eat right.

RESEARCH
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Variations in Marginal Taste Perception by Body Mass Index Classification: A Randomized Controlled Trial

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ABSTRACT

Background The propensity to overeat may, in part, be a function of the satisfaction derived from eating. If levels of satisfaction derived from food differ among normal-weight, overweight, and obese adults, the quantification of satisfaction from food may help explain why some people eat more than others.

Objective To quantify the satisfaction obtained from eating one specific food, chocolate, by measuring taste perception as normal-weight, overweight, and obese participants consumed additional pieces of chocolate. To measure the effect of nutritional information on chocolate consumption.

Design Randomized, controlled trial.

Participants/setting We analyzed data on 290 adults; 161 had a body mass index (BMI) that was considered normal ($<$25), 78 had a BMI considered overweight ($\geq$25 and $<$30), and 51 had a BMI considered obese ($\geq$30).

Intervention Participants were given samples of chocolate, one at a time, until they chose to stop eating. With each sample, participants were given a questionnaire. Half of the study participants were randomly selected to receive nutritional information (n=150).

Main outcome measures Perceived taste for each sample.

Statistical analyses performed We used time-series-regression to model perceived taste changes while controlling for participant characteristics.

Results Study participants consumed between 2 and 51 pieces of chocolate with a mean of 12.1 pieces. Average taste perception decreased with each piece. We found no significant difference in taste perceptions between normal- and overweight participants. However, obese participants had higher levels of initial taste perception than normal- and overweight participants (P=0.02). Also, obese participants reported taste perceptions that declined at a more gradual rate than normal- and overweight participants (P<0.01). Self-reported hunger, prior to the study, affected taste perception, but providing nutritional information did not.

Conclusions Obese participants started with higher levels of perceived taste and also experienced slower rates of decline than did normal-weight and overweight individuals.
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OBESITY IS A GROWING PUBLIC HEALTH PROBLEM.[1] Thirty percent of the US population is obese, and obesity-related health problems (eg, diabetes, hypertension) are increasing.[2,3] Causes of obesity are varied, but food consumption decisions play an important role, especially decisions about what foods to eat and how much to consume. Food consumption decisions are driven, in part, by individual taste perceptions.[4,5] As individuals consume more of a food item, their level of perceived taste from additional consumption may tend to decline (ie, additional consumption may become less pleasurable).[6] In the field of economics, declining perceived value as more of an item is consumed is referred to as "diminishing marginal utility."[7] Thus, we refer to the decline in taste perception that individuals experience from consuming one additional unit of a given food item as *diminishing marginal taste perception*. If individuals experience differing initial taste perceptions or rates of diminishing marginal taste, they may consume different quantities of food.

The relationship between perceived taste and quantity consumed has traditionally been referred to as *sensory-specific satiety*. Continued consumption of one type of food creates satiation and thus decreased consumption.[8] Researchers have found that simply thinking about the same food leads to satiety.[9] In addition, obese humans experience a greater preference for variety (ie, great sensory-specific satiety) than nonobese participants.[10] However, sensory-specific satiety research has mostly been of the pre- and post-eating variety: researchers measure satiety before eating and then again after finishing.[11] Satiety is not traditionally measured at points between the beginning and the end. Yet, decisions on the margin—whether to eat another piece or not—are important to consider to understand food consumption decisions.

The field of economics is, in large part, about how people make decisions, especially on the margin.[7] Specifically, the economic theory of diminishing marginal utility posits that as an individual consumes more of a good, their marginal utility from additional consumption of that good tends to diminish.[7] The utility individuals derive from food consumption is a function of their taste perceptions. Thus, if utility diminishes with additional consumption, we would expect marginal taste perceptions to diminish with additional consumption as well. Furthermore, the rate at which marginal taste perceptions diminish may differ among normal-weight, overweight, and obese individuals. Quantifying differences in marginal taste perception may represent a new obesity risk factor or obesity phenotype and inform future weight-loss interventions.

