

## Original Article

# Obese Individuals Have Higher Preference and Sensitivity to Odor of Chocolate

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## Abstract

The worldwide epidemic of obesity has inspired a great deal of research into its causes and consequences. It is therefore surprising that so few studies have examined such a fundamental part of eating behavior: our sense of smell. The aim of the present study was to examine the differences in olfaction in obese and nonobese individuals. Participants ( $n = 40$ ) categorized as obese (body mass index  $\geq 30$ ) or nonobese (body mass index  $< 30$ ) completed a standardized olfactory threshold test to an ecologically valid food-related odor (chocolate), followed by a taste test. We found that compared with those not obese, obese individuals rated the chocolate odor as more pleasant and were substantially more sensitive to the odor. There was also evidence that their sense of taste was more acute for sour and salty tastants. Correlational analyses further revealed that those measures of olfaction and taste were positively associated with body mass index. These findings suggest that obese individuals show increased sensitivity and preference for an odor associated with energy dense foods. They also suggest that differences in our sense of smell offer a promising area for future research in obesity.

**Key words:** BMI, obesity, odor, olfaction, sensitivity

## Introduction

Obesity is a worldwide problem that carries serious health risks including cardiovascular disease and diabetes (Malnick and Knobler 2006). It also places a significant burden on a nation's health care resources and in the United Kingdom alone in 2007, was estimated to cost the National Health Service £4.2 billion (Morgan and Dent 2010). The fact that these problems are now affecting developing countries (Popkin et al. 2012) highlights the truly global nature of this epidemic. This makes the examination of the factors involved in obesity a top priority for all countries around the world. Obesity is the product of energy consumption surpassing energy expenditure, but understanding why some individuals have a higher propensity toward obesity is necessarily complex, involving a number of factors including lifestyle, metabolism, and genetics (Aronne et al. 2009). One aspect that has received relatively little attention is the role of our sense of smell in obesity. This is surprising, given that the sensory properties of food play a key role in food preference and our ability to detect those properties is generally down to our sense of

smell more than our other senses (Murphy et al. 1977; Murphy and Cain 1980). Hence the vast majority of what we commonly refer to as the "taste" of food is actually processed by the olfactory and not taste system (Rozin 1982; Wysocki and Pelchat 1993). In an era of unprecedented growth of highly processed foods that populate our supermarkets, food manufacturers must compete for our custom and one central factor is food flavor. One could therefore infer that our ability to acquire a liking for these new flavors and foods is driven to a large extent by our olfactory system. Additionally in recent years, evidence has suggested an even greater role for our sense of smell in food intake. For instance, we have known for some time that critical drivers of hunger and satiety are controlled at the cellular level by peptides and hormones such as orexin and insulin and that these systems are expressed in olfactory-related parts of the brain. More recent work has shown that these metabolic factors target the olfactory bulb and olfactory mucosa and hence are involved in the initial steps of processing odors, before being relayed to higher parts of

the brain (Palouzier-Paulignan et al. 2012). These higher parts of the brain include the orbitofrontal cortex, a region believed to be key in associating the reward value of the sensory (including smell and taste) properties of food (Rolls 2005).

Given the role of our sense of smell in eating behavior, a pertinent question is whether there is a difference in olfactory function between obese and nonobese individuals. In part answer to this, human functional magnetic resonance imaging work demonstrated that exposure to preferred food odors led to differences in brain activation; for obese individuals, there was greater activity in the hippocampal and parahippocampal areas but in contrast, activity was higher in the posterior insula for lean individuals (Bragulat et al. 2010). This suggests that neural processing of hedonic olfactory information differs in obesity and given the key role of the hippocampus in memory, that such cognitive processes may also be implicated in compulsive overeating. From a different perspective, research (Trellakis et al. 2011) found that the generally disliked odor of black pepper oil was rated as significantly less pleasant in obese versus nonobese individuals. One possible explanation for this finding is that the association of an odor to bitter tasting foods of generally lower calorific value is more negative in obese versus nonobese individuals.

