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Eating Without a Nose: Olfactory Dysfunction and Sensory-Specific Satiety

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Abstract

Odor stimuli play an important role in the perception of food flavor. Olfactory dysfunction is thus likely to affect eating behavior. In the present study, we hypothesized that dysfunctional olfactory perception promotes sensory-specific satiety, a decrease in pleasure derived from a certain test food during and shortly after its consumption relative to other unconsumed control foods. A total of 34 hyposmic/anosmic participants were compared with 29 normosmic control participants. All participants repeatedly consumed a fixed portion of one and the same food item, a procedure known to induce sensory satiation. We found evidence for sensory-specific satiety (SSS) regardless of olfactory function. It thus appears that olfactory deficits have no major effect on SSS.

Key words: anosmia, hyposmia, sensory-specific satiety

Introduction

Some people are born with an impaired sense of smell, but more often olfactory dysfunction is the result of head trauma, or infections, or neurodegeneration associated with normal aging and with diseases such as Parkinson's and Alzheimer's disease (Doty 1979; Olichney et al. 2005; Drummond et al. 2007; Haxel et al. 2008; Jankovic 2008). When one is still somewhat able to smell one is said to be hyposmic, whereas anosmia refers to a complete loss of the ability to smell. Such olfactory impairment is far from rare, especially among elderly (Hummel et al. 2007; Smeets et al. 2009). Recovery from smell loss is possible and is in fact quite common (though less so when it is the result of head trauma; Reden et al. 2006). But albeit olfactory function generally recovers, a return to a full, normal sense of smell is unusual (London et al. 2008).

Like any disability olfactory dysfunction can have a large impact on one's quality of life (see e.g., Toller 1999; Miwa et al. 2001; Frasnelli and Hummel 2005; Gudziol et al. 2009; Smeets et al. 2009). But unlike any other disability, olfactory deficits mainly affect everyday aspects of life pertaining to chemosensory functioning, such as cooking and eating (Hummel and Nordin 2005). This is no surprise. Odor is generally thought to play an important role in the perception and evaluation of a food's flavor (Stillman 2002; Yeomans 2006; Auvray and Spence 2008). Indeed, as Smeets and colleagues noted (p. 404): "Odors play a major role in the enjoyment of food by adding richness, complexity, and variety." People with an acquired olfactory dysfunction frequently report a change in their dietary habits. Meal preparation and consumption are reported as being less enjoyable than before, suggesting that olfactory impairment negatively affects the hedonic evaluation of food flavors (see e.g., Toller 1999; Aschenbrenner et al. 2008). This may explain the heightened nutritional risk observed in the elderly (Ferris and Duffy 1989; Rolls 1999; Drewnowski and Shultz 2001), and it provides a tentative explanation for the observed association between olfactory deficits and anorexia nervosa (Fedoroff et al. 1995; Roessner et al. 2005). Nevertheless, in a recent study, it was found that olfactory dysfunction, although affecting olfactory perception of food flavors, did not have an effect on the hedonic evaluation of coffee and tea (Seo and Hummel 2009). It thus seems that the diminished enjoyment of food/drinks and consumption cannot be ascribed to a presumed reduction in perceived food palatability. However, note that this does not rule out an important role of olfaction in the hedonic evaluation of food.

Yeomans (2006) has pointed out the potentially important role of odor stimuli in the development of sensory-specific satiety (henceforth, SSS), a decrease in the pleasantness derived from a food with its consumption relative to other unconsumed foods (Rolls 1986). For example, it has been demonstrated that merely chewing or smelling a food for

about as long as it would normally be eaten in a meal can induce SSS (Rolls ET and Rolls JH 1997). Furthermore, O'Doherty et al. (2000) showed in a functional magnetic resonance imaging study that activation in a region of the orbitofrontal cortex produced by the odor of the food eaten to satiety decreased relative to the odor of a food not eaten.