In addition, nutritional labeling may affect marginal food consumption.[12] Some prepared foods have had labeling requirements for many years.[13] Recently implemented legislation requires certain restaurants to label foods as well. However, evidence for the effect of food labeling on consumption is mixed.[12,14-18] Studies of stated preferences show effects of nutritional labeling on consumption, but these preferences were often not equivalent to actual choices.[19] Nutritional labeling may affect food consumption differently for obese people because they may value food consumption differently, may experience more pleasure with food consumption, or may taste food differently.[20,21]

This study had three primary objectives: first to model taste perceptions in a longitudinal or time series fashion across the number of samples consumed; second, to determine if taste perceptions, in terms of both the overall level and the rate of decline, differ between normal-weight, overweight, and obese individuals; and finally, to analyze what effect, if any, the availability of nutritional information would have on taste perceptions. This study was approved by the University of Iowa Institutional Review Board (HawkIRB #20125772).

RESEARCH SNAPSHOT

Research Questions: Does marginal taste perception differ among normal-weight, overweight, and obese individuals? Does nutritional information affect marginal taste perception?

Key Findings: In this study of 290 adults, we found no significant difference in taste perceptions between normal and overweight participants. However, obese participants had initial taste perceptions that were greater than nonobese participants and declined at a more gradual rate than nonobese participants. Providing nutritional information did not affect marginal taste perception.

MATERIALS AND METHODS

We recruited participants via an e-mail message to all students, faculty, staff, and retirees of the University of Iowa and through posters and flyers at the University of Iowa Hospital. We included adults ages 18 to 80 who could speak and read English and were mentally able to consent. We excluded participants who were prisoners or currently pregnant. We also excluded participants with diabetes or food allergies. Over 1,000 people responded, and 297 participants completed the study between August 14, 2012, and January 16, 2013, but we only analyzed data from 290 participants: seven participants provided insufficient information for analysis (ie, ate only one sample or did not report taste perceptions). We had initially planned to recruit 440 participants and intended to have an equal balance between men and women. Our initial sample size calculation was powered by a Student *t* test. However, after we began the study we discovered we were having a difficult time both recruiting and scheduling male participants. Due to resource and time constraints, we elected to terminate the study after reaching the approximate number of female participants originally planned. This left us with roughly 36% of our proposed sample size for male participants. Because of the limited number of male participants, we used a longitudinal regression model to control for subject sex.

When recruited, participants were told they would be asked to review their taste perceptions while consuming multiple pieces of milk chocolate, but a preference for chocolate was not required. Participants were not given specific instructions about eating or not eating before participating. The study took place in a clinic room in the Clinical Research Unit of the hospital during regular business hours: 9 AM to 6 PM when participants were available.

After each participant gave consent, we measured both their height and weight. Participants were weighed with their clothes and shoes on, and shown their weight. Participants were randomized into "informed" and "uninformed" groups using a 1:1 ratio. A sequence of random numbers was generated before the study began. Each participant was given the next number on the list. Even numbers were assigned to the informed group, and odd numbers were assigned to the uninformed group. The objective of randomizing individuals was to observe the impact of nutritional information on taste perceptions. The informed group was given nutritional information about the chocolate—specifically that each piece had 27 calories and 1.5 g fat—before the chocolate tasting began, and the uninformed group was given this information after they had finished tasting chocolate. Nutritional information was provided to any participant upon request, at any time during the study. To observe the longest possible trend in taste perceptions, we asked participants to eat as much chocolate as they could, but not so much that they felt uncomfortable. We also asked that they eat at least two pieces. We built two booths for participants so that they could not see other participants or the research assistant. There was a small cutout in each booth for the research assistant to slide chocolate samples and other study materials to participants.

Upon entering a booth, the participant was given a pretasting questionnaire, a small bottle of water, a pretzel, and an initial chocolate sample. Participants were given as long as they wanted to complete the surveys and samples. At any time during the study, the participant could pass their empty

