



Published in final edited form as:

Int J Obes (Lond). 2020 August ; 44(8): 1668–1677. doi:10.1038/s41366-020-0583-x.

No evidence for an association between obesity and milkshake liking

Kathryn M. Wall^{a,b}, Michael C. Farruggia^{a,b,c}, Emily E. Perszyk^{a,b,c}, Arsene Kanyamibwa^{a,b}, Sophie Fromm^{a,b}, Xue S. Davis^{a,b}, Jelle R. Dalenberg^{a,b}, Alexandra G. DiFeliceantonio^{a,b}, Dana M. Small^{a,b,c,d}

^aDepartment of Psychiatry, Yale University School of Medicine, 300 George Street, New Haven, CT 06511, USA

^bModern Diet and Physiology Research Center, New Haven, CT 06519, USA

^cInterdepartmental Neuroscience Program, Yale University, 333 Cedar Street, New Haven, CT, U.S.

^dDepartment of Psychology, Yale University, New Haven, CT, United States.

Abstract

Background—Prevailing models of obesity posit that hedonic signals override homeostatic mechanisms to promote overeating in today’s food environment. What researchers mean by “hedonic” varies considerably, but most frequently refers to an aggregate of appetitive events including incentive salience, motivation, reinforcement, and perceived pleasantness. Here we define hedonic as orosensory pleasure experienced during eating and set out to test whether there is a relationship between adiposity and the perceived pleasure of a palatable and energy dense milkshake.

Methods—The perceived liking, wanting and intensity of two palatable and energy-dense milkshakes were assessed using the Labeled Hedonic Scale (1), visual analogue scale, and Generalized Labeled Magnitude Scale (2) in 110 individuals ranging in body mass index (BMI) from 19.3 to 52.1 kg/m². Waist circumference, waist-hip ratio, and percent body fat were also measured. Importantly, unlike the majority of prior studies, we attempted to standardize internal state by instructing participants to arrive to the laboratory neither hungry nor full and at least one-hour fasted. Data were analyzed with general linear and linear mixed effects models (GLMs). Hunger ratings were also examined prior to hedonic measurement and included as covariates in our analyses.

Results—We identified a significant association between ratings of hunger and milkshake liking and wanting. By contrast, we found no evidence for a relationship between any measure of adiposity and ratings of milkshake liking, wanting, or intensity.

Users may view, print, copy, and download text and data-mine the content in such documents, for the purposes of academic research, subject always to the full Conditions of use:http://www.nature.com/authors/editorial_policies/license.html#terms

Address and contact for corresponding author: Dana M Small, PhD, dana.small@yale.edu, (D.M.S.).

Competing Interests: The authors declare no competing interests.

Conclusions—We conclude that adiposity is not associated with the pleasure experienced during consumption of our energy-dense and palatable milkshakes. Our results provide further evidence against the hypothesis that heightened hedonic signals drive weight gain.

Keywords

obesity; overweight; hedonic; liking; wanting; palatability; preference; perception; taste; flavor; aroma; fat; feeding

1. Introduction

The obesity epidemic is often blamed on the ubiquity of hyperpalatable energy-dense foods (3–5). Implicit in this view is that the pleasure derived from eating these foods systematically varies as a function of adiposity, because those who experience greater pleasure overeat and gain weight. Although an earlier review from 2006 concluded that there is little evidence that pleasure drives overeating in obesity (6), the belief that hedonic signals, including pleasure, drive overeating is still widely held and the more recent literature examining the association between adiposity and pleasure derived from eating is highly inconsistent.

Resolving this inconsistency depends first upon how pleasure is defined. Ingestive behavior is multifaceted and encompasses numerous distinct motivational processes. Theoretical frameworks of motivation range from drive reduction, to incentive motivation, “wanting” and “liking”, reinforcement learning, and effort appraisal; all relevant to ingestive behavior and associated with distinct neurobiological underpinnings (7–9). Moreover, the terms ‘liking’ and ‘preference’ -- often used interchangeably in the literature -- are tested through unique behavioral paradigms. Liking is typically assessed by self-report with participants rating how much they like (or dislike) a stimulus according to a standard scale (e.g. visual analog, Likert scale, ‘Labeled Hedonic Scale’ (LHS)) (1). In contrast, preference is determined by a decision or selection when two or more alternatives are presented, usually within a forced-choice tracking procedure when the food or beverage is sampled (10). Preference also applies to questionnaires where lists of foods are ranked or rated for preference. However, preference does not map directly onto liking or perceived pleasure. For example, imagine a series of lemonade beverages of increasing sweetness. One participant, John, prefers the sweetest beverage while another participant, Heather, prefers the second sweetest beverage. This does not mean that John finds sweetness more pleasurable than Heather, because Heather may well rate both lemonades as more liked than John (11). Systematic preferences toward sensations with greater sweetness, and therefore higher energy densities, are meaningful and important observations, but they do not mean that such preferences reflect enhanced hedonic responses.

Here we focus on understanding whether a relationship exists between measures of adiposity and conscious liking, or “sensory pleasure,” which depends on self-report, and may be uniquely human (12). However, even this narrowed definition includes multiple distinct domains. Visual, aromatic, and contextual food cues can be rated for how liked or disliked they are but are still distal to the pleasure experienced during eating. They can and do,

however, promote craving and food intake (13), which are related to pleasure but are nevertheless distinct psychological and neurobiological phenomena (14). Lists of food items can be assessed for liking or preference. Orosensory systems can also be evaluated discreetly (e.g. sweet taste) or as flavor (“taste” of a food item or beverage). Regardless of the domain or stimulus evaluated there is significant inconsistency regarding its relationship with adiposity (typically quantified using body mass index (BMI)). One recent review concluded that there was little evidence for associations between adiposity and taste sensitivity, hedonics and preference, but perhaps some indication for increased preference for fat in individuals with overweight and obesity (15). However, inspection of primary research studies reveals evidence for positive, negative and no relationship between food liking and BMI (16–53). Additionally, many studies do not assess the influence of adiposity on liking ratings produced during the sampling of actual foods or beverages. Yet, it is this experience that defines the pleasure of food. We therefore endeavored to perform a larger-scale analysis by combining perceptual ratings across a series of studies in our laboratory all using similar methods (e.g. controlling for time since last meal and hunger ratings), identical rating scales and stimuli (chocolate and strawberry milkshake), and multiple measures of adiposity.

