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Food Preferences and Obesity

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Obesity is a multifactorial disease with several potential causes that remain incompletely understood. Recent changes in the environment, which has become increasingly obesogenic, have been found to interact with individual factors. Evidence of the role of taste responsiveness and food preference in obesity has been reported, pointing to a lower taste sensitivity and a higher preference and intake of fat and, to a lesser extent, sweet foods in obese people. Studies in the last decades have also suggested that individual differences in the neurophysiology of food reward may lead to overeating, contributing to obesity. However, further studies are needed to confirm these findings. In fact, only a limited number of studies has been conducted on large samples, and several studies were conducted only on women. Larger balanced studies in terms of sex/gender and age are required in order to control the confounding effect of these variables. As many factors are intertwined in obesity, a multidisciplinary approach is needed. This will allow a better understanding of taste alteration and food behaviours in obese people in order to design more effective strategies to promote healthier eating and to prevent obesity and the related chronic disease risks.

Keywords: Obesity; Food preferences; Taste; Body mass index; Propylthiouracil; Reward

INTRODUCTION

Obesity has nearly tripled worldwide since 1975 [1]. Since then, the availability of food has increased tremendously, particularly processed foods that are high in sweet, fat, and salt. Obesity is a multifactorial disease with several potential causes, but the impact of recent environmental changes, including an overabundance of palatable food and little opportunity to work off the extra energy, appears to be undeniable [2], even if these changes are not sufficient to explain the pandemic [3]. Obesity, which is defined as abnormal or excessive fat accumulation that may impair health [1], is a major risk factor for noncommunicable diseases such as cardiovascular diseases, diabetes, musculoskeletal disorders and some cancers. Furthermore, childhood obesity is associated with a higher risk of obesity, premature death, and disability in adulthood. According to the World Health Organization, children in low- and middle-income countries are more vulnerable to inadequate pre-natal, infant, and young child nutrition. These children are exposed to high-fat, high-sugar, high-salt, energy-dense, and micronutrient-poor foods, which tend to be cheaper but also lower in nutrient quality. These dietary patterns, in conjunction with lower levels of physical activity, have resulted in sharp increases in childhood obesity even as undernutrition issues have remained unsolved [4].

In addition to economic and environmental factors, many other factors are well known to influence food choices and preferences, such as physiological and neurophysiological factors, sensory acuity, psychological traits, and cultural and social aspects [5,6]. Since not everyone who lives in the current obesogenic environment develops obesity, individual-level risk fac-

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tors should be identified in order to develop effective strategies to prevent and treat obesity more effectively.

This paper will review the main sensory, psychological, and physiological factors that influence food choices, contribute to shape food preferences, and have been found to be associated with obesity. Although the literature on the topic is quite wide, many studies have been conducted on a small sample. Table 1 presents studies conducted among more than 40 obese individuals, while studies with smaller samples are also commented upon in this manuscript.

OBESITY AND FOOD PREFERENCES

In simple terms, obesity is a consequence of an energy imbalance, when energy intake exceeds energy expenditure over a considerable period [1]. High-fat and energy-dense diets have been found to be strongly associated with the increased prevalence of obesity worldwide [7]. A higher liking or preference for fats in obese people was reported in several studies [8-18]. This preference for fatty foods seems to be more of a cause of obesity than an effect, as it was also found that children from obese/overweight families had a higher preference for fatty foods than children of normal-weight parents, even if they were not obese [19]. Fatty foods are innately liked, which may be due to multiple reasons, including their orosensory properties and post-ingestive and metabolic effects [12,17,20,21]. Fat is a concentrated source of energy with rewarding post-ingestive effects [20]. Sweet and salty high-fat foods have been proven to be particularly palatable, and gender differences have been reported, with obese women tending to prefer sweet-fat foods [22,23] and obese men tending to prefer savoury-fat foods [22].

Based on a hypothesis of a sweet tooth in obese people, preferences for sweet foods in this group are expected and have been widely investigated. However, the results are mixed. Several studies showed that liking of foods did not substantially differ between obese and non-obese individuals, and reported that obese individuals liked sweetness to the same extent, or even less strongly, than non-obese individuals [24-28]. However, more recent studies have found evidence that obese people like sweet foods more than lean individuals [11,29]. Furthermore, it is well known that even if liking for sweetness is innate, individuals differ in their liking for sweetness. Individuals have different optima of sweetness, and there are individuals for whom an increase in sweetness is associated with an increase in preference. On the contrary, for other individuals, preference decreases as sweetness increases, or it increases up to a certain intensity and then decreases [30,31]. A few studies examined the relationship between the sweet-liking phenotype and body mass index (BMI), with mixed results. While Garneau et al. [32] did not find any association in a sample of children and young adults, Iatridi et al. [33] reported that sweet likers had an higher BMI and fat-free mass but only in the older groups. Based on these findings, the authors suggest that exposure to an obesogenic environment contributes to an increase in sweet-liking.