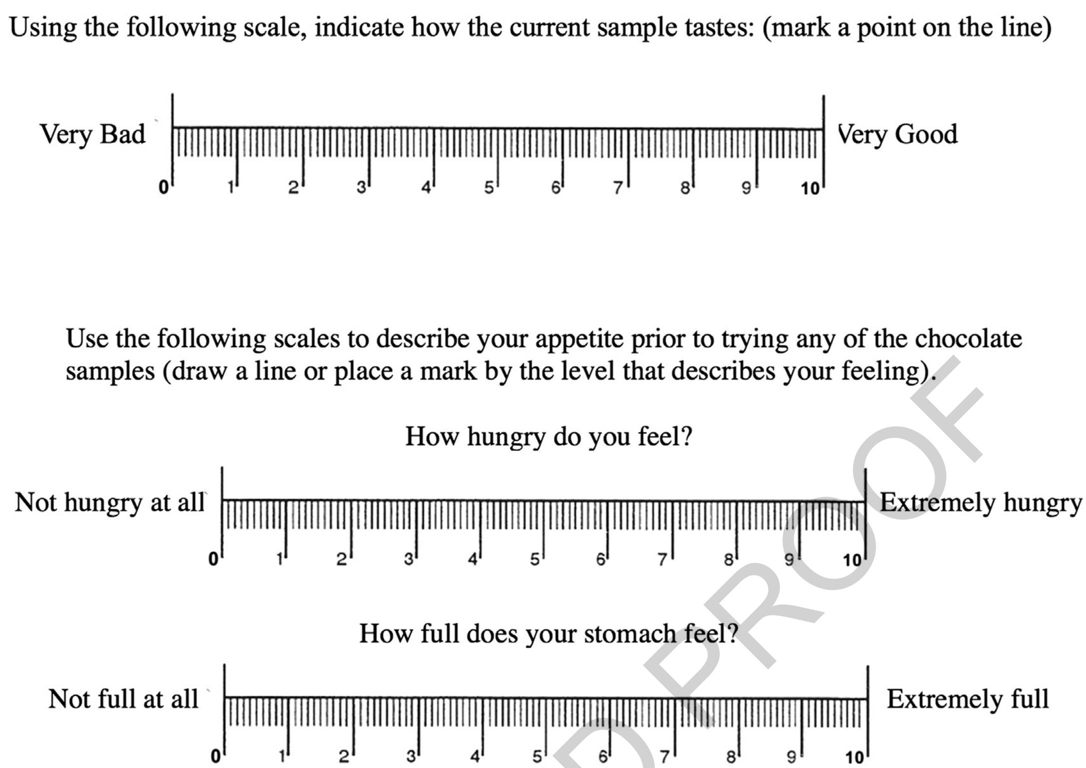

Figure 1. Scales used to evaluate the taste of chocolate samples, hunger, and fullness among adults (n=290) participating in a study of taste perception in response to chocolate.

water bottle back to us and receive a new bottle. Each chocolate sample was individually wrapped in a gold-foil wrapper with no discernible markings. The pretzel provided a control comparison for how much a participant's perception of an alternative food item changed as he or she consumed more chocolate. Pretzels were approximately 1.5 g each and had 6.1 calories. The pretasting questionnaire contained questions about how the participant liked both the pretzel and chocolate sample on a scale from 0 ("very bad") to 10 ("very good"), and how hungry ("not full at all") or how full they felt ("extremely full"). An example of the scales used can be found in Figure 1. After completing this questionnaire, the participant passed it back through the window to the research assistant.

Next, we gave participants another chocolate and a shorter questionnaire asking them to again rate the chocolate sample on a scale of 0 to 10 (Figure 1). After a participant finished a sample and completed the questionnaire, he or she passed the completed questionnaire through the window and waited for the next sample. Participants were required to consume the entire piece of chocolate before moving on to the next sample. This process continued until the participant wished to discontinue participation.

After participants had finished as many chocolates as they wished to eat, they were given a post-tasting questionnaire and a pretzel. The second pretzel sample was meant as a control food. Specifically, we used the pretzel to determine if the changes in marginal taste perception for chocolate were driven by simple changes in hunger or sensory-specific satiety. The post-tasting questionnaire asked them to rate the final pretzel sample, contained questions about their overall impression of the samples they tried, and asked questions about their regular diet. We gave each participant a 2-hour parking pass and $5 gift card to a local coffee shop.

We analyzed each participant's taste perception for a given chocolate sample as a longitudinal function of the number of samples previously consumed. To account for subject-specific preferences, we used a generalized linear mixed model that incorporated a random (subject-specific) intercept. Variables included the number of samples consumed, the participant's body mass index (BMI), age, sex, reported hunger level at the start of the study, and an indicator for receiving the nutritional information. We analyzed several possible model specifications, and for each of the control variables, we considered the possibility that the variable might affect a participant's initial level of taste perceptions (ie, have an additive effect) or affect the rate at which perceptions diminished (ie, have an interactive effect on the sample number). We used the Akaike Information Criterion to select the model specification that best fit the data.[22]

BMI categories were defined using standard BMI cutoffs of <25 for normal weight, ≥ 25 and <30 for overweight, and ≥ 30 for obese.[23] Three options for incorporating the effect of BMI on taste perceptions are analyzed: (1) using indicators for the three BMI categories of normal weight, overweight, and obese; (2) using an indicator for obesity alone; and (3) using a continuous variable for BMI.