2. Methods

2.1 Participants

In total, we included data from 110 participants (69 women, 41 men, mean age: 28.92 ± 6.68 years, mean BMI: 28.62 ± 6.89 kg/m², range 19.3 – 52.1 kg/m²) acquired from three separate study cohorts (54–56). On occasion, a single individual had participated in multiple studies. In these cases, the data acquired at the first encounter was used. There was no assessment of power *a priori* as this was a convenience sample. Participants were recruited through flyers and advertisements around Yale University and the city of New Haven. All study procedures were approved by the Yale University School of Medicine Human Investigation Committee (HIC) and informed consent was obtained from everyone. Participants reported having no known taste, smell, neurological, psychiatric or other pathological disorder. Because these cohorts were part of functional neuroimaging studies, potential participants were excluded for MRI contraindications.

2.2 Measures

Anthropometric measures were obtained from participants and included body weight (n = 110), height (n = 110), BMI (n = 110), waist circumference (n = 66), hip circumference (n = 66), and body fat percentage (n = 72). Participants were asked to wear light clothing and to take off their shoes before height and weight were measured. Body fat percentage (BF%) was calculated using air displacement plethysmography (BodPod). Waist and hip circumference were assessed with a measuring tape. Waist-hip ratio (cm waist/cm hip) and BMI (weight (kg) / [height (m)]²) were calculated based on their component measures.

2.3 Procedure

2.3.1 Stimuli—Two flavored milkshakes (chocolate and strawberry) were made in the laboratory. Chocolate milkshakes were made with 354ml each of whole milk, Garelick Farms Chug Chocolate and Garelick Farms Chug Cookies & Cream milkshakes. Strawberry

milkshakes were made with 946 ml of whole milk and 177 ml of Hershey's strawberry syrup (52). The macronutrient content of the chocolate milkshake was 100 kcal per 100ml [14g carbohydrate, 14g sugar, 4g protein and 3g fat] and of the strawberry milkshake was 106 kcal per 100ml [17g carbohydrate, 17g sugar, 3g protein and 3g fat].

2.3.2 Stimulus Delivery—Chocolate and strawberry milkshakes were delivered to participants in the MR scanner environment. Unfortunately, the fMRI environment does not permit chewing. This is because chewing (and to some extent even swallowing) produces unacceptable amounts of movement, which then hinders data analysis. As such, the sampling of energy sources of any kind is limited to small boluses of liquid delivered using specialized liquid delivery devices. Importantly, the subject experience is not that of drinking because the bolus size is negligible (0.5mL). The experience is closer to repeatedly sampling a taste of either a creamy food or beverage. In brief, 0.5 mL of milkshake is delivered over the course of 2s using an MRI compatible gustometer. The gustometer consists of programmable BS-8000 syringe pumps (Braintree Scientific, Braintree, Massachusetts) that are loaded with 60 mL syringes containing milkshake. Syringes were connected to 25 ft of Tygon tubing (Saint Gobain Performance Plastics, Akron, Ohio) that were fed through the wall of the scanner control room and were further connected to a Teflon gustatory manifold attached to the MR head coil. The manifold consisted of several arteries that converged onto a single point, allowing for liquid solutions to drip passively through the mouthpiece onto the tongue (57). Milkshakes were at room temperature when delivered to subjects in the scanner. Each milkshake was removed from the refrigerator at least one hour before the session began to ensure temperature consistency between subjects and studies.

2.3.3 Ratings—Subjects completed questionnaires during a screening or behavioral session prior to the fMRI study. The Dietary Fat and free Sugar (DFS) (58) and Three Factor Eating Questionnaire (TFEQ) (59) were administered to collect information on food intake and eating behaviors. The DFS is a food frequency questionnaire comprised of 26 questions, yielding three scores: sugar, saturated fat, and total intake (Cronbach's $\alpha = 0.76$ in Francis and Stevenson (2013)(58)). This questionnaire, which evaluates typical consumption of high-fat/high-sugar foods, was chosen as a brief measure of habitual dietary fat and sugar intake as there is evidence that diet can influence fat and sugar perception (15,60). Therefore, the DFS was included as a basic measure of intake. The TFEQ consists of 51 questions about eating behavior designed to determine degree of restrained eating, disinhibited eating, and experience of hunger (Cronbach's $\alpha = 0.93, 0.91$ and 0.85 for these subscales, respectively, in Stunkard and Messick (1985)(59)). The TFEQ was therefore included to assess relationships between eating behavior and perception and adiposity.

Participants were instructed to arrive to the scanning sessions neither hungry nor full and at least one-hour fasted. Hunger ratings were also assessed upon arrival using a visual analogue scale (VAS) that was bounded by "not hungry at all" and "extremely hungry" or a general labeled magnitude scale (gLMS) that includes empirically placed semantic labels ranging from "no sensation" to "strongest imaginable sensation." In the event a subject made ratings more extreme than very hungry or very full, the scan was rescheduled. Subjects also provided multiple ratings of the chocolate and strawberry milkshakes. Perceptual ratings

were made inside the scanner with participants indicating magnitude by moving a cursor along a line with a rotating trackball. The Labeled Hedonic Scale (LHS) was used to assess liking (1). In contrast to the often employed 9-point scale, the LHS is an empirically-derived scale designed to produce normally distributed ratio-level data, and is relatively resistant to ceiling effects and other similar confounds (1). In addition, it includes empirically-derived and placed semantic labels ranging from “most disliked sensation imaginable” to “most liked sensation imaginable.” Intensity ratings were assessed with the generalized Labeled Magnitude Scale (gLMS) described above (2) which, like the LHS, produces ratio-level data resistant to ceiling effects. Milkshake wanting was assessed using a 200mm VAS that was bounded by “I would never want to consume this” and “I would want to consume this more than anything” (10).

2.4 Statistical Analysis

Our primary objective was to assess the relationship between adiposity and perceptual ratings of milkshake liking, wanting, and intensity. Our pre-planned secondary analyses included testing the association between adiposity and subjective hunger, as well as subjective hunger and milkshake liking/wanting/intensity. If these associations were all significant, we would then test if hunger moderated a potential association between adiposity and liking/wanting. Additional exploratory analyses included evaluating relationships between milkshake liking/wanting/intensity and diet and eating behavior.

All statistical analyses were performed in R (3.5.1, 2018-07-02). Datasets that included repeated measures were analyzed with linear mixed models (LMMs) using package Lme4 (v1.1-21). P-values and type 3 ANOVAs for these models were calculated using the Satterthwaite approximation of degrees of freedom (package LmerTest, v3.0-1). Datasets that did not include repeated measures were analyzed with type 3 ANOVAs using the ‘Anova’ function from package ‘car’ (v3.0-2). We checked the normality of the data using the Shapiro-Wilk test of normality. Where the data was not normal, log and square root transformations were used to make the data normal and analyses were rerun. The p-values remain virtually unchanged. This is consistent with normality not being a key assumption in linear models (61).