The evaluation of the hedonic quality of a food mainly rests upon the evaluation of its flavor; that is, its taste and smell. When unable to perceive food aromas, flavors are reduced to taste and hence deprived of much of their specificity and richness. For example, to a person with anosmia the flavor of a piece of apple pie will be much the same as the flavor of a piece of chocolate cake: sweet. It has been suggested that SSS is the result of becoming bored with a flavor of a given food (see e.g., Maier et al. 2007). Surely in the case of smell loss any food flavor is, or quickly becomes, boring. Therefore, in the present study, it was hypothesized that SSS is exaggerated in persons with olfactory dysfunction relative to normosmic controls, which is not only expressed as 1) a larger decrease in relative liking for the flavor of a test food but also as 2) stronger generalization of this SSS to similar food flavors. To test these hypotheses, hyposmic/anosmic participants were compared with normosmic controls. All participants were instructed to repeatedly consume and evaluate the pleasantness of flavor and mouthfeel of different food items. We further hypothesized that any exaggerated SSS among the hyposmic/anosmic participants would be limited to the pleasantness ratings of flavor as olfactory deficit affects flavor perception but not somatosensory perception of food texture (see e.g., Crosland et al. 1926, 1928).

Materials and methods

Participants

Participants with olfactory dysfunction were recruited via the Dutch Anosmia Association (Anosmievereniging; www.ruikenenproeven.nl). A total of 35 self-declared hyposmic/anosmic persons agreed to take part in 2 separate experiments regarding eating behavior, one of which concerns the present study. Results of the other study, which related to an examination of subjective and cephalic food cue reactivity, will be reported elsewhere.

For each of these participants with an impaired sense of smell, we recruited a control participant with a normal sense of smell matching in gender, age, and educational level. We thus managed to recruit 35 control participants. All participants were subjected to the extended version of the Sniffin' Sticks test (Hummel et al. 1997; Haehner et al. 2009). This assessment of nasal chemosensory performance comprises different tests for odor threshold detection, discrimination, and identification. According to normative data, an overall assessment score, or TDI score ≤30 indicates olfactory dysfunction. If the TDI score ≤15, then one is said to be functionally anosmic (see Hummel et al. 2007). Individual TDI scores revealed that 6 control participants were actually hyposmic. Another participant claiming to have had a very poor sense of smell for the past 5 years or so performed surprisingly well on the Sniffin' Sticks test, scoring above 30. Therefore, we decided not to include the data from these 7 participants in our final analyses, leaving a total sample size of 34 participants with olfactory dysfunction versus 29 control participants. A total of 9 participants with olfactory dysfunction reported they had never had any sense of smell, and one participant reported experiencing olfactory dysfunction less than a year. Other participant characteristics for each of these 2 groups are displayed in Table 1.

Procedure and materials

The present study protocol was evaluated and approved by a local ethics committee. Prior to testing, all participants (with or without olfactory dysfunction) provided informed consent together with self-reported information regarding depressive symptoms (Beck Depression Inventory; Beck et al. 1961), restraint status (Restraint Scale; Herman and Polivy 1980), eating behavior (Dutch Eating Behavior Questionnaire (DEBQ); Van Strien et al. 1986) and chemosensory functioning.

Participants were tested individually in a continually ventilated but quiet laboratory room measuring approximately 10 m^2. Before testing, the participant's body weight and height was measured to determine body mass index (kg/m^2). Furthermore, as mentioned above, each participant was first subjected to the Sniffin' Sticks test (Hummel et al. 1997) to assess current chemosensory performance.

Next, the participant was seated at a table in the laboratory and was told that the experiment involved repeated tastings and occasional evaluation of 4 different food items, namely, sweet cinnamon spread (Speculoos; Lotus Bakeries), savory cheese spread (smeerkaas; Leerdammer Kazen), sweet cinnamon cookies (Koffieleutjes; Peijnenburg), and savory cheese cookies (Kaasvlinders, Hoppe Food Group). The participant then was served bite-sized portions of these food items; that is, one cheese cookie and a single cinnamon cookie. The soft pastes (i.e., cinnamon and cheese spread) were served on a disposable plastic tablespoon, so the participant could eat the spread right off the spoon. The participant was instructed to consume each of these foods in whatever order they preferred and to rate pleasantness of flavor and mouthfeel of each food on separate 100-mm line scales ranging between 0 "highly unpleasant" to 100 "highly pleasant." Next, they received 5 fixed bite-sized portions of one of the 4 foods to consume repeatedly in a signaled exposure procedure. What food served as this test food was determined randomly for each separate participant.