Sensory-specific satiety, namely the decline of the pleasantness/desire to eat a particular food after eating that food compared to the decline in pleasantness of uneaten foods [34], has been hypothesized to be related to obesity, both positively and negatively [35]. There is some evidence that obese people have lower levels of sensory-specific satiety, which may explain their attitude towards overeating [36,37], but results are inconclusive [38]. However research on sensory-specific satiety has suggested that a reduction in dietary variety of highly palatable, energy-dense foods may be useful in the treatment and prevention of obesity, as it reduces food intake [35].

OBESITY AND TASTE ACUITY

Individuals differ in their taste acuity, which may influence food acceptability and eating behaviours [39,40]. It is well known that individuals differ greatly in their responsiveness to 6-n-propylthiouracil (PROP), and that a heightened response to this compound is associated to a heightened response to bitterness as well as to other sensory properties, such as sweetness, pungency, and even fat [41-43]. This may explain the relationship that has been found between responsiveness to PROP and food preferences, intake, and BMI, even if the results are mixed [39,44]. An inverse relationship between PROP responsiveness and BMI was found in several studies both in the general population [45-47] and in obese individuals [48], but other studies reported no relationship [49,50]. These mixed results may be explained by the many variables that influence the relationship between PROP taste sensitivity and BMI, such as genetic factors, ethnicity, oestrogenic phase, variations in the endocannabinoid system, age, sex, and cognitive factors [44].

Individuals differ greatly also in the density of fungiform papillae in the tongue, which host the taste receptors. A higher density has been associated with heightened sensitivity, but studies on larger samples did not confirm this association [51,52] and rather suggested that other factors play a role apart from the number of papillae, such as taste pore density [53,54]. Recently, some studies reported that obese children [55] and adults [56]

Table 1. Studies on Food Preferences, Taste Responsiveness, and Personality Traits Affecting Eating Behaviours in Obesity (Only Studies with >40 Obese Subjects Are Reported). References, Study Design, Number of Subjects, Gender, Age, BMI, Main Outcomes and the Presence of Sensory Tests (Which Included a Tasting of Solutions, Foods or Beverages) Are Reported for Each Study

Study	Study design	No. of subjects	Age, yr	Gender	BMI, kg/m^2	Outcome: food preferences and/or intake	Outcome: taste responsiveness	Outcome: personality traits and eating behaviours	Including sensory tests
Mendoza et al. (2007) [7]	General population	1,454 Obese 8,233 Non-obese	>20 -	825 Women (16.9% of women) 629 Men (13.1% of men) -	≥30 -	Dietary energy density was associated with a higher BMI in women and trended toward a significant association in men.	-	-	
Dressler et al. (2013) [8]		54 Overweight/obese 29 Lean/normal		83 Women (100%)	>25 <25	Liking for spreadable fats, several types of breads, and other products was higher in overweight/obese individuals.	-	-	
Lampure et al. (2014) [9]	General population	37,181 (*n* obese not reported)	44.4 Mean age women 51.9 Mean age men	28,504 Women (*n* obese not reported)	-	Obese women and men were found to have a strong liking for the fat-and-sweet sensations.	-	-	
Lampure et al. (2016) [10]	General population	664 Obese 24,112 Non-obese	- -	Women (75.8%) Women (75.1%)	- -	Liking for fat and for salt was higher in obese than in non-obese individuals.	-	-	
Bartoshuk et al. (2006) [11]	Attendees at lectures	305 Obese 144 Underweight	-	-	30 (mean) <18.5 (mean)	Sweet foods and fat food liking increased with BMI and was higher in obese than underweight individuals.	-	-	
	Attendees at lectures	3,740 (*n* obese not reported)	-	-	<50	-	The higher the BMI, the lower the perceived sweetness.		Yes
Proserpio et al. (2017) [18]	Obese vs. control group	46 Obese 45 Non-obese	47.86 (mean) 41.64 (mean)	26 Women (56.5%) 21 Women (46.6%)	37.53 (mean) 22.03 (mean)	Liking of samples with the strongest butter aroma was higher in obese individuals.	Sweetness and vanilla flavour of the samples with the strongest butter aroma were perceived as more intense by obese (particularly women).	-	Yes
Drewnowski et al. (1992) [22]	Obese patients	475 Obese	-	386 Women (81.2%) 89 Men	32.9 36.4	Obese men listed mainly protein/fat sources among their favourite foods, while obese women listed mainly carbohydrate/fat sources.	-	-	