In terms of more functional aspects of olfactory function, there is a surprising shortage of research. One study found that the incidence of olfactory dysfunction was higher in morbidly obese (body mass index [BMI] > 45) compared with moderately (BMI < 45) obese individuals (Richardson et al. 2004), suggesting a possible link between poorer sense of smell and overeating (see also related animal work, Thiebaud et al. 2014). In contrast, when a food odor was used in more recent work, it was found that those high in BMI were better at detecting food odors (Stafford and Welbeck 2011). It could be, therefore, that obese individuals are actually more sensitive to odors associated with food and that this interacts with food consumption. However, that study was based on a median split of BMI, which could be considered as rather arbitrary. An alternative method would be to recruit individuals above and below a certain BMI that corresponds to obesity status, for example, BMI > 30 (Herbert et al. 2006). Additionally, that study (Stafford and Welbeck 2011) did not measure liking for the food odor, which given the subject area and previous findings would appear important. One of the main aims of the current study was therefore to rectify these 2 limitations to test odor hedonics and threshold (sensitivity) in obese and nonobese individuals.

Another aim of the present study was to examine differences in taste perception in these populations. It is important to note that humans have an innate preference for sweet tasting foods (Steiner 1979) that together with an aversion to bitter tastes is likely based on evolutionary adaptation, where sweet frequently signaled the presence of edible and energy-rich food such as ripe fruit, whereas bitter the opposite and possible poisons. In times of food scarcity, where energy expenditure to seek out food was high, these strategies of targeting foods high in sugar and fat were of clear advantage to humans. Evidently, these conditions are now reversed in many countries around the world, with plentiful supplies of such foods available with relatively little effort. From this background, it may appear obvious that obese individuals have simply failed to retrain themselves to the current food landscape and to an extent this is supported by data showing a preference for higher lipid and sucrose tasting foods in obese individuals (Drewnowski et al. 1985; Golay et al. 2005). Additionally, a positive relationship has been found between dietary fat intake and high BMI (Macdiarmid et al. 1998). Hence, obese individuals have a preference for food types associated with

increasing BMI, but what about actual differences in taste perception? One study found that obese individuals rated sweet tastes as less intense than nonobese individuals but reported that sweet tasting food were preferred more by obese subjects compared with leaner individuals (Bartoshuk et al. 2006). Such findings could suggest that an impaired sense of sweet taste in obese individuals results in greater food consumption, presumably to obtain the same levels of reward as their nonobese counterparts. Against that theory however, one study found that individuals with a higher BMI reported a lower preference for sweet tasting foods than leaner individuals (Felsted et al. 2007). Apart from sweet taste, it is also important to consider alterations in perception of savory foods, especially when one considers the increase in the availability of processed foods and their high salt content (Rolls 2003). Interestingly here, there is evidence for *greater* sensitivity to salt in obese versus nonobese groups (Pasquet et al. 2007).

In the present study, we therefore wanted to examine for the first time how sensitive obese individuals were to an ecologically valid food odor (chocolate), associated with highly calorific foods. We also wished to investigate any differences in the perception of taste in 4 tastants (bitter, sweet, salty, and sour). On the basis of previous research, we predict that sensitivity to the chocolate odor would be highest in the obese versus nonobese group and we tentatively expect taste perception would be more acute in the former.

## Method

### Participants

Forty University students (25 females and 15 males) participated in the study and were aged between 18 and 24 years ( $M = 19.9$  years,  $SD = 1.5$  years). Participants were recruited using a variety of online systems (Sona participant booking system, social media) where the study was advertised as examining factors that influence our sense of smell and taste. All participants were nonsmokers, reporting good health and not currently in any weight loss programs or taking appetite suppressants. Participants with problems with their sense of smell and taste were excluded as were underweight individuals ( $BMI < 18.5$ ). All participants gave written informed consent and the study protocol was given ethical approval from the department's ethics committee (British Psychology Society guidelines, consistent with the declaration of Helsinki).