For a period of approximately 5 min, the experimenter instructed the participant to pick a portion of the test food from a serving tray and then 1) look at it for 10 s, 2) sniff at it for 10 s, 3) to chew and experience the mouthfeel of it for 10 s, and then 4) to swallow it. This signaled exposure paradigm has

Table 1 Participant characteristics per group (Olfactory Dysfunction vs. Controls)

	Olfactory Dysfunction	Controls	
N	34	29	
n male	12	10	$\chi^2 = 0.005$, ns
n female	22	19	
n "I've never been able to smell normally"	9	n/a	
n "I haven't been able to smell normally for over 10 years"	9	n/a	
n "I haven't been able to smell normally for longer than 5 but less than 10 years"	6	n/a	
n "I haven't been able to smell normally for longer than 3 but less than 5 years"	2	n/a	
n "I haven't been able to smell normally for longer than 1 but less than 3 years"	7	n/a	
n "I haven't been able to smell normally for less than a year now"	1	n/a	
Mean (+SD) age (in years)	51.32 (10.45)	51.03 (12.34)	$F < 1$, ns
Mean (+SD) body mass index (kg/m^2)	26.03 (3.64)	26.03 (4.50)	$F < 1$, ns
Mean (+SD) TDI score	13.40 (5.43)	34.93 (3.21)	$F_{1,62} = 350.01$, $P < 0.001$
n TDI score <15	22		
n 15 < = TDI score <30	12		
Mean (+SD) BDI score	7.81 (5.20)	5.72 (4.66)	$F_{1,62} = 2.71$, $P = 0.11$
Mean (+SD) RS score	10.26 (5.08)	9.79 (4.32)	$F < 1$, ns
Mean (+SD) DEBQ emotional eating	2.14 (0.78)	2.10 (0.70)	$F < 1$, ns
Mean (+SD) DEBQ external eating	2.53 (0.59)	2.76 (0.45)	$F_{1,62} = 2.85$, $P = 0.10$
Mean (+SD) DEBQ dietary restraint	2.59 (0.88)	2.76 (0.76)	$F < 1$, ns

TDI score refers to the total score on the Sniffin' Sticks test, BDI refers to the Beck Depression Inventory, RS refers to the Restraint Scale, and the DEBQ. Note that for the latter self-report measure the mean item scores for each separate subscale are provided. If appropriate, the potential difference between the 2 groups was analyzed for each separate participant characteristic. The results of these analyses are displayed in the last column. Only the *P* values of (near) significant *F* tests are reported; in the other cases, the test result is simply referred to as nonsignificant (ns); SD, standard deviation.

shown to induce strong SSS (see Brunstrom and Mitchell 2006; Havermans, Geschwind et al. 2009; Havermans, Janssen, et al. 2009). After the signaled exposure, the participant again received the 4 food items to eat and evaluate. Following these final ratings, the participant was thanked and received a monetary voucher, its value ranging between 10 and 50 euro, to compensate for travel expenses.

In the present experiment, we compared 2 groups (Olfactory Dysfunction vs. Controls) examining the shift in evaluated pleasantness of the flavor and mouthfeel of the test food with its repeated consumption. According to our hypotheses, this shift should be negative (from pretest to posttest) relative to the control food, that is, the food that has both a different texture and flavor from the test food. For example, if a participant received the sweet cinnamon spread as the test food, the control food for this participant would be the savory cheese cookie.

In case of generalization of SSS, one would expect to see a negative shift in evaluated pleasantness of the flavor of the food that has a flavor similar to that of the test food. Referring to the abovementioned example, this similar flavor food would be the sweet cinnamon cookie. No such or much less generalization would be expected for the food that has a different flavor but a texture similar to that of the test food. Apart from this flavor-specific satiety, texture-specific satiety would be expressed as a negative shift in evaluated pleasantness of the mouthfeel of the food that has a similar texture (but not flavor) as that of the test food. Again referring to the example mentioned above, this similar texture food item would be the cheese spread. The experimental design is displayed in Table 2.