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Table 1. Continued

Study	Study design	No. of subjects	Age, yr	Gender	BMI, kg/m^2	Outcome: food preferences and/or intake	Outcome: taste responsiveness	Outcome: personality traits and eating behaviours	Including sensory tests
Drewnowski et al. (1991) [28]	Community-based sample	61 Obese 21 Lean	20–45	29 Women (47.5%) 16 Women (76.2%)	-	Obese subjects characterized by large weight fluctuations showed elevated preferences for sugar and fat mixtures compared with the stable subgroup, while early age at onset of obesity (<10 years) had no significant effects on taste preferences. No differences in preferences for sugar solutions were reported.	No differences in perceptions for sugar solutions were reported.	-	Yes
Spinelli et al. (2021) [50]	General population	166 Obese 2,141 Non-obese	43.88 37.21	86 Women (51.8%) 1,270 Women (59.3%)	33.55 23.05	No association between PROP and BMI in obese and non-obese individuals.	-	Sensitivity to disgust predicted BMI only indirectly (mediated by restrained eating) in non-obese individuals. No association in obese individuals was reported.	Yes
Proserpio et al. (2016) [56]	Obese vs. control group	51 Obese 52 Non-obese	42.00 (mean) 38.38 (mean)	28 Women (54.9%) 27 Women (51.9%)	34.08 21.57	Liking for high-energy dense products was higher in obese than in normal-weight subjects.	Obese subjects showed higher threshold values (=reduced sensitivity) for basic tastes and fat and a reduced number of fungiform papillae compared with non-obese individuals.	No difference in neophobia was reported between obese and non-obese individuals.	Yes
Davis et al. (2004) [72]	Obese vs. control group	40 Obese 108 Non-obese	33.3	148 Women (100%)	>30 <30	-	-	Overweight women were significantly more sensitive to reward than those of normal weight, but more anhedonic than the overweight women.	
Proserpio et al. (2018) [92]	Obese vs. control group	45 Obese 40 Non-obese	43.46 Mean age for women 52.4 Mean age for men 40.38 Mean age for women 41.84 Mean age for men	25 Women (55.5%) 21 Women (52.5%)	37.57 (mean) 22.67 (mean)	-	PROP responsiveness and fungiform papille number were lower in obese men (vs. obese women and non-obese).	Obese individuals were more neophobic than non-obese individuals.	Yes

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Table 1. Continued

Study	Study design	No. of subjects	Age, yr	Gender	BMI, kg/m^2	Outcome: food preferences and/or intake	Outcome: taste responsiveness	Outcome: personality traits and eating behaviours	Including sensory tests
Elfhag et al. (2006) [94]	Obese patients	60 Obese	43.5 Mean age 20–65	44 Women (73.3%)	40.1	-	-	Strong sweet taste was associated with a neurotic personality and strong fat preference with lower levels of restrained eating.	
Interventions									
Altun et al. (2016) [61]	Patients undergoing laparoscopic sleeve gastrectomy (LSG)	52 Obese	19–60	30 Women (57.7%)	32.5–63.0 before surgery	-	Significant improvement in taste acuity to sweet, sour, salty, and bitter tastants in morbidly obese patients after LSG during a follow-up period of 3 months.	-	Yes
Holinski et al. (2015) [62]	Patients undergoing laparoscopic Roux-en-Y gastric by-pass, sleeve gastrectomy, or adjustable gastric banding	44 Obese 23 Lean (control)	47.1 (obese) 39.5 (lean)	29 Women (65.9 %) 15 Women (65.2 %)	BMI >40 or >35 with relevant co-morbidities	About 22.7% of morbidly obese patients were shown to have limited in gustatory and olfactory function; six months after surgery, olfactory and gustatory function was not different when compared to healthy controls.			Yes
Andriessen et al. (2018) [64]	Intervention (low calorie diet)	123 Overweight and obese	18–65	75 Women (60.9%)	27–45 (range)	Decreased preference for high-carbohydrate, high-fat, and low-energy products after the intervention	-	-	
Van Vuuren et al. (2017) [67]	Patients undergoing laparoscopic sleeve gastrectomy (LSG)	106 Obese	42 (mean)	81% Women	Mean BMI before surgery 44	Decreased enjoyment for sweet and fatty foods and decreased desire for fatty and sweet after bariatric surgery (after 4/6 weeks and after 6/8 months); Increase of intensity of sweet and fatty after the LSG (after 4/6 weeks and after 6/8 months).	-	-	

BMI, body mass index; PROP, 6-n-propylthiouracil.

have a lower number of fungiform papillae than normal-weight individuals. In line with these findings, in a longitudinal study, a decrease in abundance of fungiform papillae with increasing adiposity was observed [57]. Furthermore, other authors [58], while not finding differences in the density of papillae, showed that obesity is associated with altered gene expression in taste buds, reporting a consistent reduction in the expression of taste-related genes (in particular reduced type II taste cell genes) in the obese group compared to the lean group. In addition, some studies pointed out an alteration in taste responsiveness in obese individuals, reporting that obese people experience reduced sweetness [11,29], umami [59], and a reduced taste responsiveness in general [56].