To be consistent with previous literature, we used the ratings from the first exposure in our initial analyses. We later re-ran analyses with the average rating across exposures and these analyses produced similar results (data not shown). To investigate the relationship between perceptual ratings and adiposity, separate models were constructed with milkshake liking, wanting, and intensity as dependent variables and BMI, waist-hip ratio, waist circumference, and body fat percentage as independent variables. Sex, research study ID, age, and hunger served as covariates. Additionally, separate models were created to test average milkshake liking, wanting and intensity across all exposures to the milkshake. Research study ID, sex, age, and hunger were used as covariates. To investigate the influence of hunger on perceptual ratings, we constructed separate models with milkshake liking, wanting, and intensity ratings as dependent variables and hunger ratings as the independent variable. A similar procedure was performed to test for associations between hunger and adiposity

measures. Sex, research study ID, and BMI were used as covariates for perceptual rating models whereas research study ID, and sex were used as covariates for adiposity models.

To investigate the relationship between food intake and perceptual ratings, separate models were constructed with milkshake liking, wanting, and intensity as dependent variables and DFS free sugar score, DFS saturated fat score and DFS total score as independent variables. Similarly, the relationships between food intake and adiposity measures were investigated through separate models with BMI, waist-hip ratio, waist circumference, and body fat percentage as dependent variables and DFS free sugar score, DFS saturated fat score, and DFS total score as independent variables. To investigate the relationship between the TFEQ measures of eating behavior and perceptual ratings, separate models were constructed with milkshake liking, wanting, and intensity as dependent variables, and TFEQ cognitive food restraint score, TFEQ disinhibition score, and TFEQ hunger score as the independent variables. Additionally, the relationships between the TFEQ measures of eating behavior and adiposity measures were investigated through separate models with BMI, waist-hip ratio, waist circumference, and body fat percentage as dependent variables and TFEQ cognitive food restraint score, TFEQ disinhibition score, and TFEQ hunger score as the independent variables.

For all analyses, α was set to two-tailed $p < .05$. Correction for multiple comparisons were performed by adjusting the α according to the Bonferroni method. For LMMs, subject ID was entered as a random variable. We identified one outlier (0.9% of the dataset), defined as more than 2.5 standard deviations from the between subject variable mean. The removal of the outlier did not change the analyses so the data were retained.

3. Results

3.1 Perceptual ratings are not significantly related to adiposity

GLMs showed no significant relationships between adiposity and perceptual ratings (liking, wanting, and intensity). This was true even when not correcting for multiple comparisons. Furthermore, hunger had no influence on these findings (Figure 1). Similar findings were obtained when average ratings from all milkshake exposures were analyzed (data not shown).

3.2 Hunger is related to liking and wanting but not intensity or adiposity

GLMs indicated a significant positive relationship between hunger and liking, as well as hunger and wanting, but not between hunger and perceived intensity. Once p-values were corrected for multiple comparisons, only the relationship between hunger and wanting remained significant. There was no association between hunger and any of the measures of adiposity (Figure 2). These analyses indicate that hunger but not adiposity is associated with milkshake wanting.

3.3 Self report fat and sugar intake and eating behavior are not associated with adiposity or perceptual ratings

GLMs corrected for multiple comparisons showed no significant relationship between DFS free sugar score, DFS saturated fat score, or DFS total score and measures of adiposity or perceptual ratings. (Table 1).

Likewise, GLMs between adiposity measures and perceptual ratings with cognitive food restraint, disinhibition, and hunger scores from the TFEQ showed no significant relationships (Table 1).

4. Discussion

It is often assumed that increased hedonic experience from eating promotes overeating and obesity. Here we combined data from multiple studies in our lab in which participants rated the perceptual attributes of two palatable and energy-dense milkshakes and regressed these ratings against multiple measures of adiposity. We found no evidence for a relationship between any of the adiposity measures (BMI, percent body fat, waist hip ratio, waist circumference) and the perceived liking, wanting or intensity of the milkshakes. This null finding is consistent with many prior reports evaluating the relationship between BMI and the rated perception of foods and beverages, tastes, and aromas, as well as conclusions from two prior reviews (6,15).

As predicted, we did identify a significant, albeit weak, positive association between ratings of hunger and milkshake liking. This observation is potentially important in explaining the inconsistent reports in the literature. Among prior publications reviewed, only three explicitly controlled for the participants' self-reported hunger in the analyses that were performed (19,27,30). Additionally, although the majority of studies required a minimum fasting period prior to assessment (i.e., at least 1–4 hours), they routinely did not account for potential variance in the time since the last meal. It is therefore possible that participants with higher adiposity were hungrier. If so, hunger rather than adiposity may be driving positive associations with liking. Relatedly, other studies have shown that fullness is inversely related to food palatability and intake (62).

Another factor that could contribute to variable results is the use of food lists rather than the sampling of food. Humans perform poorly at predicting how pleasant they will find the taste of a food (62). Of the seven food and beverage liking studies we identified using real food/ flavor stimuli, three reported a positive association (23,31,32) and five no association (19,30,34,63,64) with BMI. Notably, the studies finding a positive association did not evaluate and/or control for hunger. Also, of relevance, two of the studies using real food also assessed other aspects of food motivation. Saelens and Epstein (1996) (19) asked female participants to either eat food or perform a sedentary activity, such as playing a video game or reading magazines. Women with overweight and obesity were more likely to choose food consumption over the sedentary alternative compared to women with normal weight. Likewise, Giesen et al. (2010) (30) found that individuals with overweight/obesity were willing to work more for high-calorie snacks versus low-calorie fruits and vegetables, which they interpreted as an increase in the 'relative-reinforcing value' of food. These studies

support a positive association between adiposity and motivation to consume unhealthy food in the context of normal hedonic responses, which is in line with the conclusion of a review paper on adiposity and food reward (6) and with the incentive sensitization theory (65).

A final issue worth considering relates to the instruments used to collect ratings. Many studies used a 9-point scale (33,35), which is prone to biases such as centering and end effects, or the tendency to avoid using the extreme ends of the scale or to distribute ratings across the range that is presented (reviewed in (66)). In addition, categorical scales only yield ordinal level data because there is no zero point, nor evidence that the distance between categories is equal (67). Thus, the resulting data violates many of the assumptions for ordinary linear regression models (e.g., normality) (68,69). This raises questions over the validity of applying ordinary linear regression models to evaluate data from such scales. Finally, scales anchored with reference to food -- for example, least-liked food on the left and extremely-liked food on the right -- assume that the value ascribed to extremely-liked food is similar across all users (23). Here we used the LHS, which is a category-ratio scale that was derived using magnitude estimation that produces ratio-level data and is bound by cross-modal semantic labels that allows subjects to draw across all of their hedonic experiences (1). It therefore overcomes many of the shortcomings of the 9-point scale.