### Design

The study used a between-subjects design where according to participant's (Table 1) BMI, they were allocated to either the nonobese ( $<30$ ) or obese ( $\geq 30$ ) group. The main dependent variables were their olfactory threshold scores and taste acuity measures.

## Materials

### Olfactory threshold test

The odor used for the threshold test was a sweet smelling dark chocolate odorant (Code 0679, Anglo Brands), which was diluted in propylene glycol (Fisher Scientific). The odorant was prepared

**Table 1.** Mean (SE) participant characteristics

	Nonobese	Obese
Age	19.4 (0.3)	20.4 (0.4)
Male/female	5/15	11/9
BMI	20.3 (0.4)	31.3 (0.3)

using fifteen 250-mL squeeze bottles, in 15 dilution steps, starting at 0.125% (Step 1) with each successive step diluted by a factor of 2 using serial dilution to the lowest (Step 15). In addition to the odor containing bottles, for each dilution step, 2 “blank” squeeze bottles (containing dilutant only) were used in the threshold test. Testing commenced by asking participants to smell the bottle with the highest concentration to familiarize themselves with the target odor. They were then presented with the triplet containing the weakest concentration. Following presentation of the last bottle of the triplet (counterbalanced), participants were asked which bottle contained the odor (1, 2, or 3). If the participant answered correctly (and it was the lowest concentration), they were presented with the same triplet again (in a different order) and the task repeated until they made a mistake, which resulted in the triplet containing the next concentration step being presented. Using a single up-down staircase system (as used widely in olfactory research, e.g., Hummel et al. 2007), this was then repeated until there were 7 “turning points,” with the mean of the last 4 points determining the threshold for the individual. Each bottle was held under the participant’s nose ( $\approx 2$  cm) and gently waved between each nostril to ensure optimal inhalation. A blindfold was used by the participants to avoid odor identification. The experimenter wore cotton gloves (Boots) to reduce any cross-contamination of odors.

#### Gustatory test

Suprathreshold taste was examined using a kit, which is part of a larger test from the “Sniffin sticks” battery (Burghart Instruments), which has been used widely in research (Seo and Hummel 2009). In the test here, 4 bottles were used with spray attachments, each containing 10 g distilled water plus the following: sour (0.5 g citric acid), salty (0.75 g NaCl), bitter (0.005 g quinine hydrochloride), and sweet (1 g sucrose). Participants were presented with each tastant (counterbalanced order), which was sprayed directly onto the tongue by the experimenter. After each taste, they completed visual analog scale (VAS) ratings using 100-mm unmarked line labeled “not at all” and “extremely” at either end, with the adjective “intensity,” “pleasantness,” “bitter,” “sweet,” “salty,” and “sour” centered above the line. Participants sipped some water before each taste.

#### Procedure

Participants were instructed to refrain from eating, smoking, and chewing gum, within 2 h of their testing session. The study took place between 0900 and 1300 hours at the University’s Department of Psychology. The room used for the study was large and well ventilated to avoid other odors in the room affecting the results of the odor test. Participants completed an informed consent form followed by ratings of how hungry they felt using VAS. Next, they rated the intensity and pleasantness of the chocolate odor (strongest concentration) followed by the threshold test. They then completed the gustatory test for the 4 taste sprays. On completion of this test, participants were given a full debriefing and thanked for their time.

#### Data analyses

For both olfactory and taste acuity tests, data were analyzed using SPSS (version 22.0 for Windows, SPSS, Inc.). The threshold data were analyzed using a univariate analysis of variance (ANOVA) with group (nonobese/obese) as the between-subjects factor. The same test was applied separately for the odor ratings (intensity and pleasantness). For the taste acuity tests, a multivariate ANOVA was used in order to explore each tastant’s ratings for bitterness, sweetness, saltiness, sourness, pleasantness, and intensity, using group (nonobese/

obese) as the between-subjects factor. Because previous research has shown evidence for the level of hunger (provided with/without lunch before testing, Stafford and Welbeck 2011) to influence olfactory sensitivity, we completed the above analyses (including taste) with baseline hunger ratings as a covariate. This revealed no significant effect of hunger and for clarity we present the unadjusted means in Results.

