite. On one hand, the mere act of eating may play a critical role; on the other hand, decreases in appetite may be the key piece of the puzzle. Disentangling these two possibilities will provide insight into the mechanisms driving the observed effects. The present results introduce a number of additional mechanistic questions. For example, what role does participants' desire for and enjoyment of each food item play? Mechanistic questions of this nature are an important target for future research.

As described in the methods section, the primary analyses focused on ghrelin rather than self-reported hunger due to concerns about demand characteristics affecting self-reported hunger. However, results for the interaction between self-reported hunger and BMI predicting each outcome are reported in the online supplemental material. Unlike the ghrelin analyses, these analyses demonstrated that the two-way hunger by BMI interaction did not significantly predict any of the social or non-social outcomes. There are at least two plausible interpretations of these results. One option is that the self-reported hunger questions did not accurately capture hunger in this study, possibly due to the demand characteristics present in the study surrounding hunger and eating. Physiological measures (e.g., ghrelin) are not affected by demand characteristic or other biases that may influence participants' self-reports. A second option is that ghrelin and self-reported hunger reflect two different ways of assessing appetite. Indeed, ghrelin and self-reported hunger were unrelated in the current study, $r = 0.08$, $p = 0.350$, supporting this argument. At first blush, this lack of correlation may be surprising. However, animal and human data clearly show that ghrelin is relevant to appetite-regulation and is implicated in meal initiation (Cummings et al., 2001; Egecioglu et al., 2010; Klok et al., 2007; Koliaki, Kokkinos, Tentolouris, & Katsilambros, 2010). Thus, the present results support the argument that ghrelin and self-reported hunger are capturing unique variance in a person's appetite. These data also suggest that

changes in appetite-relevant hormones that occur after eating may the key to understanding the BMI-social connection link. These data raise a number of provocative questions about the potentially differential role of appetite-relevant hormones versus self-reported hunger in shaping peoples' social experiences.

The present study offers one potential methodological answer to contradictory findings in prior literature. Specifically, some studies show that BMI is related to perceived social connection (Hawkley & Cacioppo, 2007; Lauder et al., 2006; Schumaker et al., 1985), whereas others do not (Carr & Friedman, 2006; Dierk et al., 2006; Miller et al., 1995; Sarlio-Lähteenkorva, 2001). The current results demonstrated that the context for measuring social connection matters; whether a person had recently eaten altered the association between BMI and perceived social connection. Accordingly, inconsistent prior results may be partially explained by researcher's lack of attention to when participants most recently ate. At a minimum, future research in this area should ask participants about recent food consumption at the time of their participation. Optimally, the current data suggest that researchers should carefully control how recently participants have eaten. An important next step is to replicate these findings using a sample size that was determined *a priori* based on the current study's observed effects sizes.

The current results also point to important targets for applied research examining unintended consequences of eating and dieting. Specifically, not having recently eaten led to a discrepancy between how people with a higher and lower BMI felt about their relationships. Accordingly, dieting (which often causes people to avoid eating and also increases appetite) may lead to a difference in perceived social disconnection among people with a higher versus lower BMI. If dieting has these unintended social costs, it may provide key insight into why dieting may be more difficult for some people versus others. In order to fully understand this possibility, additional research is needed comparing dieters and non-dieters along the BMI continuum on different social outcomes.

5. Conclusion

In sum, whether a person had recently eaten modified the relationship between BMI and perceived social connection. People with a higher BMI felt more socially disconnected than those with a lower BMI, but only if they had not recently eaten. These results were consistent across multiple social connection measures, and also using an experimental food manipulation or continuously measured ghrelin, a hormone implicated in appetite regulation.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.appet.2017.01.016.

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