Result

Flavor pleasantness ratings

To determine the degree of SSS concerning the flavor pleasantness ratings, we first calculated the shift in these ratings from pretest to posttest for each separate food item; that is,

the test food, the food with a flavor similar to the test food, the food with a texture similar to that of the test food, and the control food differing both in flavor and texture from the test food. These difference scores served as the dependent variable in a 3-way Flavor (2: similar vs. dissimilar to the test food) × Texture (2: similar vs. dissimilar to the test food) × Group (2: olfactory dysfunction vs. control) analysis of covariance (ANCOVA), with participant's age entered as a covariate. The latter covariate was added as the older participants within the olfactory dysfunction condition were likely to have suffered from smell loss for longer with older age. The mean shifts in evaluation of the flavor of each of the 4 foods for each group are displayed in Figure 1.

Two participants with olfactory dysfunction felt unable to evaluate food flavor and texture and thus did not complete the experiment. Another anosmic participant too felt unable to evaluate flavor but did complete the experiment, only evaluating pleasantness of mouthfeel of the different foods. One participant from the control group found the cinnamon spread at pretest so distasteful that he decided to refrain from further participation.

The ANCOVA revealed a main effect of Flavor, $F_{1,55}$ = 16.83, $P < 0.001$, $\eta^2_{partial}$ = 0.23, and of Texture, $F_{1,55}$ = 6.91, $P = 0.01$, $\eta^2_{partial}$ = 0.11. These effects were qualified by a marginally significant Flavor × Texture interaction effect, $F_{1,55} = 2.91$, $P = 0.09$, $\eta^2_{partial} = 0.05$, indicating that the flavor of particularly the test food decreased with its repeated consumption (see also Figure 1). No further main effects or interaction effects were found (all P's > 0.05), with the exception of the covariate age, $F_{1,55} = 4.16$, $P < 0.05$. This latter effect refers to a weaker negative shift in overall flavor pleasantness ratings with older age, which is in line with previous studies indicating less SSS among the elderly (Rolls 1999). Unlike hypothesized, this analysis suggests that SSS is

Table 2 Experimental design

		Pretest		Test phase	Posttest	
Group	Olfactory Dysfunction	Evaluation of:		5 min signaled exposure test food	Evaluation of:	
		Test food	Similar texture		Test food	Similar texture
		Similar flavor	Control food		Similar flavor	Control food
	Controls	Evaluation of:		5 min signaled exposure test food	Evaluation of:	
		Test food	Similar texture		Test food	Similar texture
		Similar flavor	Control food		Similar flavor	Control food

At pretest (and at posttest), the participants had to evaluate 4 different foods, one of which served as the test food. The control food differed from the test food in both flavor and texture. The other 2 remaining foods would resemble the test food in either flavor (similar flavor) or texture (similar texture).