## Results

### Odor tests

For the threshold test, analyses revealed a significant effect of group,  $F(1, 38) = 32.24, P < 0.001, \eta^2 = 0.46$ , where consistent with prediction, the obese group was more sensitive to the chocolate odor ( $M = 14.13$ , standard error [SE] = 0.38) than the nonobese group ( $M = 10.24$ , SE = 0.57) (Figure 1). For the VAS ratings, we found an effect for odor pleasantness,  $F(1, 38) = 7.21, P = 0.01, \eta^2 = 0.16$ , where as expected, obese individuals rated the chocolate odor as more pleasant ( $M = 71.5$ , SE = 5.2) compared with the nonobese group ( $M = 53.9$ , SE = 4.0).

### Taste tests

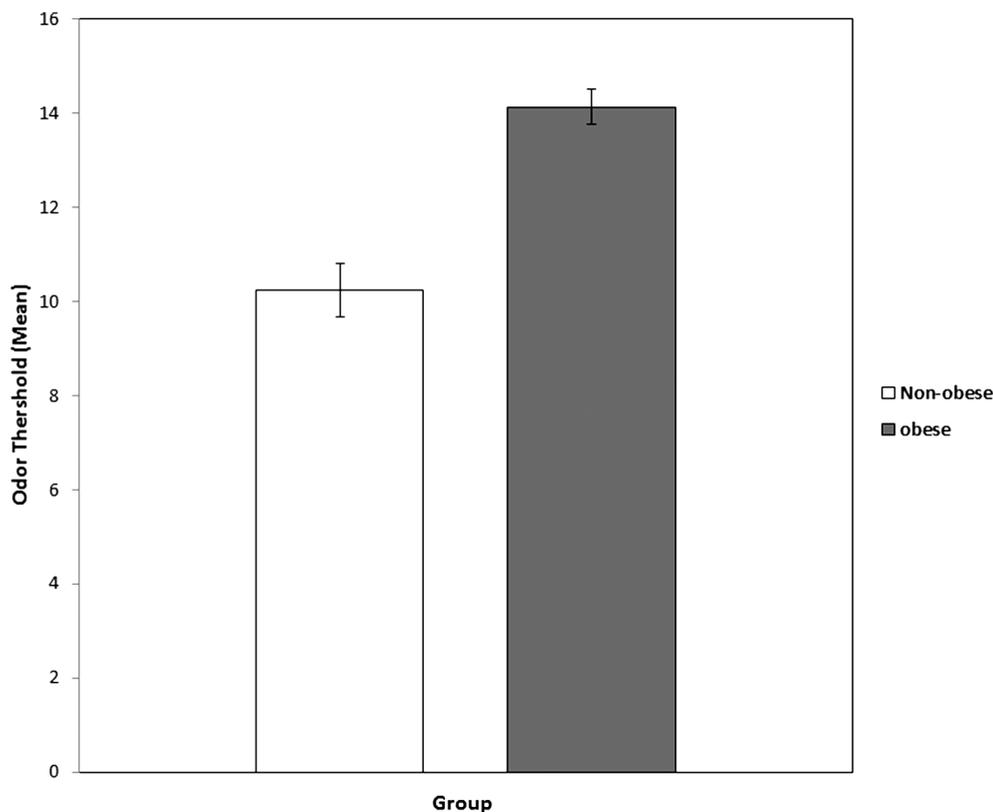
Analyses of the taste VAS ratings revealed significant effects for salty,  $F(1, 38) = 5.39, P = 0.03, \eta^2 = 0.12$ , with the obese group rating the tastant as more salty ( $M = 94.8$ , SE = 1.5) than the nonobese group ( $M = 89.0$ , SE = 2.0). Similarly, for the sour tastant,  $F(1, 38) = 4.20, P < 0.05, \eta^2 = 0.10$ , we found the obese group rated the tastant as higher in sourness ( $M = 91.2$ , SE = 2.2) than the nonobese group ( $M = 80.2$ , SE = 4.9). The effects for bitter and sweet tastants were not significant. These findings partially agree with the prediction of higher taste acuity in the obese versus nonobese group.