Importantly, a lack of a relationship between adiposity and food hedonics does not imply that there is no association between obesity and food reward or food reinforcement. Food reward can be defined as “a [food] stimulus for which animals (including humans) are willing to work (or pay) for,” whereas food reinforcement refers to “the behavioral process via which unconditioned or operant responses are acquired by an organism upon presentation of a rewarding or punishing [food] stimulus” (70). Using these definitions, many prior studies have reported heightened food reward and reinforcement among individuals with overweight or obesity (e.g. (15,71)). Direct, within-study comparisons of food liking and food reinforcement further demonstrate that food reinforcement significantly differs as a function of weight status despite no differences in hedonic value among individuals with healthy weight and those with overweight/obesity (27,30,72). Food cravings, or “elaborated desires” (73) also increase with adiposity. A meta-analysis of 45 publications ($n > 3000$) suggests that greater frequency or intensity of food cravings can promote overeating and predict subsequent weight gain (74), while a survey of individuals with increased food cravings were more likely to have overweight and obesity as well as engage in sedentary behaviors that promote weight gain, such as spending more hours watching television (75). Finally, many functional brain imaging studies report strong associations between the blood oxygen level dependent (BOLD) response to beverage and food related stimuli and adiposity or risk for weight gain (76–82).

4.1 Strengths, Limitations, and Future Directions

Our study has several strengths that lend confidence in our findings. Multiple measures of adiposity were obtained and we used the gold standard instrument for measuring hedonics in a large sample of individuals who sampled a palatable and energy dense food. We also accounted for a comprehensive set of potential confounds including subjective hunger, participant sex, and age. We also note several limitations. First, it is possible that ratings of

milkshake beverages do not generalize to solid foods or other stimuli. Therefore, it will be important to try to replicate our finding using solid foods. Second, ratings were obtained while participants were engaged in an fMRI study, raising the possibility that this unique environment systematically biased ratings. Due to the diameter of the scanner bore, this environment also necessitated exclusion of individuals with morbid obesity. Future work should therefore include individuals with BMIs at extreme ends of the spectrum, including underweight and morbid obesity. Another important avenue for future work should be to expand stimuli to other foods and beverages. Finally, since we did find an association between hunger and liking it would be worthwhile to examine and compare liking ratings under different internal states over a range of BMI.

4.2 Conclusion

Our study found no evidence for a relationship between adiposity and milkshake liking, despite controlling for hunger, employing a large sample size and using the gold standard instrument to assess hedonic experience. This result is consistent with the conclusion made in an earlier review (6) and strongly suggests that the experience of enhanced pleasure during the consumption of palatable and energy dense foods does not contribute to obesity. Our findings also underscore the importance of controlling for participant hunger when assessing the hedonic properties of food.

Acknowledgements

This work was supported by the National Institutes of Health R01 grants R01 CA180080 and R01 DK085579 (D.M.S); and the Yale Medical School Fellowship (M.C.F).

References

1. Lim J, Wood A, Green BG. Derivation and Evaluation of a Labeled Hedonic Scale. *Chem Senses*. 2009 11 1;34(9):739–51. [PubMed: 19833660]
2. Green BG, Shaffer GS, Gilmore MM. Derivation and evaluation of a semantic scale of oral sensation magnitude with apparent ratio properties. *Chem Senses*. 1993 12 1;18(6):683–702.
3. Berthoud H-R. Multiple neural systems controlling food intake and body weight. *Neurosci Biobehav Rev*. 2002 6 1;26(4):393–428. [PubMed: 12204189]
4. Rossi MA, Stuber GD. Overlapping Brain Circuits for Homeostatic and Hedonic Feeding. *Cell Metab*. 2018 1 9;27(1):42–56. [PubMed: 29107504]
5. Saper CB, Chou TC, Elmquist JK. The Need to Feed: Homeostatic and Hedonic Control of Eating. *Neuron*. 2002 10 10;36(2):199–211. [PubMed: 12383777]
6. Mela DJ. Eating for pleasure or just wanting to eat? Reconsidering sensory hedonic responses as a driver of obesity. *Appetite*. 2006 7 1;47(1):10–7. [PubMed: 16647788]
7. Berridge KC. Food reward: Brain substrates of wanting and liking. *Neurosci Biobehav Rev*. 1996 1 1;20(1):1–25. [PubMed: 8622814]
8. Dayan P, Balleine BW. Reward, Motivation, and Reinforcement Learning. *Neuron*. 2002 10 10;36(2):285–98. [PubMed: 12383782]
9. Salamone JD, Correa M. Motivational views of reinforcement: implications for understanding the behavioral functions of nucleus accumbens dopamine. *Behav Brain Res*. 2002 12 2;137(1):3–25. [PubMed: 12445713]
10. Lawless HT, Heymann H. *Sensory Evaluation of Food: Principles and Practices* [Internet]. 2nd ed. New York: Springer-Verlag; 2010 [cited 2019 Jul 23]. (Food Science Text Series). Available from: <https://www.springer.com/gp/book/9781441964878>