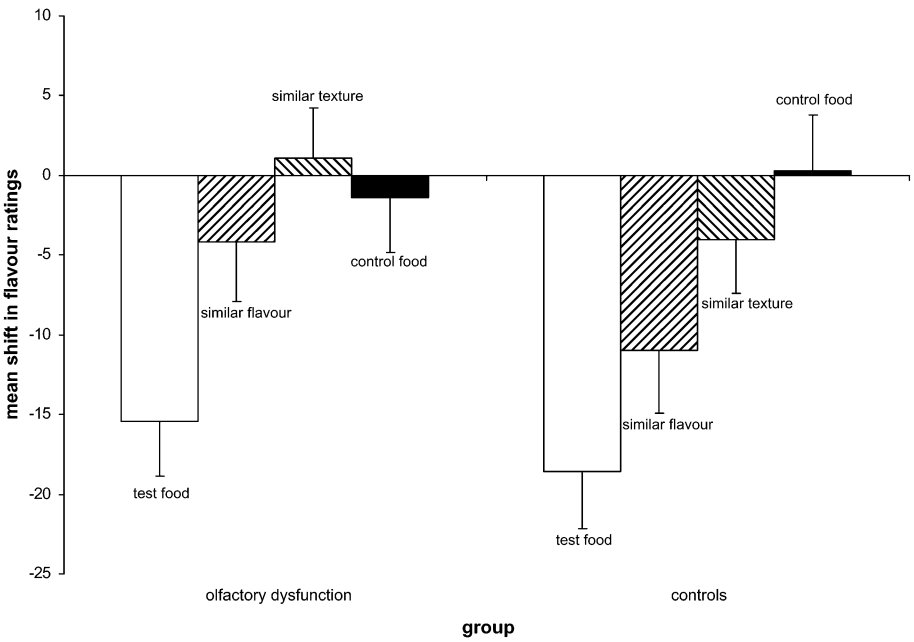

Figure 1 Mean shift in flavor pleasantness ratings (+standard error of the mean) for each food item and for each separate group (Olfactory Dysfunction vs. Control). Negative shifts reflect a decrease in pleasantness ratings, whereas positive shifts denote an increase in pleasantness ratings.

similar in both groups (The same ANCOVA with Gender added as between-subjects factor rendered a similar pattern of results. Gender itself did not prove to be a significant factor, $F_{1,53} = 0.72$, $P = 0.40$, and did not interact with any of the other factors, all P's > 0.10. Gender was thus left out of the final analyses.).

One might argue that the absence of a group difference in the above analysis is due to the participants within the olfactory dysfunction condition being hyposmic/anosmic for a very long time. They perhaps learned to compensate for their smell loss, including how to deal with the possibility of embellished SSS. Indeed, quite a few participants indicated being hyposmic/anosmic for over 10 years (see also Table 1) and thus we decided to repeat the above analysis excluding those participants. This analysis rendered the same pattern of results with a main effect for Flavor ($F_{1,43} = 15.32$, $P < 0.001$, $\eta^2_{partial} = 0.26$) and a main effect for Texture ($F_{1,43} = 5.45$, $P < 0.05$, $\eta^2_{partial} = 0.11$), qualified by a marginally significant Flavor × Texture interaction effect ($F_{1,43} = 2.75$, $P = 0.10$, $\eta^2_{partial} = 0.06$). No other effects were found (smallest $P > 0.10$), implying a similar degree of SSS between the 2 groups.

Another potential reason why the above analyses did not reveal the hypothesized group difference is that the olfactory dysfunction group is too heterogeneous, that is, it included too many hyposmic participants who can still perceive smells and aromas, though to a lesser extent than the normosmic controls. Indeed, in a previous study, we found that manipulating the intensity of a flavor does not affect SSS (Havermans, Geschwind et al. 2009), and it is thus conceivable that hyposmic persons who perceive flavors as less intense than normosmic persons do, likewise do not show any change in sensitivity toward SSS. Therefore, we conducted the 3-way ANCOVA again, now including all participants but adding a third level to the factor Group by distinguishing between hyposmic (30 > TDI score > = 15; $n = 12$) and anosmic (TDI score < 15; $n = 17$) participants. This analysis revealed a similar pattern as in the original analysis, showing a main effect for Flavor ($F_{1,53} = 13.23$, $P < 0.01$, $\eta^2_{partial} = 0.20$), a main effect for Texture ($F_{1,53} = 5.94$, $P < 0.05$, $\eta^2_{partial} = 0.10$), and a near significant Flavor × Texture effect ($F_{1,53} = 3.20$, $P = 0.08$, $\eta^2_{partial} = 0.06$). No other effects were found (smallest $P > 0.10$). It seems that, at least for the flavor pleasantness ratings, olfactory dysfunction may not affect SSS.

To examine generalized SSS, we conducted a 2-way Group (2: olfactory dysfunction vs. controls) × Food (3: similar flavor, similar texture, or control food) analysis of variance (ANOVA) directly comparing the shifts in ratings for the similar flavor and similar texture foods with the so-termed control food (see also Table 2) with simple contrasts analyses (see Field 2005). This analysis revealed a marginally significant effect for Food when contrasting the similar flavor food with the control food ($F_{1,57} = 3.19$, $P = 0.08$, $\eta^2_{partial} = 0.05$) but not when comparing the similar texture food with the control food ($F_{1,57} < 1$). This pattern is suggestive of flavor-specific satiety. No further effects were found (smallest $P > 0.10$).