Taken together, these results point towards reduced taste sensitivity in obese individuals; however, this reduced taste sensitivity was found to be reversible with weight loss due to surgery. In fact studies of calorie restriction-induced weight loss and bariatric surgery in humans have suggested that taste alterations and food preferences are reversible and consequently may represent secondary effects of obesity [60-64]. However, the possibility cannot be ruled out that other factors than weight loss *per se*, such as reward value and gut-brain-interactions, drive the observed modifications in taste perception [65]. Furthermore, some studies that considered obese individuals after bariatric surgery also reported a lower intake and liking of high-fat and sweet foods [66]. Post-gastric bypass patients reached satiety much faster than was the case before surgery, and the reason for reduced food intake was a lack of "desire" [67]. This may indicate that obesity surgery—and specifically gastric bypass—not only reduces the amount that people eat, but also changes their perception of food and thus their eating behaviours, suggesting the concept of "behaviour surgery" [68]. However, the effects of obesity surgery on the hedonics of taste remain largely unexplored.

BEHIND EATING BEHAVIOURS: FOOD REWARD

Studies in the last decades have also suggested that individual differences in the neurophysiology of food reward may lead to overeating, thus contributing to obesity [69].

A prominent view in the last decades to explain obesity has been the reward deficiency hypothesis [70,71]. This theory postulated that obese individuals find foods less rewarding than other individuals, and consequently eat more foods to accumulate rewarding experiences and so make up their reward deficiency. Consistent with this view, obese women were found to be more anhedonic than overweight women—that is, they were characterized by a diminished ability to experience pleasure from natural reinforcers such as food [72]. An alternative view suggested that the attenuated brain responses to energy-dense foods observed in obese reflect weaker learning signals, rather than a reward deficiency and thus anhedonia [73]. However, emerging evidence suggests that some cases of obesity may reflect an incentive-sensitization brain signature of cue hyper-reactivity, causing excessive "wanting" to eat [74]. According to this view, "liking," which refers to the hedonic impact of a pleasant reward, is distinguished from "wanting," which is defined as the psychological process of incentive salience generated in the form of cue-triggered motivation [74]. Some authors [75,76], but not all [77], have suggested that obesity may be associated with an increased motivation for food consumption ("wanting"), without necessarily any greater explicit hedonic response or pleasure being derived from the orosensory experience of eating ("liking"). Therefore, overeating in obesity may reflect more responsiveness to non-homeostatic stimuli (i.e., driven by environmental and cognitive factors), rather than a defect or failure of endogenous homeostatic systems involved in energy balance [75]. According to the incentive-sensitization theory, obese individuals may be especially vulnerable to developing neural sensitization of dopamine-related mesocorticolimbic systems of "wanting." This would lead to excessive "wanting" to eat, typically triggered by palatable food cues, which could become especially exacerbated in moments of stress or emotional arousal that heighten mesolimbic reactivity [74]. Evidence supporting this explanation comes from neuroimaging studies of obese individuals that have reported a sensitization-type brain activation signature to food cues that is remarkably similar to the signature of people who suffer from drug addiction to drug cues [78-80]. In line with these results, some studies found that obese individuals had an increased attentional bias for food stimuli [81]. However, current results on attentional bias for food cues in obese participants are very mixed, as there is empirical evidence for approach, avoidance, and approach-avoidance attention processes in obese versus healthy weight participants when viewing food cues; thus, further studies are required [82].

PERSONALITY TRAITS AND ATTITUDES AND OBESITY

Attitudes [83], and more recently also personality traits [84-86], have been found to affect food preferences and intake. Individual differences exist in the level to which people experience the emotion of disgust, and higher levels of sensitivity to core disgust have been associated with eating disorders, such as anorexia nervosa, binge eating, and bulimia [87,88]. Furthermore, some studies indicated that defects in experiencing disgust may contribute to overweight and obesity by allowing the overconsumption of food [89-91]. More precisely, Watkins et al. [89] found that lean and obese individuals did not significantly differ in the degree to which they were prone to experiencing disgust (propensity), but obese individuals were less likely to appraise the experience of disgust as negative (sensitivity), which may contribute to their failure to reduce caloric consumption [89]. Furthermore, the authors reported reduced insula activation in obese individuals. These findings raise the possibility that lower disgust sensitivity and reduced insula activation may contribute to the tendency of obese individuals to overeat. In addition, food neophobia, defined as the reluctance to eat novel and unfamiliar foods, was found to be higher in obese individuals and those with a higher BMI [92,93]. Furthermore, a strong sweet taste preference was associated with more neurotic personality traits, in particular lack of assertiveness and embitterment, in obese individuals [94].