11. Dalenberg JR, Gutjar S, Horst GJ ter, Graaf K de, Renken RJ, Jager G. Evoked Emotions Predict Food Choice. *PLOS ONE*. 2014 12 18;9(12):e115388. [PubMed: 25521352]
12. LeDoux JE, Brown R. A higher-order theory of emotional consciousness. *Proc Natl Acad Sci U S A*. 2017 07;114(10):E2016–25. [PubMed: 28202735]
13. Jansen A A learning model of binge eating: Cue reactivity and cue exposure. *Behav Res Ther*. 1998 3 1;36(3):257–72. [PubMed: 9642846]
14. Small DM, Veldhuizen MG, Felsted J, Mak YE, McGlone F. Separable Substrates for Anticipatory and Consummatory Food Chemosensation. *Neuron*. 2008 3 13;57(5):786–97. [PubMed: 18341997]
15. Cox DN, Hendrie GA, Carty D. Sensitivity, hedonics and preferences for basic tastes and fat amongst adults and children of differing weight status: A comprehensive review. *Food Qual Prefer*. 2016 3 1;48:359–67.
16. Witherly SA, Pangborn RM, Stern JS. Gustatory responses and eating duration of obese and lean adults. *Appetite*. 1980 3 1;1(1):53–63.
17. Drewnowski A, Henderson SA, Cockcroft JE. Genetic Sensitivity to 6-n-Propylthiouracil Has No Influence on Dietary Patterns, Body Mass Indexes, or Plasma Lipid Profiles of Women. *J Am Diet Assoc*. 2007 8 1;107(8):1340–8. [PubMed: 17659901]
18. Pangborn RM, Bos KEO, Stern JS. Dietary fat intake and taste responses to fat in milk by under-, normal, and overweight women. *Appetite*. 1985 3 1;6(1):25–40. [PubMed: 3838873]
19. Saelens BE, Epstein LH. Reinforcing Value of Food in Obese and Non-obese Women. *Appetite*. 1996 8 1;27(1):41–50. [PubMed: 8879418]
20. Diehl JM. [Food preferences of 10- to 14-year-old boys and girls]. *Schweiz Med Wochenschr*. 1999 2 6;129(5):151–61. [PubMed: 10081073]
21. Nakamura K, Shimai S, Kikuchi S, Tanaka M. Correlation between a liking for fat-rich foods and body fatness in adult Japanese: a gender difference. *Appetite*. 2001 2;36(1):1–7. [PubMed: 11161340]
22. Salbe AD, DelParigi A, Pratley RE, Drewnowski A, Tataranni PA. Taste preferences and body weight changes in an obesity-prone population. *Am J Clin Nutr*. 2004 3 1;79(3):372–8. [PubMed: 14985209]
23. Bartoshuk Linda M, Duffy Valerie B, Hayes John E, Moskowitz Howard R, Snyder Derek J. Psychophysics of sweet and fat perception in obesity: problems, solutions and new perspectives. *Philos Trans R Soc B Biol Sci*. 2006 7 29;361(1471):1137–48.
24. Davis C, Patte K, Levitan R, Reid C, Tweed S, Curtis C. From motivation to behaviour: A model of reward sensitivity, overeating, and food preferences in the risk profile for obesity. *Appetite*. 2007 1 1;48(1):12–9. [PubMed: 16875757]
25. Czyzewska M, Graham R. Implicit and explicit attitudes to high- and low-calorie food in females with different BMI status. *Eat Behav*. 2008 8 1;9(3):303–12. [PubMed: 18549989]
26. Keskitalo K, Tuorila H, Spector TD, Cherkas LF, Knaapila A, Kaprio J, et al. The Three-Factor Eating Questionnaire, body mass index, and responses to sweet and salty fatty foods: a twin study of genetic and environmental associations. *Am J Clin Nutr*. 2008 8 1;88(2):263–71. [PubMed: 18689360]
27. Temple JL, Legierski CM, Giacomelli AM, Salvy S-J, Epstein LH. Overweight children find food more reinforcing and consume more energy than do nonoverweight children. *Am J Clin Nutr*. 2008 5 1;87(5):1121–7. [PubMed: 18469229]
28. Hill C, Wardle J, Cooke L. Adiposity is not associated with children's reported liking for selected foods. *Appetite*. 2009 6 1;52(3):603–8. [PubMed: 19501756]
29. Duffy VB, Bartoshuk LM. Food acceptance and genetic variation in taste. *J Am Diet Assoc*. 2000 6;100(6):647–55. [PubMed: 10863567]
30. Giesen JCAH, Havermans RC, Douven A, Tekelenburg M, Jansen A Will Work for Snack Food: The Association of BMI and Snack Reinforcement. *Obesity*. 2010;18(5):966–70. [PubMed: 20150901]
31. Ettinger L, Duizer L, Caldwell T. Body Fat, Sweetness Sensitivity, and Preference: Determining the Relationship. *Can J Diet Pract Res*. 2012 3;73(1):45–8. [PubMed: 22397966]

32. Dressler H, Smith C. Food choice, eating behavior, and food liking differs between lean/normal and overweight/obese, low-income women. *Appetite*. 2013 6 1;65:145–52. [PubMed: 23428940]
33. Deglaire A, Méjean C, Castetbon K, Kesse-Guyot E, Hercberg S, Schlich P. Associations between weight status and liking scores for sweet, salt and fat according to the gender in adults (The Nutrinet-Santé study). *Eur J Clin Nutr*. 2015 1;69(1):40–6. [PubMed: 25074389]
34. Laureati M, Bertoli S, Bergamaschi V, Leone A, Lewandowski L, Giussani B, et al. Food neophobia and liking for fruits and vegetables are not related to Italian children's overweight. *Food Qual Prefer*. 2015 3 1;40:125–31.
35. Lampuré A, Castetbon K, Deglaire A, Schlich P, Péneau S, Hercberg S, et al. Associations between liking for fat, sweet or salt and obesity risk in French adults: a prospective cohort study. *Int J Behav Nutr Phys Act*. 2016 7 4;13(1):74. [PubMed: 27378200]
36. Proserpio C, de Graaf C, Laureati M, Pagliarini E, Boesveldt S. Food odors influence behavioral and physiological parameters of human eating behavior. In 2016 [cited 2019 Jul 23]. Available from: <https://air.unimi.it/handle/2434/554605#.XTdSBfJKj0M>
37. Polk SE, Schulte EM, Furman CR, Gearhardt AN. Wanting and liking: Separable components in problematic eating behavior? *Appetite*. 2017 8 1;115:45–53. [PubMed: 27840087]
38. Rodin J, Moskowitz HR, Bray GA. Relationship between obesity, weight loss, and taste responsiveness. *Physiol Behav*. 1976 10 1;17(4):591–7. [PubMed: 1013209]
39. Thompson DA, Moskowitz HR, Campbell RG. Taste and olfaction in human obesity. *Physiol Behav*. 1977 8;19(2):335–7. [PubMed: 607246]
40. Malcolm R, O'Neil PM, Hirsch AA, Currey HS, Moskowitz G. Taste hedonics and thresholds in obesity. *Int J Obes*. 1980;4(3):203–12. [PubMed: 7419338]
41. Frijters JER, Rasmussen-Conrad EL. Sensory Discrimination, Intensity Perception, and Affective Judgment of Sucrose-Sweetness in the Overweight. *J Gen Psychol*. 1982 10 1;107(2):233–47. [PubMed: 7175511]
42. Pasquet P, Frelut ML, Simmen B, Hladik CM, Monneuse M-O. Taste perception in massively obese and in non-obese adolescents. *Int J Pediatr Obes*. 2007 1 1;2(4):242–8. [PubMed: 17852551]
43. Hardikar S, Höchenberger R, Villringer A, Ohla K. Higher sensitivity to sweet and salty taste in obese compared to lean individuals. *Appetite*. 2017 4 1;111:158–65. [PubMed: 27988366]
44. Brondel L, Van Wymelbeke V, Hanus CC, Romer M, Jiang T, Rigaud D. Increase food-intake in relation to food variety in humans: is sensory-specific satiety diminished by “alimentary zapping”? In: *Fundamental & Clinical Pharmacology* [Internet]. montpellier, France; 2006 [cited 2019 Jul 23]. Available from: <https://hal.archives-ouvertes.fr/hal-00022997>
45. Trellakis S, Tagay S, Fischer C, Rydleuskaya A, Scherag A, Bruderek K, et al. Ghrelin, leptin and adiponectin as possible predictors of the hedonic value of odors. *Regul Pept*. 2011 2 25;167(1):112–7. [PubMed: 21185875]
46. Soussignan R, Schaal B, Boulanger V, Gaillet M, Jiang T. Orofacial reactivity to the sight and smell of food stimuli. Evidence for anticipatory liking related to food reward cues in overweight children. *Appetite*. 2012 4 1;58(2):508–16. [PubMed: 22245131]
47. Bragulat V, Dziedzic M, Bruno C, Cox CA, Talavage T, Considine RV, et al. Food-related odor probes of brain reward circuits during hunger: a pilot fMRI study. *Obes Silver Spring Md*. 2010 8;18(8):1566–71.
48. Havermans RC, Roefs A, Nederkoorn C, Jansen A. No rapid recovery of sensory-specific satiety in obese women. *Flavour*. 2012 4 4;1(1):5.
49. Eiler WJA, Dziedzic M, Case KR, Considine RV, Kareken DA. Correlation between Ventromedial Prefrontal Cortex Activation to Food Aromas and Cue-driven Eating: An fMRI Study. *Chemosens Percept*. 2012 3 1;5(1):27–36. [PubMed: 25485031]
50. Stafford LD, Whittle A. Obese Individuals Have Higher Preference and Sensitivity to Odor of Chocolate. *Chem Senses*. 2015 5 1;40(4):279–84. [PubMed: 25771359]
51. Jiang T, Soussignan R, Schaal B, Royet J-P. Reward for food odors: an fMRI study of liking and wanting as a function of metabolic state and BMI. *Soc Cogn Affect Neurosci*. 2015 4;10(4):561–8. [PubMed: 24948157]