Mouthfeel pleasantness ratings

We hypothesized that any potentially exaggerated SSS among the hyposmic/anosmic participants would be limited to ratings of food flavor. That is why we also included hedonic ratings of food texture or rather mouthfeel pleasantness ratings. Again, to determine SSS with regard to the mouthfeel ratings, we first calculated the shift in pleasantness ratings for mouthfeel from pretest to posttest. These difference scores served as the dependent variable in a 3-way Flavor (2: similar vs. dissimilar to the test food) × Texture (2: similar vs. dissimilar to the test food) × Group (2: olfactory dysfunction vs. control) ANCOVA, with participant's age entered as the covariate. The mean shifts in mouthfeel ratings for the foods and for each separate group are displayed in Figure 2. Note that because of participant dropout, as described above, no mouthfeel data were obtained for a total of 3 participants (one from the controls).

We found an overall effect of Flavor ($F_{1,56} = 7.57$, $P < 0.01$, $\eta^2_{partial} = 0.12$) and Texture ($F_{1,56} = 13.03$, $P < 0.01$, $\eta^2_{partial} = 0.19$), qualified by the Flavor × Texture interaction ($F_{1,56} = 6.01$, $P < 0.05$, $\eta^2_{partial} = 0.10$), reflecting a strong decrease in liking for particularly the test food thus implying SSS (see also Figure 2). No other main or interaction effects were found (smallest $P > 0.10$). The same pattern of results was rendered when running the same analysis excluding the hyposmic/anosmic participants who noted that they had experienced the loss of the sense of smell for at least the past 10 years. Again, main effects were found for Flavor ($F_{1,44} = 7.51$, $P < 0.01$, $\eta^2_{partial} = 0.15$) and Texture ($F_{1,44} = 9.47$, $P < 0.01$, $\eta^2_{partial} = 0.18$), qualified by a Flavor × Texture interaction effect, $F_{1,44} = 5.39$, $P < 0.05$, $\eta^2_{partial} = 0.11$. Next, we conducted the same ANCOVA including all participants but discriminating between hyposmic and anosmic participants by treating these as 2 separate groups. This analysis too rendered the same pattern of results with main effects of Flavor ($F_{1,54} = 8.10$, $P < 0.01$, $\eta^2_{partial} = .13$) and Texture ($F_{1,54} = 10.43$, $P < 0.01$, $\eta^2_{partial} = 0.16$) and a marginally significant Flavor × Texture effect ($F_{1,54} = 3.23$, $P = 0.08$, $\eta^2_{partial} = 0.06$). No further main or interaction effects were found, all P's > 0.13. These analyses considering the mouthfeel pleasantness ratings all show that SSS occurred, similar to the SSS described above for the flavor pleasantness ratings.

To assess any transfer of the apparent SSS, we again conducted a 2-way Group (2: olfactory dysfunction vs. controls) × Food (3: similar flavor, similar texture, or control food) ANOVA comparing the shifts in mouthfeel ratings for the similar flavor and similar texture foods with the so-termed control food as reference with simple contrasts. This rendered no significant main or interaction effects, (smallest $P = 0.16$), implying that regarding the mouthfeel ratings no generalization of SSS seems to have occurred.