Finally, we asked participants to report hunger levels and taste perceptions of a control food (ie, a pretzel) before and after consuming the chocolate samples. We tested the difference in mean tastes before and after the study using both a

Table 1. Baseline characteristics according to BMI[a] category of adults (n=290) participating in a study of taste perception in response to chocolate

Variable	Normal weight	Overweight	Obese	Overall	*P* value[b]
n	161	78	51	290	—
BMI					
Mean	21.8	27.1	35.1	25.5	—
SD[c] (range)	2.0 (17.3-25.0)	1.5 (25.0-30.0)	5.5 (30.0-55.3)	5.7 (17.3-55.3)	
Informed (%)	83 (52)	42 (54)	25 (49)	150 (51)	0.86
Age					
Mean	35.2	42.5	44.7	38.8	<0.001
SD (range)	15.5 (18-75)	16.3 (18-72)	15.1 (18-74)	16.1 (18-75)	
Female (%)	134 (83)	52 (67)	46 (90)	233 (80)	0.001
Race (%)					0.001
American Indian	0 (0.0)	0 (0.0)	1 (2.0)	1 (0.3)	
Asian	23 (14.3)	4 (5.1)	2 (3.9)	29 (10.0)	
African American	2 (1.2)	1 (1.3)	5 (9.8)	8 (2.8)	
Hispanic	6 (3.7)	0 (0.0)	1 (2.0)	7 (2.4)	
Caucasian	132 (82.0)	72 (92.3)	44 (86.3)	248 (85.5)	
Other	0	1 (1.3)	0 (0.0)	1 (0.3)	
Education (%)					0.50
Some high school	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	
High school degree	16 (9.9)	6 (7.7)	2 (3.9)	24 (8.3)	
Attended college	28 (17.4)	21 (26.9)	11 (21.6)	60 (20.7)	
Undergraduate degree	57 (35.4)	24 (30.8)	22 (43.1)	103 (35.5)	
Graduate degree	60 (37.3)	27 (34.6)	16 (31.4)	103 (35.5)	
Income ($)					0.11
<20,000	58 (36.0)	21 (26.9)	7 (13.7)	86 (29.7)	
20,000-45,000	40 (24.8)	22 (28.2)	15 (29.4)	77 (26.6)	
45,000-65,000	33 (20.5)	17 (21.8)	18 (35.3)	68 (23.4)	
65,000-90,000	15 (9.3)	10 (12.8)	8 (15.7)	33 (11.4)	
>90,000	15 (9.3)	8 (10.3)	3 (5.9)	26 (9.0)	
Initial hunger score					0.21
Mean	4.2	3.78	4.4	4.1	
SD (range)	2.3 (0-10)	2.1 (0-8.6)	2.0 (0.5-8.6)	2.2 (0-10)	
Total samples eaten					0.36
Mean	11.6	12.5	13.0	12.1	
SD (range)	6.8 (2-51)	6.3 (5-35)	7.3 (5-35)	6.8 (2-51)	
Initial chocolate taste					0.09
Mean	7.32	7.5	7.9	7.4	
SD (range)	1.9 (1-10)	1.8 (1.6-10)	1.7 (4.0-10)	1.9 (1-10)	
Change in taste					0.84
Mean	−2.11	−2	−1.9	−2.0	
SD (range)	2.3 (−8.9 - +3)	2.2 (−8.0 - +3)	2.1 (−7.0 - +3)	2.2 (−8.9 - +3)	

(*continued on next page*)

Table 1. Baseline characteristics according to BMI[a] category of adults (n=290) participating in a study of taste perception in response to chocolate (*continued*)

Variable	Normal weight	Overweight	Obese	Overall	*P* value[b]
Time in study					0.28
Mean	26.1	28.5	27.3	26.9	
SD (range)	11.1 (2-81)	10.1 (13-53)	10.3 (15-55)	10.7 (2-81)	

[a]BMI=body mass index.
[b]Reported *P* values compare statistical differences between normal-weight, overweight, and obese participants.
[c]SD=standard deviation.

paired Student *t* test and the Wilcoxon signed-rank test (and report the most conservative estimate). All other statistical comparisons across BMI categories were made using either a χ^2 test, for categorical variables, or one-way analysis of variance, for numerical values.