52. Sun X, Veldhuizen MG, Babbs AE, Sinha R, Small DM. Perceptual and Brain Response to Odors Is Associated with Body Mass Index and Postprandial Total Ghrelin Reactivity to a Meal. *Chem Senses*. 2016 3;41(3):233–48. [PubMed: 26826114]
53. Yeomans MR, Prescott J. Smelling the goodness: Sniffing as a behavioral measure of learned odor hedonics. *J Exp Psychol Anim Learn Cogn*. 2016;42(4):391–400. [PubMed: 27732049]
54. Farrugia MC, van Kooten MJ, Burke MV, Scheinost D, Constable RT, Small DM. Fingerprinting Adiposity and Metabolic Function in the Brains of Overweight and Obese Humans. *bioRxiv*. 2019 3 1;540997.
55. Sun X, Kroemer NB, Veldhuizen MG, Babbs AE, Araujo IE de, Gitelman DR, et al. Basolateral Amygdala Response to Food Cues in the Absence of Hunger Is Associated with Weight Gain Susceptibility. *J Neurosci*. 2015 5 20;35(20):7964–76. [PubMed: 25995480]
56. DiFeliceantonio A, Nakamura Y, Qiu M, Geha P, Small D. Body weight is related to striatal response to predicted, but not unpredicted milkshake receipt and this relationship is not influenced by baseline cerebral blood flow. In: Society for the Study of Ingestive Behavior 24th Annual Meeting Denver, CO; July 7 – 11.
57. Veldhuizen MG, Bender G, Constable RT, Small DM. Trying to Detect Taste in a Tasteless Solution: Modulation of Early Gustatory Cortex by Attention to Taste. *Chem Senses*. 2007 7 1;32(6):569–81. [PubMed: 17495173]
58. Francis H, Stevenson R. Validity and test–retest reliability of a short dietary questionnaire to assess intake of saturated fat and free sugars: a preliminary study. *J Hum Nutr Diet*. 2013;26(3):234–42. [PubMed: 23190372]
59. Stunkard AJ, Messick S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *J Psychosom Res*. 1985 1 1;29(1):71–83. [PubMed: 3981480]
60. Keast RS. Effects of sugar and fat consumption on sweet and fat taste. *Curr Opin Behav Sci*. 2016 6 1;9:55–60.
61. Gelman Andrew. *Data Analysis Using Regression and Multilevel/Hierarchical Models*.
62. Rogers PJ, Hardman CA. Food reward. What it is and how to measure it. *Appetite*. 2015 7 1;90:1–15. [PubMed: 25728883]
63. Conner MT, Booth DA. Preferred sweetness of a lime drink and preference for sweet over non-sweet foods, related to sex and reported age and body weight. *Appetite*. 1988 2 1;10(1):25–35. [PubMed: 3355124]
64. Drewnowski A, Grinker JA, Hirsch J. Obesity and flavor perception: Multidimensional scaling of soft drinks. *Appetite*. 1982 12 1;3(4):361–8. [PubMed: 7168568]
65. Robinson TE, Berridge KC. The neural basis of drug craving: An incentive-sensitization theory of addiction. *Brain Res Rev*. 1993 9 1;18(3):247–91. [PubMed: 8401595]
66. Lim J. Hedonic scaling: A review of methods and theory. *Food Qual Prefer - FOOD QUAL Prefer*. 2011 Jun 1;22:733–47.
67. Peryam DR, Pilgrim FJ. Hedonic scale method of measuring food preferences. *Food Technol*. 1957;11, Suppl:9–14.
68. Gay C, Mead R. A Statistical Appraisal of the Problem of Sensory Measurement. *J Sens Stud*. 1992;7(3):205–28.
69. Villanueva NDM, Petenate AJ, Da Silva MAAP. Performance of three affective methods and diagnosis of the ANOVA model. *Food Qual Prefer*. 2000 9 1;11(5):363–70.
70. de Araujo IE, Schatzker M, Small DM. Rethinking Food Reward. *Annu Rev Psychol*. 2020;71(1):null.
71. Appelhans BM, Woolf K, Pagoto SL, Schneider KL, Whited MC, Liebman R. Inhibiting Food Reward: Delay Discounting, Food Reward Sensitivity, and Palatable Food Intake in Overweight and Obese Women. *Obesity*. 2011;19(11):2175–82. [PubMed: 21475139]
72. Rollins BY, Loken E, Savage JS, Birch LL. Measurement of food reinforcement in preschool children. Associations with food intake, BMI, and reward sensitivity. *Appetite*. 2014 1 1;72:21–7. [PubMed: 24090537]
73. Kavanagh DJ, Andrade J, May J. Imaginary Relish and Exquisite Torture: The Elaborated Intrusion Theory of Desire. *Psychol Rev*. 2005;112(2):446–67. [PubMed: 15783293]