### Correlations

To further explore the relationship between BMI, olfaction, and taste, we completed correlations between BMI and the variables where we found clear differences in the above analyses: odor threshold, pleasantness, sour tastant (sour), and salt tastant (salty). As can be seen in Table 2, the analyses demonstrated that all of these measures were positively associated with BMI, with stronger associations for the 2 olfactory measures. These findings suggest that increases in these dimensions of olfaction and gustation are associated with higher BMI.

## Discussion

The main findings of the study were that consistent with prediction, obese individuals (BMI  $\geq 30$ ) were better at detecting the chocolate odor compared with the nonobese group. To our knowledge, this is the first study to specifically examine olfactory threshold to a food odor in obese versus nonobese adults. The direction of the finding is consistent with our previous study (experiment 2) (Stafford and Welbeck 2011) where those high in BMI showed higher acuity to a food-related (herbs) odor. Additionally, by recruiting participants with a widely used BMI threshold, we can be more confident that the effects relate to obesity, which also permits comparison to related research. Previous work in this area has found evidence for higher incidences of olfactory dysfunction in obese populations (Richardson et al. 2004), which might appear to contradict the current findings. However, unlike the present work, that study did not utilize an odor specifically related to food, which may well account for the divergent findings. Indeed, in our previous study (experiment



**Figure 1.** Mean ( $\pm$ SE) olfactory threshold for nonobese and obese groups.

**Table 2.** Bivariate correlations between BMI and olfactory and gustatory measures ( $n = 40$ )

	$r$	Significance
Olfactory threshold	0.66	$P < 0.001$
Olfactory pleasantness	0.42	$P = 0.007$
Salty taste—salty	0.32	$P = 0.047$
Sour taste—sour	0.37	$P = 0.02$

1) (Stafford and Welbeck 2011), olfactory sensitivity to a “nonfood” odor was also found to be poorer in those with higher BMIs, consonant with that earlier work. Collectively these findings suggest that obese groups are characterized by having a better sense of smell to food but not nonfood odors. Another novel finding was that the pleasantness ratings for the chocolate odor were higher in the obese versus nonobese group. Interestingly, an earlier study reported no differences in odor pleasantness for benzaldehyde (bitter almonds) between healthy young obese and nonobese individuals (Thompson et al. 1977), whereas at the other end of the hedonic spectrum, work found that pleasantness for a black pepper oil was lower in obese compared with nonobese subjects (Trellakis et al. 2011). Taken together, it could be that differences in pleasantness between obese/nonobese groups materialize at the extreme ends of the spectrum. So, for odors such as chocolate that have a clear association to highly calorific foods, preference is clearly visible in obese individuals, whereas the reverse is true for odors such as black pepper oil that have a much weaker association to energy dense foods. Given these sharp contrasts in both sensitivity and preference, it could be theorized that alterations in processing food odors in obese populations might actually facilitate excessive food intake. Relevant here,

the orbitofrontal cortex is the center for bringing together sensory inputs from smell and taste to produce overall perception of taste (Rolls 2005); the same area has also been shown to be activated during a reward/punishment task related to addictive behavior such as gambling (Rolls and Grabenhorst 2008). If we also view obesity as a form of addiction, as proposed elsewhere (Latner et al. 2014), it could be that odors related to highly rewarding foods act as “kindling” to induce food craving, analogous to how drug cues invoke craving in drug addicts (Ballenger and Post 1978; Robinson and Berridge 1993). Furthermore, incentive sensitization theories of addiction propose that addicted individuals are overly sensitized to drug cues, suggesting that even short exposures to drug associated paraphernalia (e.g., packet of cigarettes) can induce craving and drug seeking (Robinson and Berridge 1993). In a similar way, obese individuals are more sensitive to food odors and presumably would work harder to secure the associated foods. In support of this, animal work has shown that obese mice were faster to detect food than nonobese mice (Getchell et al. 2006), suggesting a greater motivation to seek out food rewards.