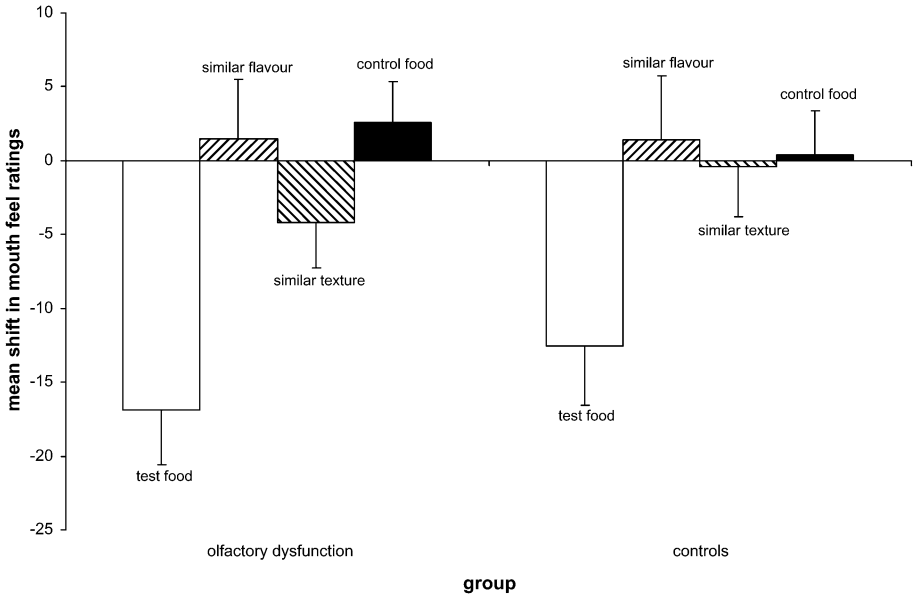

Figure 2 Mean shift in mouthfeel pleasantness ratings (+standard error of the mean) for each food item and for each separate group (Olfactory Dysfunction vs. Control). Negative shifts reflect a decrease in pleasantness ratings, whereas positive shifts denote an increase in pleasantness ratings.

Conclusion

We hypothesized that olfactory impairment affects flavor perception and as a consequence has a detrimental effect on the joy of eating. More specifically, SSS should develop to a stronger degree in persons with olfactory dysfunction. This should be especially apparent when considering the evaluation of flavor. The results revealed SSS when considering both flavor and mouthfeel pleasantness ratings, but this SSS did not differ between the 2 groups. In line with our hypotheses and previous research (Guinard and Brun 1998), we found evidence for flavor-specific satiety but not texture-specific satiety. But again, unlike what we had hypothesized, this pattern of results did not differ between groups. In other words, olfactory dysfunction does not appear to have any marked effect on SSS. Note, however, that considering that eating behavior is very complex the present sample size was still somewhat small.

Seo and Hummel (2009) already found that olfactory dysfunction distorts odor perception but does not affect hedonic evaluation of a food. The present study demonstrates that the relative decrease in hedonic ratings of flavor and mouthfeel of a repeatedly consumed food too appears unrelated to chemosensory functioning. What then underlies the often reported diminished pleasure of eating with the loss of the ability to smell? Perhaps, the real joy in eating has very little to do with one's perceived liking of a given food. As can be read from Table 1, the hyposmic/anosmic participants tended to score lower on the external eating scale of the DEBQ than the normosmic controls did. This makes perfect sense as external eating here refers to one's tendency to eat in response to external stimuli such as the sight but also smell and taste of food (Van Strien et al. 1986). According to some researchers, such external eating is mediated by food craving. Exposure to food cues induces craving, which in turn motivates eating (Jansen 1998; Nederkoorn et al. 2004). Conceivably, these cue-elicited food cravings are experienced to a much lesser extent in people with olfactory dysfunction. Cue-elicited food craving refers to a strong desire to eat a given food and one may speculate that the joy of eating is largely determined by being able to satisfy this strong craving. In other words, eating is a lot less satisfying (and hence less enjoyable) when one experiences little craving. Preliminary results from our laboratory suggest that hyposmic/anosmic persons may indeed experience less food cue-induced urges to eat (Jansen A, Havermans RC, Dorssers M, van den Boogard B, Unpublished data). However, whether such a decrease of cue-elicited food craving is in fact the primary cause of diminished enjoyment of food reported by hyposmic/anosmic persons requires further research.

In sum, the present findings show that quantitative olfactory impairment (i.e., hyposmia or anosmia) does not appear to affect SSS, at least not to a striking degree. This is somewhat surprising given that odor is generally thought to be such an important aspect of flavor and hence is often thought to play an equally important role in appetite. However, there are some animal studies showing that olfactory stimulation may not be as important in determining appetite as is often presumed. For example, Vigorito and Sclafani (1987) made rats temporarily anosmic by a zinc sulfate treatment. These rats did not show any reduction in their intake of a Polycose solution. To conclude that the present results imply that olfaction is less important than gustation in the mediation of sensory satiation would be preliminary, but the notion certainly warrants further research.

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