74. Boswell RG, Kober H. Food cue reactivity and craving predict eating and weight gain: a meta-analytic review. *Obes Rev.* 2016;17(2):159–77. [PubMed: 26644270]
75. Vallis M Sustained behaviour change in healthy eating to improve obesity outcomes: It is time to abandon willpower to appreciate wanting. *Clin Obes.* 2019 4;9(2):e12299. [PubMed: 30746897]
76. Bruce AS, Holsen LM, Chambers RJ, Martin LE, Brooks WM, Zarccone JR, et al. Obese children show hyperactivation to food pictures in brain networks linked to motivation, reward and cognitive control. *Int J Obes* 2005. 2010 10;34(10):1494–500.
77. Dimitropoulos A, Tkach J, Ho A, Kennedy J. Greater corticolimbic activation to high-calorie food cues after eating in obese vs. normal-weight adults. *Appetite.* 2012 2 1;58(1):303–12. [PubMed: 22063094]
78. Feldstein Ewing SW, Claus ED, Hudson KA, Filbey FM, Yakes Jimenez E, Lisdahl KM, et al. Overweight adolescents' brain response to sweetened beverages mirrors addiction pathways. *Brain Imaging Behav.* 2017 8 1;11(4):925–35. [PubMed: 27392791]
79. Mehta S, Melhorn SJ, Smeraglio A, Tyagi V, Grabowski T, Schwartz MW, et al. Regional brain response to visual food cues is a marker of satiety that predicts food choice. *Am J Clin Nutr.* 2012 11;96(5):989–99. [PubMed: 22990034]
80. Rothmund Y, Preuschhof C, Bohner G, Bauknecht H-C, Klingebiel R, Flor H, et al. Differential activation of the dorsal striatum by high-calorie visual food stimuli in obese individuals. *NeuroImage.* 2007 8 15;37(2):410–21. [PubMed: 17566768]
81. Stice E, Yokum S, Blum K, Bohon C. Weight Gain Is Associated with Reduced Striatal Response to Palatable Food. *J Neurosci.* 2010 9 29;30(39):13105–9. [PubMed: 20881128]
82. Stoeckel LE, Weller RE, Cook EW, Twieg DB, Knowlton RC, Cox JE. Widespread reward-system activation in obese women in response to pictures of high-calorie foods. *NeuroImage.* 2008 6 1;41(2):636–47. [PubMed: 18413289]

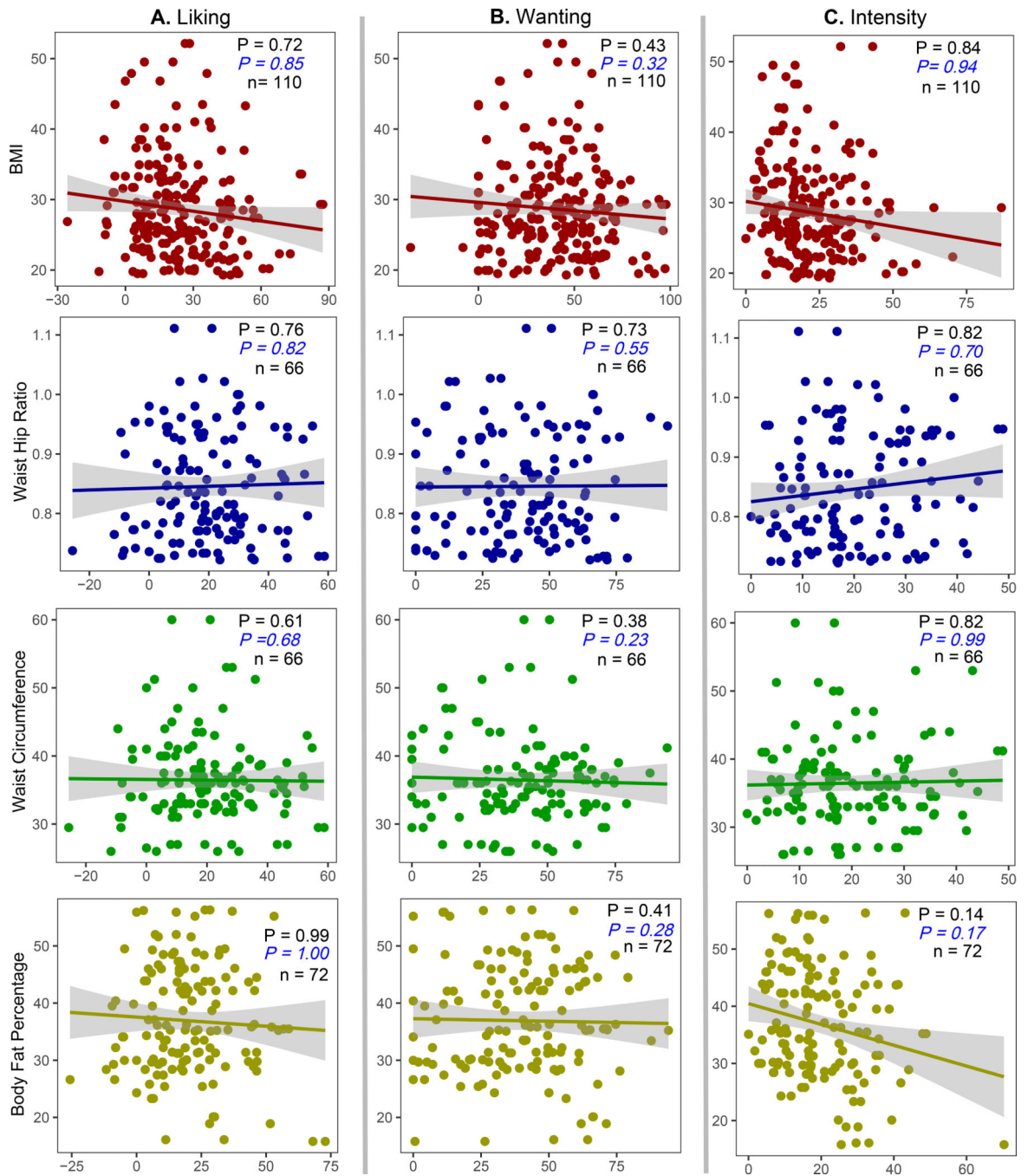


Figure 1. Perceptual ratings of milkshake as a function of adiposity.