CONCLUSIONS

The psychological and physiological mechanisms responsible for obesity are incompletely understood. Evidence of the role of taste responsiveness and food preferences in obesity has been reported, but further studies are needed to confirm previous findings on larger and more balanced (in terms of gender and age) samples. In fact, studies on large samples are limited, and most studies have been characterized by an overrepresentation of women. Balancing for gender and age is extremely important as it is well known that these factors strongly affect taste responsiveness, food preferences, and personality traits, and they may therefore act as confounding factors. Furthermore, sensory tests (both to measure taste responsiveness and liking) have only been used in a limited manner, and when they were used, a variety of different scales and methods were adopted; as a result, it is difficult to directly compare results.

Although there is evidence that obese individuals live in different orosensory worlds than do non-obese individuals, it is unclear how this is associated with food preferences, enjoyment, and reward. As many different factors are intertwined in obesity, a multidisciplinary approach is needed. This will allow a better understanding of taste alterations and food behaviours in obese individuals in order to design more effective strategies to promote healthier eating and to prevent obesity and the related chronic disease risks.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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REFERENCES

1. World Health Organization. Fact sheet: obesity and overweight [Internet]. Geneva: WHO; 2020 [cited 2021 Mar 25]. Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight.
2. Berthoud HR, Lenard NR, Shin AC. Food reward, hyperphagia, and obesity. Am J Physiol Regul Integr Comp Physiol 2011;300:R1266-77.
3. Meldrum DR, Morris MA, Gambone JC. Obesity pandemic: causes, consequences, and solutions: but do we have the will? Fertil Steril 2017;107:833-9.
4. World Health Organization. The double burden of malnutrition: priority actions on ending childhood obesity [Internet]. Geneva: WHO; 2020 [cited 2021 Mar 25]. Available from: https://www.who.int/publications/i/item/9789290227892.
5. Koster EP. Diversity in the determinants of food choice: a psychological perspective. Food Qual Prefer 2009;20:70-82.
6. Monteleone E, Spinelli S, Dinnella C, Endrizzi I, Laureati M, Pagliarini E, et al. Exploring influences on food choice in a large population sample: the Italian Taste project. Food Qual Prefer 2017;59:123-40.
7. Mendoza JA, Drewnowski A, Christakis DA. Dietary energy density is associated with obesity and the metabolic syndrome in U.S. adults. Diabetes Care 2007;30:974-9.
8. Dressler H, Smith C. Food choice, eating behavior, and food liking differs between lean/normal and overweight/obese, low-income women. Appetite 2013;65:145-52.
9. Lampure A, Deglaire A, Schlich P, Castetbon K, Peneau S, Hercberg S, et al. Liking for fat is associated with sociodemographic, psychological, lifestyle and health characteristics. Br J Nutr 2014;112:1353-63.