RESULTS

Table 1 presents summary statistics for participant demographics in the study. A total of 290 individuals completed the study. Most participants were female (80%), but there was a wide variety of ages (18 to 75 years). The average person was on the border between normal and overweight (BMI=25.5). During the study, the median number of chocolates eaten was 10. On average, participants spent 26.9 minutes tasting chocolate in total and around 2.7 minutes per piece of chocolate. The perceived taste of the chocolate samples, from the first to the last sample that a participant tasted, decreased by around 2.0 points, on average. Most participants (82.7%) reported a net decline in perceived taste from their first to last chocolate sample; however, 33 participants (11.4%) reported a net increase.

Figure 2 plots the average reported taste perceptions by the sample number for the three BMI categories. This figure has three notable features. First, average taste perceptions decreased, in a fairly monotonic fashion, as the sample number increased. Second, obese participants reported consistently greater taste perceptions than nonobese participants. For example, for all samples consumed, obese participants rated the samples around 0.5 points higher (on a 10-point scale) than overweight

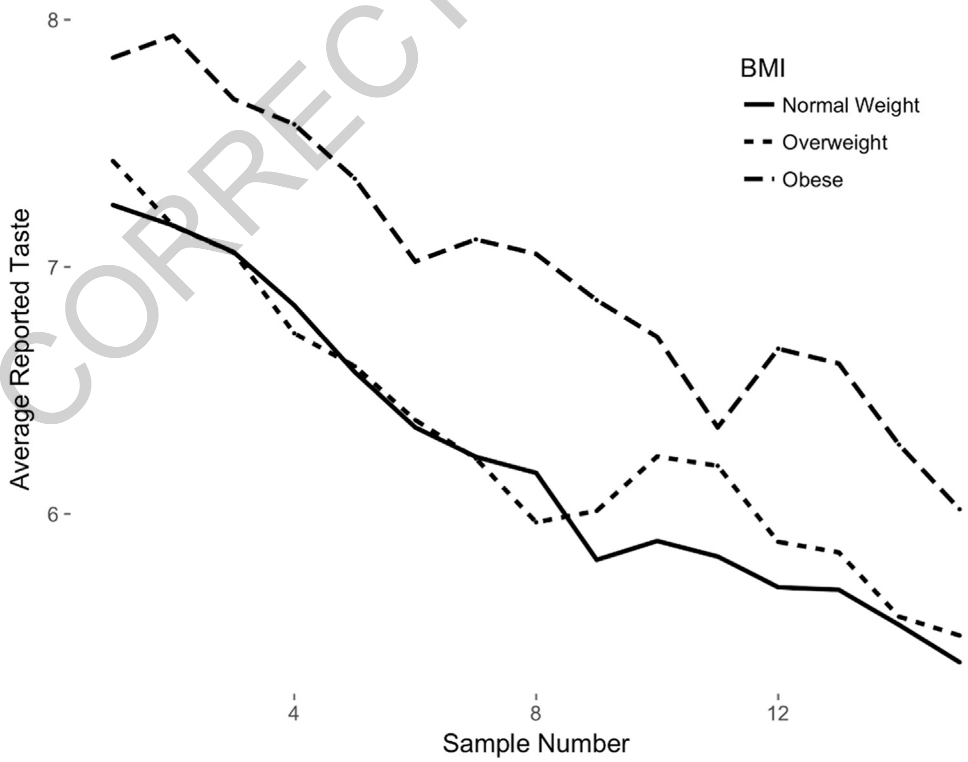

Figure 2. Change in taste perceptions of chocolate by body mass index (BMI) category. As the number of chocolate samples consumed increased, participants reported lower taste perceptions, on average. Obese individuals tended to report higher taste perceptions compared with normal-weight or overweight individuals (*P*=0.02).