The present study also found differences in taste perception in obese versus nonobese groups. The salty tastant was perceived as more salty in obese compared with nonobese individuals, which is in general agreement with previous threshold work where sensitivity was higher for salt in massively obese compared with nonobese adolescents (Pasquet et al. 2007). Better detection of salty foods might also be important in the finding that obese versus lean adults consumed a higher proportion of their dietary energy from salty foods (Cox et al. 1999). However, this would also seem to predict greater sensitivity to other savory tastants such as umami (monosodium glutamate), which was in fact found to be poorer in obese versus normal weight females (Pepino et al. 2010), but paradoxically

better in overweight compared with normal weight men (Donaldson et al. 2009). It therefore appears that at present, there is no clear relationship between sensitivity to savory tastants and obesity. In terms of our finding that the sour tastant was perceived as more sour in the obese versus nonobese group, this may support the finding of increased neophobia (fussy eaters) in obese compared with non-obese children (Monneuse et al. 2008). Hence, one might theorize that if individuals are rating the sour tastant as higher in sourness, this might be a factor in obese children's greater fussiness to foods that are generally more sour, which also tend to be foods lower in energy density.

The correlational analyses further revealed that increases in olfactory (sensitivity and pleasantness) and taste (salty/sour acuity) were associated with BMI. This could be interpreted as broader evidence for the influence of smell and taste in weight increases, but of course neither directionality nor causality can be shown from these data alone; hence, it could also be the case that such alterations in olfactory/gustatory function are a consequence of increased BMI. Interestingly, this latter explanation may be the more likely, because from a different perspective, the olfactory function of recovering anorexics began to improve as BMI increased (Aschenbrenner et al. 2008).

The current study used a food odor high in ecological validity. Nevertheless, future research is needed to understand how generalizable these findings are not only to other "sweet"-related odors but also to odors connected to savory foods, for example, pizza. It also needs to be recognized that the taste tests used in this study were looking at taste acuity/perception rather than taste threshold (sensitivity). We also recognize that because the taste tests were always completed after the olfactory tests, there is a possibility of an order effect; performance on taste tests affected by olfactory tests. The rationale for using a fixed test order, as with many other studies (Aschenbrenner et al. 2008; Seo and Hummel 2009; Stafford et al. 2013), is to avoid the larger problem of our sense of smell being affected by recent consumption. Nevertheless, to avoid this problem, future studies could possibly test participants on smell and taste at different sessions. In terms of the subjective (VAS) ratings participants made for the odor and tastants, it could be argued that a more precise measure would have been the General Labeled Magnitude Scale (Bartoshuk et al. 2005). The advantage of that scale is that it attempts to take account of differing perceptions of "not at all" and "extremely." On a broader point, though we found differences in olfactory/gustatory processing between obese and nonobese individuals, these tests were completed independently, which is in contrast to the interactive way smell and taste operate during eating. Hence, further work is required to examine if such contrasts also appear in overall flavor perception, necessarily using retronasal rather than orthonasal olfactory designs. Such research should also investigate differences in the taste perception of dietary fat, especially as recent work has shown that dietary fat intake was associated with taste sensitivity (Tucker et al. 2014).

In summary, we found that an odor strongly associated with sweet calorific foods was found to be more pleasant by obese individuals who were also better at detecting the odor compared with those not obese. Though differences in salty/sour taste perception were also found, it is theorized that alterations in olfactory function to food odors may well be a more fruitful area of research in understanding obesity.

## Conflict of Interest

The authors declare no conflicts of interest.

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