10. Lampure A, Castetbon K, Deglaire A, Schlich P, Peneau 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;13:74.
11. Bartoshuk LM, Duffy VB, Hayes JE, Moskowitz HR, Snyder DJ. Psychophysics of sweet and fat perception in obesity: problems, solutions and new perspectives. Philos Trans R Soc Lond B Biol Sci 2006;361:1137-48.
12. Drewnowski A. Taste preferences and food intake. Annu Rev Nutr 1997;17:237-53.
13. 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;36:1-7.
14. Ricketts CD. Fat preferences, dietary fat intake and body composition in children. Eur J Clin Nutr 1997;51:778-81.
15. Mela DJ, Sacchetti DA. Sensory preferences for fats: relationships with diet and body composition. Am J Clin Nutr 1991;53:908-15.
16. Lanfer A, Knof K, Barba G, Veidebaum T, Papoutsou S, de Henauw S, et al. Taste preferences in association with dietary habits and weight status in European children: results from the IDEFICS study. Int J Obes (Lond) 2012;36:27-34.
17. 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;48:359-67.
18. Proserpio C, Laureati M, Invitti C, Cattaneo C, Pagliarini E. BMI and gender related differences in cross-modal interaction and liking of sensory stimuli. Food Qual Prefer 2017;56:49-54.
19. Wardle J, Guthrie C, Sanderson S, Birch L, Plomin R. Food and activity preferences in children of lean and obese parents. Int J Obes Relat Metab Disord 2001;25:971-7.
20. Montmayeur JP, le Coutre J. Fat detection: taste, texture, and post ingestive effects. Boca Raton: CRC Press/Taylor & Francis; 2009. Chapter 11, Human perceptions and preferences for fat-rich foods; p. 265-91.
21. Dransfield E. The taste of fat. Meat Sci 2008;80:37-42.
22. Drewnowski A, Kurth C, Holden-Wiltse J, Saari J. Food preferences in human obesity: carbohydrates versus fats. Appetite 1992;18:207-21.
23. Macdiarmid JI, Vail A, Cade JE, Blundell JE. The sugar-fat relationship revisited: differences in consumption between men and women of varying BMI. Int J Obes Relat Metab Disord 1998;22:1053-61.
24. Pangborn RM, Simone M. Body size and sweetness preference. J Am Diet Assoc 1958;34:924-8.
25. Wooley OW, Wooley SC, Dunham RB. Calories and sweet taste: effects on sucrose preference in the obese and nonobese. Physiol Behav 1972;9:765-8.
26. Cox DN, Perry L, Moore PB, Vallis L, Mela DJ. Sensory and hedonic associations with macronutrient and energy intakes of lean and obese consumers. Int J Obes Relat Metab Disord 1999;23:403-10.
27. Cox DN, van Galen M, Hedderley D, Perry L, Moore PB, Mela DJ. Sensory and hedonic judgments of common foods by lean consumers and consumers with obesity. Obes Res 1998;6:438-47.
28 Drewnowski A, Kurth CL, Rahaim JE. Taste preferences in human obesity: environmental and familial factors. Am J Clin Nutr 1991;54:635-41.
29. Sartor F, Donaldson LF, Markland DA, Loveday H, Jackson MJ, Kubis HP. Taste perception and implicit attitude toward sweet related to body mass index and soft drink supplementation. Appetite 2011;57:237-46.
30. Iatridi V, Hayes JE, Yeomans MR. Reconsidering the classification of sweet taste liker phenotypes: a methodological review. Food Qual Prefer 2019;72:56-76.
31. Kim JY, Prescott J, Kim KO. Patterns of sweet liking in sucrose solutions and beverages. Food Qual Prefer 2014;36:96-103.
32. Garneau NL, Nuessle TM, Mendelsberg BJ, Shepard S, Tucker RM. Sweet liker status in children and adults: consequences for beverage intake in adults. Food Qual Prefer 2018;65:175-80.
33. Iatridi V, Armitage RM, Yeomans MR, Hayes JE. Effects of sweet-liking on body composition depend on age and lifestyle: a challenge to the simple sweet-liking-obesity hypothesis. Nutrients 2020;12:2702.
34. Rolls BJ, Rolls ET, Rowe EA, Sweeney K. Sensory specific satiety in man. Physiol Behav 1981;27:137-42.
35. Raynor HA, Epstein LH. Dietary variety, energy regulation, and obesity. Psychol Bull 2001;127:325-41.
36. Epstein LH, Paluch R, Coleman KJ. Differences in salivation to repeated food cues in obese and nonobese women. Psychosom Med 1996;58:160-4.
37. Nasser J. Taste, food intake and obesity. Obes Rev 2001;2:213-8.
38. Mela DJ. Food, diet and obesity. Boca Raton: CRC Press; 2005. Chapter 7, Sensory responses, food intake and obesity; p. 137-59.
39. Tepper BJ. Nutritional implications of genetic taste varia-