Table 2. Regression results for the optimal model specification in a study of marginal taste perception among adults (n=290)[a]

Covariate	Coefficient (SE[b])	95% CI
Intercept	7.0449** (0.2134)	6.6269-7.4630
Sample number	−0.1392** (0.0090)	−0.1568 - −0.1215
Obese BMI[c]	0.5162* (0.2492)	0.0261-1.0063
Obese BMI : sample no.[d]	0.0447** (0.0118)	0.0216-0.0677
Hunger level	0.1324** (0.0441)	0.0457-0.2190
Female : sample no.	−0.0851** (0.0103)	−0.1053 - −0.0650
Akaike information criterion[e]	9196.0305	
Bayesian information criterion[e]	9244.1293	
No. of observations	3,018	
No. of groups	290	

[a]The best fitting model of marginal taste perception contained parameters for number of chocolate samples, obesity indicator, hunger level, along with interaction terms between obesity or female sex and the number of samples. Participant's age and an indicator variable for whether the participant was given nutrition information before the study were considered but not included in the final model because they were insignificant and decreased the model's fit.
[b]SE=standard error.
[c]BMI=body mass index.
[d]A colon represents an interaction between two variables.
[e]Model fit was assessed using Akaike Information Criterion and the Bayesian Information Criterion.
*$P<0.05$.
**$P<0.01$.

and normal-weight participants. Third, the taste perceptions of normal-weight and overweight participants followed a nearly identical downward trend, distinct from the curve for obese participants. The slight divergence between the normal and overweight group averages, occurring at sample number 10, was driven by a handful of participants who discontinued participation around the 10th sample.

We next developed regression models to explain an individual's taste perceptions as a longitudinal function of the sample number. We found the relationship between sample number and perceived tastes to be linear. Across all specifications that we explored, we found the model using a single cutoff for obesity consistently produced the best fit. We found no evidence of a difference in taste perceptions between normal-weight and overweight participants in any of the models that we analyzed. Finally, we found no evidence that participant age nor the randomization of nutritional information had any effect on taste perceptions. These variables were insignificant, diminished model performance, and were removed from the final model.

Table 3. Hunger level and taste perception of control food (pretzel) before and after consuming chocolate samples in a study of marginal taste perceptions among adults (n=290)[a]

Variable	Before	After	Difference	*P* value
Mean hunger level[b]	4.14	1.25	−2.89	<0.001
Mean pretzel taste[c]	6.77	6.90	0.13	0.24

[a]Pretzels were used to determine if the changes in marginal taste perception for chocolate were driven by simple changes in hunger or sensory-specific satiety.
[b]Hunger was measured on a 0- to 10-point scale with 0 indicating not hungry.
[c]Pretzel taste perceptions were reported on a 0- to 10-point scale with 0 indicating bad taste.

Table 2 presents the results of the specification that obtained the lowest Akaike Information Criterion across all models. Using this model, we find that female participants experienced a faster decline in taste perceptions: taste perceptions decreased by 0.09 additional points per sample compared with male participants. Individuals that reported being hungrier also started with a higher level of perceived taste, with initial taste perceptions increasing by 0.13 for each additional point on the hunger scale. Obese participants had initial taste perceptions that were, on average, 0.52 points greater than nonobese participants. In addition, obese participants reported taste perceptions that declined at a more gradual rate (−0.0945 per sample, which is due to −0.1392, the coefficient on sample number, and 0.0447, the coefficient on the interaction between sample number, and the obesity indicator) than nonobese participants (−0.1392 per sample).

Table 3 reports the mean and difference in reported hunger levels and control-pretzel taste perceptions before and after the study's chocolate samples were administered. In general, study participants reported hunger levels decreased by around 3 points, on a 10-point scale, over the course of the study; however, the perceived tastes of the pretzel sample did not change.

DISCUSSION

Our results demonstrate that people experienced diminishing marginal taste perceptions for chocolate as more was consumed, a phenomenon consistent with both economic theory and the concept of sensory-specific satiety. Moreover, we found that obese participants rated each chocolate sample more highly than nonobese participants, and their taste perceptions decreased at a slower rate than nonobese participants. In contrast, we found no difference between overweight and normal-weight participants. Thus, if participants continue to consume food until they reach a similar level of absolute taste perception, obese participants would need to consume more chocolate than nonobese participants.