Scatter plots representing milkshake A) liking, B) wanting, and C) intensity as a function of body mass index, waist hip ratio, waist circumference and body fat percentage. P values in black were adjusted for sex, study, age and hunger. P values in blue were adjusted for sex, study and age. All p values are uncorrected for multiple comparisons and none are significant.

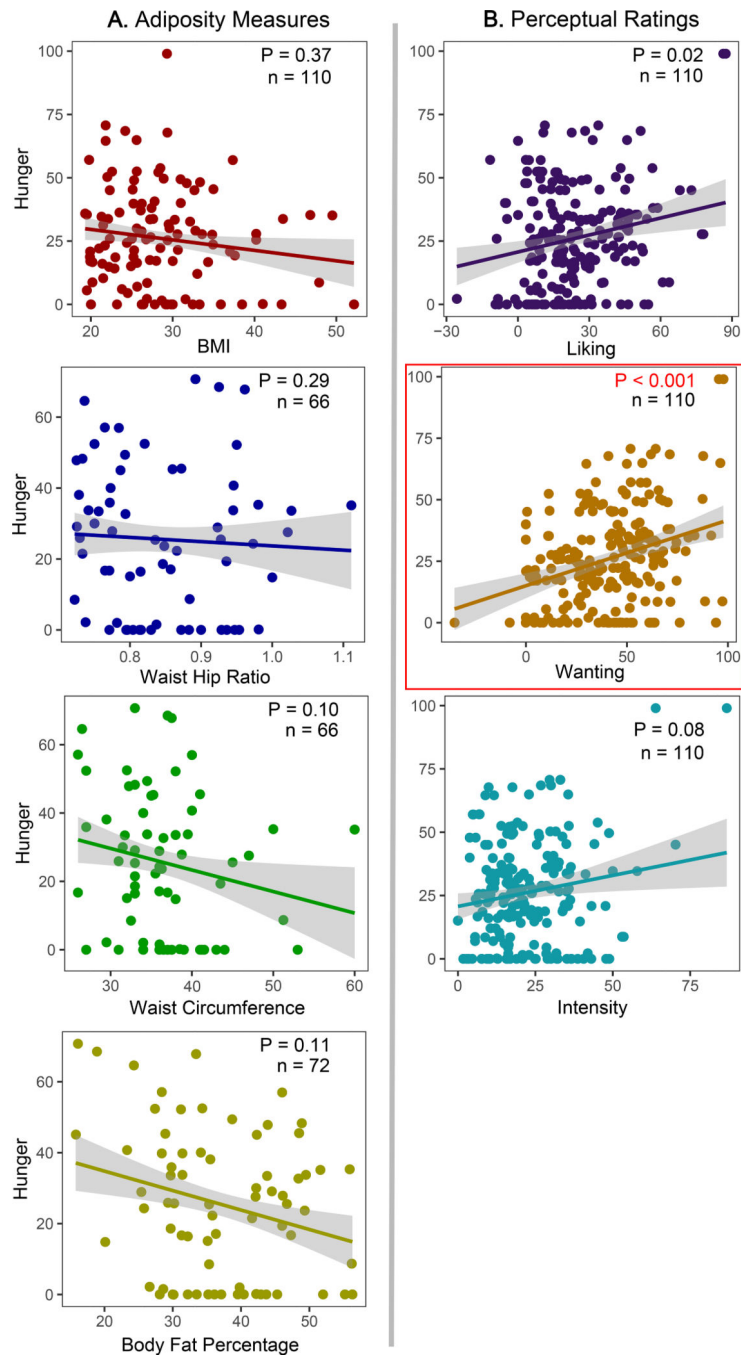


Figure 2. Hunger is related to liking and wanting but not intensity or adiposity. A) Scatter plots of hunger as a function of body mass index, waist hip ratio, circumference, and body fat percentage, adjusted for sex and study. B) Scatter plots of hunger as a function of milkshake liking, milkshake wanting, milkshake intensity, adjusted for sex, study, and BMI. All p values are uncorrected. Hunger as a function of wanting is the only p value that remains significant upon correction and remains with removal of two outliers.

Table 1.

Results of GLMs among DFS scores and perceptual ratings of milkshake and adiposity measures and among TFEQ and perceptual ratings of milkshake and adiposity measures.

		DFS SCORES			TFEQ SCORES		
		Free Sugar Score	Saturated Fat Score	Total Score	Cognitive Food Restraint	Disinhibition	Hunger
PERCEPTUAL RATINGS OF MILKSHAKE	Liking	$F(1,73) = .00, p = 1.00$	$F(1,73) = .18, p = .67$	$F(1,73) = .82, p = .37$	$F(1,82) = .28, p = .60$	$F(1,82) = 1.48, p = .23$	$F(1,82) = 1.29, p = .26$
	Wanting	$F(1,73) = .24, p = .63$	$F(1,73) = .43, p = .51$	$F(1,73) = .30, p = .59$	$F(1,82) = .74, p = .39$	$F(1,82) = 3.71, p = .06$	$F(1,82) = 2.16, p = .15$
	Intensity	$F(1,73) = .05, p = .83$	$F(1,73) = 3.68, p = .06$	$F(1,73) = 3.39, p = .07$	$F(1,82) = .06, p = .81$	$F(1,82) = .74, p = .39$	$F(1,82) = 1.78, p = .19$
ADIPOSITY MEASURES	BMI	$F(1,69) = 6.08, p = .016$	$F(1,69) = .11, p = .74$	$F(1,69) = .99, p = .32$	$F(1,77) = .06, p = .81$	$F(1,77) = .32, p = .57$	$F(1,77) = .07, p = .79$
	Waist-Hip Ratio	$F(1,61) = 1.35, p = .25$	$F(1,61) = .35, p = .56$	$F(1,61) = .22, p = .64$	$F(1,41) = .10, p = .75$	$F(1,41) = 2.42, p = .13$	$F(1,41) = .98, p = .33$
	Waist Circumference	$F(1,61) = 3.05, p = .08$	$F(1,61) = .09, p = .77$	$F(1,61) = .001, p = .98$	$F(1,41) = 1.52, p = .22$	$F(1,41) = .24, p = .63$	$F(1,41) = .00, p = .98$
	Body Fat Percentage	$F(1,67) = 1.13, p = .29$	$F(1,67) = .00, p = .99$	$F(1,67) = .08, p = .77$	$F(1,46) = 1.12, p = .29$	$F(1,46) = .07, p = .79$	$F(1,46) = .11, p = .74$