tion: the role of PROP sensitivity and other taste phenotypes. Annu Rev Nutr 2008;28:367-88.
40. Prescott J. Taste matters: why we like the foods we do. London: Reaktion Books; 2012.
41. Hayes JE, Bartoshuk LM, Kidd JR, Duffy VB. Supertasting and PROP bitterness depends on more than the TAS2R38 gene. Chem Senses 2008;33:255-65.
42. Basbaum AI, Firestein S. The senses: a comprehensive reference. 4, Olfaction and taste. Amsterdam: Elsevier; 2008. Chapter 4.20, Propylthiouracil (PROP) taste; p. 391-9.
43. Hayes JE, Keast RS. Two decades of supertasting: where do we stand? Physiol Behav 2011;104:1072-4.
44. Tepper BJ, Banni S, Melis M, Crnjar R, Tomassini Barbarossa I. Genetic sensitivity to the bitter taste of 6-n-propylthiouracil (PROP) and its association with physiological mechanisms controlling body mass index (BMI). Nutrients 2014;6:3363-81.
45. Tepper BJ, Koelliker Y, Zhao L, Ullrich NV, Lanzara C, d'Adamo P, et al. Variation in the bitter-taste receptor gene TAS2R38, and adiposity in a genetically isolated population in Southern Italy. Obesity (Silver Spring) 2008;16:2289-95.
46. Tepper BJ, Neilland M, Ullrich NV, Koelliker Y, Belzer LM. Greater energy intake from a buffet meal in lean, young women is associated with the 6-n-propylthiouracil (PROP) non-taster phenotype. Appetite 2011;56:104-10.
47. Tepper BJ, Ullrich NV. Influence of genetic taste sensitivity to 6-n-propylthiouracil (PROP), dietary restraint and disinhibition on body mass index in middle-aged women. Physiol Behav 2002;75:305-12.
48. Laureati M, Spinelli S, Monteleone E, Dinnella C, Prescott J, Cattaneo C, et al. Associations between food neophobia and responsiveness to "warning" chemosensory sensations in food products in a large population sample. Food Qual Prefer 2018;68:113-24.
49. Drewnowski A, Henderson SA, Cockroft 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;107:1340-8.
50. Spinelli S, Cunningham C, Pierguidi L, Dinnella C, Monteleone E, White T. The relationship between disgust sensitivity and BMI: is the food disgusting or am I? Food Qual Prefer 2021;92:104222.
51. Dinnella C, Monteleone E, Piochi M, Spinelli S, Prescott J, Pierguidi L, et al. Individual variation in PROP status, fungiform papillae density, and responsiveness to taste stimuli in a large population sample. Chem Senses 2018;43:697-710.
52. Garneau NL, Nuessle TM, Sloan MM, Santorico SA, Coughlin BC, Hayes JE. Crowdsourcing taste research: genetic and phenotypic predictors of bitter taste perception as a model. Front Integr Neurosci 2014;8:33.
53. Piochi M, Pierguidi L, Torri L, Spinelli S, Monteleone E, Aprea E, et al. Individual variation in fungiform papillae density with different sizes and relevant associations with responsiveness to oral stimuli. Food Qual Prefer 2019;78:103729.
54. Piochi M, Dinnella C, Prescott J, Monteleone E. Associations between human fungiform papillae and responsiveness to oral stimuli: effects of individual variability, population characteristics, and methods for papillae quantification. Chem Senses 2018;43:313-27.
55. Mameli C, Cattaneo C, Panelli S, Comandatore F, Sangiorgio A, Bedogni G, et al. Taste perception and oral microbiota are associated with obesity in children and adolescents. PLoS One 2019;14:e0221656.
56. Proserpio C, Laureati M, Bertoli S, Battezzati A, Pagliarini E. Determinants of obesity in Italian adults: the role of taste sensitivity, food liking, and food neophobia. Chem Senses 2016;41:169-76.
57. Kaufman A, Kim J, Noel C, Dando R. Taste loss with obesity in mice and men. Int J Obes (Lond) 2020;44:739-43.
58. Archer N, Shaw J, Cochet-Broch M, Bunch R, Poelman A, Barendse W, et al. Obesity is associated with altered gene expression in human tastebuds. Int J Obes (Lond) 2019;43:1475-84.
59. Pepino MY, Finkbeiner S, Beauchamp GK, Mennella JA. Obese women have lower monosodium glutamate taste sensitivity and prefer higher concentrations than do normal-weight women. Obesity (Silver Spring) 2010;18:959-65.
60. Berthoud HR, Zheng H. Modulation of taste responsiveness and food preference by obesity and weight loss. Physiol Behav 2012;107:527-32.
61. Altun H, Hanci D, Altun H, Batman B, Serin RK, Karip AB, et al. Improved gustatory sensitivity in morbidly obese patients after laparoscopic sleeve gastrectomy. Ann Otol Rhinol Laryngol 2016;125:536-40.
62. Holinski F, Menenakos C, Haber G, Olze H, Ordemann J. Olfactory and gustatory function after bariatric surgery. Obes Surg 2015;25:2314-20.
63. Burge JC, Schaumburg JZ, Choban PS, DiSilvestro RA, Flancbaum L. Changes in patients' taste acuity after Roux-en-Y gastric bypass for clinically severe obesity. J Am Diet Assoc 1995;95:666-70.
64. Andriessen C, Christensen P, Vestergaard Nielsen L, Ritz C,