Our findings indicate that obese participants needed to consume a greater quantity of chocolate than nonobese participants to experience a similar decline in taste perceptions. Specifically, obese women needed to eat 12.5 pieces of chocolate to fall to the same level of taste perception as nonobese women who ate only 10 pieces, which in our chocolate samples corresponded to a difference of 67.5 calories. Our finding that obese participants, on average, tended to report a greater level of taste perception for a given quantity of chocolate than nonobese participants may, in part, explain why obese people consume more than nonobese people. If our findings are generalizable to other food, they may help inform future interventions. Indeed, strategies aimed at reducing obesity may need to account for differences in the perceived taste; strategies that work for normal-weight or overweight individuals may not work as effectively for obese individuals if they derive more satisfaction from eating additional amounts of food. For example, dieticians might advise obese patients to select or weigh out portions prior to beginning consumption to counteract the effect of difference in marginal perceptions. If marginal perceptions decline more gradually for obese individuals, stopping decisions may be delayed during a continuous period of consumption.

To test the effect of nutritional information, we provided nutritional information for chocolate to randomly selected participants prior to the tasting experience. We found no evidence that individuals who received nutritional information prior to consumption experienced any difference in taste perceptions. In all the models we analyzed, nutritional information had no impact on a participant's initial taste perception or rate of decline. Indeed, research on nutritional information has been mixed. Some approaches seem to nudge customers to choose healthier food options,[12,14,24] but other approaches have found no effect,[15,25] and still others have found a paradoxical effect, whereby customers consumed more calories when given nutritional information.[16] One study, for example, found that when nutritional information was given for sandwiches at Subway restaurants, consumers choose healthier sandwiches but also more calorie-laden side dishes.[16] In addition, attention to food labels may decrease over time.[26] We find that nutritional information, at least when provided for pieces of chocolate, had no effect on marginal taste perception. Thus, providing nutritional information alone may have limited effectiveness in reducing rates of obesity.

We found that diminishing taste perceptions are not solely the result of satiation: pretzels consumed at the beginning of the study were reported to provide the same taste perception as pretzels consumed at the end of the study, despite substantial declines in reported hunger over the study period. Instead, marginal taste perceptions appear to diminish due to a type of sensory boredom, resulting from repeated consumption of the same item. This result is consistent with previous research on the concept of sensory-specific satiety and the economic principle of diminishing marginal utility.[7] Moreover, this observation may offer clues to a link between consumption variety and obesity. Indeed, further research has shown that people are more likely to overeat when more types of foods are offered.[27] Our results also suggest that variety could encourage overeating: even after an average of 12 pieces of chocolate, participants reported levels of marginal taste perception for the final pretzel similarly to the initial pretzel.

Our study has several limitations. First, all participants were volunteers who were specifically recruited to eat chocolate. Thus, these results may not be generalizable to other populations or foods other than chocolate. Other types of food (eg, bitter or salty) may lead to different results. Indeed, research has shown that obese individuals prefer the smell of chocolate more than nonobese individuals.[28] Second, our participants were predominantly female. Although we attempted to control for sex in each of the models in our analysis, our results may be less generalizable to a male population. Finally, participants were aware they were being studied and, as a result, could be subject to an observer effect. We attempted to mitigate this effect as much as possible by isolating participants from researchers and other participants using individual tasting booths. However, participants may still have responded or consumed in a manner unique to our laboratory environment.

Despite these limitations, we demonstrated diminishing marginal taste perceptions for food through the consumption of chocolate. Taste perceptions differed among obese and nonobese individuals, with obese individuals needing to consume more chocolate to experience similar declines in perception as nonobese individuals. In addition, we did not find nutritional information to effect taste perceptions. Thus, our findings suggest that understanding and manipulating taste perceptions, in addition to targeting nutritional awareness, may be crucial to understanding and preventing obesity. Future work should also attempt to determine if differences in taste perceptions are a cause of obesity, or if obesity leads to higher levels of marginal taste from food.

CONCLUSIONS

We identified a consistent association between taste from food, specifically chocolate, and BMI. Obese participants started with higher levels of perceived taste and also experienced slower rates of decline than did normal-weight and overweight individuals. This may represent a behavioral phenotype that could be tested with other types of food.

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P. M. Polgreen conceived of the study. P. M. Polgreen, A. C. Miller, L. A. Polgreen, and E. M. Segre helped design the study. All authors collected data. A. C. Miller analyzed the data and wrote the first draft of the manuscript. All authors wrote and reviewed subsequent drafts.