Astrup A, Meinert Larsen T, et al. Weight loss decreases self-reported appetite and alters food preferences in overweight and obese adults: observational data from the DiOGenes study. Appetite 2018;125:314-22.
65. Rohde K, Schamarek I, Bluher M. Consequences of obesity on the sense of taste: taste buds as treatment targets? Diabetes Metab J 2020;44:509-28.
66. Al-Najim W, Docherty NG, le Roux CW. Food intake and eating behavior after bariatric surgery. Physiol Rev 2018;98:1113-41.
67. Van Vuuren MA, Strodl E, White KM, Lockie PD. Taste, enjoyment, and desire of flavors change after sleeve gastrectomy: short term results. Obes Surg 2017;27:1466-73.
68. Miras AD, le Roux CW. Bariatric surgery and taste: novel mechanisms of weight loss. Curr Opin Gastroenterol 2010;26:140-5.
69. Small DM. Individual differences in the neurophysiology of reward and the obesity epidemic. Int J Obes (Lond) 2009;33(Suppl 2):S44-8.
70. Blum K, Braverman ER, Holder JM, Lubar JF, Monastra VJ, Miller D, et al. Reward deficiency syndrome: a biogenetic model for the diagnosis and treatment of impulsive, addictive, and compulsive behaviors. J Psychoactive Drugs 2000;32 Suppl:i-iv,1-112.
71. Blum K, Chen TJ, Meshkin B, Downs BW, Gordon CA, Blum S, et al. Reward deficiency syndrome in obesity: a preliminary cross-sectional trial with a Genotrim variant. Adv Ther 2006;23:1040-51.
72. Davis C, Strachan S, Berkson M. Sensitivity to reward: implications for overeating and overweight. Appetite 2004;42:131-8.
73. Kroemer NB, Small DM. Fuel not fun: reinterpreting attenuated brain responses to reward in obesity. Physiol Behav 2016;162:37-45.
74. Morales I, Berridge KC. ‘Liking’ and ‘wanting’ in eating and food reward: brain mechanisms and clinical implications. Physiol Behav 2020;227:113152.
75. Frewer LJ. Understanding consumers of food products. Cambridge: Woodhead Publishing; 2007. Chapter 17, Liking, wanting and eating: drivers of food choice and intake in obesity; p. 393-411.
76. Finlayson G, Dalton M. Current progress in the assessment of ‘liking’ vs. ‘wanting’ food in human appetite: comment on “‘You say it’s liking, I say it’s wanting...”: on the difficulty of disentangling food reward in man’. Appetite 2012;58:373-8.
77. Havermans RC. “You say it’s liking, I say it’s wanting …”: on the difficulty of disentangling food reward in man. Appetite 2011;57:286-94.
78. Stice E, Yokum S. Neural vulnerability factors that increase risk for future weight gain. Psychol Bull 2016;142:447-71.
79. Devoto F, Zapparoli L, Bonandrini R, Berlingeri M, Ferrulli A, Luzi L, et al. Hungry brains: a meta-analytical review of brain activation imaging studies on food perception and appetite in obese individuals. Neurosci Biobehav Rev 2018;94:271-85.
80. Pfaff DW, Volkow ND. Neuroscience in the 21st century: from basic to clinical. 2nd ed. New York: Springer; 2016. Chapter, Food addiction; p. 3771-96.
81. Belfort-DeAguiar R, Seo D. Food cues and obesity: overpowering hormones and energy balance regulation. Curr Obes Rep 2018;7:122-9.
82. Werthmann J, Jansen A, Roefs A. Worry or craving?: a selective review of evidence for food-related attention biases in obese individuals, eating-disorder patients, restrained eaters and healthy samples. Proc Nutr Soc 2015;74:99-114.
83. Meiselman HL, Mastroianni G, Buller M, Edwards J. Longitudinal measurement of three eating behavior scales during a period of change. Food Qual Prefer 1998;10:1-8.
84. Byrnes NK, Hayes JE. Personality factors predict spicy food liking and intake. Food Qual Prefer 2013;28:213-21.
85. Spinelli S, De Toffoli A, Dinnella C, Laureati M, Pagliarini E, Bendini A, et al. Personality traits and gender influence liking and choice of food pungency. Food Qual Prefer 2018;66:113-26.
86. De Toffoli A, Spinelli S, Monteleone E, Arena E, Di Monaco R, Endrizzi I, et al. Influences of psychological traits and PROP taster status on familiarity with and choice of phenol-rich foods and beverages. Nutrients 2019;11:1329.
87. Davey GC, Buckland G, Tantow B, Dallos R. Disgust and eating disorders. Eur Eat Disord Rev 1998;6:201-11.
88. Troop NA, Treasure JL, Serpell L. A further exploration of disgust in eating disorders. Eur Eat Disord Rev 2002;10:218-26.
89. Watkins TJ, Di Iorio CR, Olatunji BO, Benningfield MM, Blackford JU, Dietrich MS, et al. Disgust proneness and associated neural substrates in obesity. Soc Cogn Affect Neurosci 2016;11:458-65.
90. Houben K, Havermans RC. A delicious fly in the soup: the relationship between disgust, obesity, and restraint. Appetite 2012;58:827-30.
91. Liu X, Li J, Turel O, Chen R, He Q. Food-specific inhibitory

control mediates the effect of disgust sensitivity on body mass index. Front Psychol 2019;10:2391.

92. Proserpio C, Laureati M, Invitti C, Pagliarini E. Reduced taste responsiveness and increased food neophobia characterize obese adults. Food Qual Prefer 2018;63:73-9.

93. Knaapila AJ, Sandell MA, Vaarno J, Hoppu U, Puolimatka T, Kaljonen A, et al. Food neophobia associates with lower dietary quality and higher BMI in Finnish adults. Public Health Nutr 2015;18:2161-71.

94. Elfhag K, Erlanson-Albertsson C. Sweet and fat taste preference in obesity have different associations with personality and eating behavior. Physiol Behav 2006;88:61-6.