Olfactory Specific Satiety Depends On Degree Of Association Between Odour And Food

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Abstract

The pleasantness of a food odour decreases when that food is eaten to satiety or even smelled for a brief period (Olfactory Specific Satiety, OSS), which suggests that odours signal food variety and encourage approach behaviour toward novel foods. In the study here, we aimed to extend this theory to understand the consequence of manipulating the food consumed and its degree of association to the evaluated odour. We also wished to clarify if these effects related to individual sensitivity to the target odour. In the study here, participants (n=94) rated the pleasantness of a food odour (*isoamyl acetate*) and then consumed confectionary that had either Low or High association to that odour or a No food control. This was followed by final pleasantness ratings for the odour and a threshold sensitivity test. Results revealed that in line with OSS, pleasantness decreased in the High association group only. This effect was not dependent on any differences in sensitivity to the target odour. These findings are consistent with OSS, and that this effect likely depends on activation of brain areas related to odour hedonics rather than the degree to which the odour is detected.

Keywords

Sensory Specific Satiety, Odour, Taste, Food, Obesity

Introduction

Globally, the number of individuals classified as obese has increased dramatically over the years (Ng et al., 2014) and make it imperative that we understand more about the basic mechanisms regulating eating. An important part of this endeavour, is to delineate what drives satiety. One such theory, Sensory Specific Satiety (SSS) (B. J. Rolls, Rolls, Rowe, & Sweeney, 1981), is described as the reduced pleasantness for a food eaten to satiety, compared to foods not consumed. For instance, though we might find potato chips very pleasant at the start of a meal; when we have eaten an entire meal of such food to satiety, we no longer find them to be as pleasant; whereas the pleasantness for say bacon (example of an uneaten food) remains unchanged. Importantly, this effect is not dependent on the energy content of the food consumed (Bell, Roe, & Rolls, 2003). This theory helps explain our propensity for food variety seeking and why we might easily over consume in situations when confronted with a wide selection of food items, e.g. a 'buffet' style meal.

In later work, the researchers examined whether similar effects might be observed for the respective food odour (E. T. Rolls & Rolls, 1997). In that study, individuals rated the odour pleasantness of various foods contained in sealed containers at three timepoints: baseline, after chewing (but not swallowing) one of the foods, finally after consuming the same food to satiety. Results revealed that pleasantness ratings declined after both simply chewing the food and more sharply after eating the food. A follow up experiment further demonstrated the same pattern when instead of chewing the food, it was smelled for the same amount of time. These findings suggest that SSS is not reliant on food entering the gastrointestinal system and indeed can even be found purely in the olfactory domain; this effect has become known as Olfactory Specific Satiety (OSS). More recent work tested the theory in naturalistic conditions (food college restaurant), where all individuals consumed a 4-course meal: appetizer, starter, main meal, dessert that contained the target flavour/odourant (Fernandez, Bensafi, Rouby, & Giboreau, 2013). They found that pleasantness ratings were lower for the dessert for those individuals who received the appetizer infused with the same target flavour. Hence, though all participants were equally satiated (having eaten the same 4-course meal), the dessert was perceived as less pleasant for those who experienced the same flavour with their appetizer and dessert. One interpretation of this finding is that due to the same flavour in both foods, individuals associated the dessert with the previously consumed appetizer and on the basis of SSS/OSS perceived it less favourably. That study was important in demonstrating that OSS can be found beyond the more artificial environments of experiments, also how different foods can become associated to each other on the basis of a common flavour. However, as acknowledged by those authors, since individuals rated the 'flavour' of the dessert, one could concede that the design did not permit the testing of the food odour itself. This is important from a theoretical perspective, i.e. can foods become generalized to associated odours and more broadly, it has implications for the role of odours in food consumption. Relevant here, work has shown that smelling a food odour (orthonasal) rather than experiencing the odour of the food in the mouth (retronasal) was a more accurate predictor of subsequent intake (de Wijk, Polet, Engelen, van Doorn, & Prinz, 2004). This suggests that smelling a food prior to consumption has a crucial role in guiding the amount of food we actually consume.

The present study aimed to answer these questions using a novel design that permitted the manipulation of the degree of association between odour and ingested food. Individuals were allocated to one of three experimental conditions which varied in the degree to which the food was associated to the test odour: Control-no food (No association); Chocolate confectionary (Low association); Fruit based confectionary (High association). Participants provided pleasantness ratings for the odour (*isoamyl acetate*) before and following snack consumption. On the basis of previous related work, we would expect pleasantness ratings to decline for the High association condition. An additional aim of the study was to understand whether these effects would be influenced by the individuals' sensitivity (threshold) to that same odour. Although previous work found that SSS was evident in both normosmic and hyposmic/anosmic individuals (Havermans, Hermanns, & Jansen, 2010), the threshold test for that study utilized a non-food odour (butanol) and since that study was directed more at SSS, did not obtain measures of the test food odour. Therefore in the present study, all participants completed a threshold sensitivity test for the same odour. We tentatively predict that individuals less sensitive to the test odour would exhibit weaker OSS effects.

Methods

Participants

Ninety-four students (70 females) from the University of Portsmouth participated in the study and were aged between 19 and 32 years (M = 20.2 years, SD = 2.4 years). The study was described as examining factors that influence our sense of smell and taste. Individuals who had any problems with their sense of smell were advised not to participate; as were those with any respiratory problems (e.g. asthma) or allergies to certain odours/tastants. The study protocol was given ethical approval from the department's ethics committee (British Psychology Society guidelines).

Design

The study used a mixed design where participants (Table 1) were tested in cluster groups (6-12 participants) where all participants in each cluster completed the same condition. Each cluster group was assigned randomly to one of three conditions that varied in odour association (Control, Low Association, High Association). Participants completed pleasantness ratings of the odour at two Time points: baseline and post test.

Snack Food

For the low association snack, participants consumed one chocolate based confectionary (Mars 'Celebrations' assortment, Tesco Portsmouth, appx 50kcal), and for the high association, they consumed one fruit associated confectionary (Pear drop, Tesco Portsmouth, appx 15kcal).

Test For Olfactory Specific Satiety

Two 250ml squeeze bottles (CJK Packaging, UK) were used for this task. Each bottle contained *isoamyl acetate* diluted with proplyene glycol at a concentration of 0.06%. The bottles were labelled 'Odour A' and 'Odour B' to avoid any expectancy effects, i.e. participants knowing they were being exposed to the same odour; this was also consistent with previous work (E. T. Rolls & Rolls, 1997). Participants rated the pleasantness of the odour using a Visual Analogue Scale (VAS), with a 100mm unmarked line labelled "not at all" and "extremely" at either end and the following text above: ‘Please place a vertical mark ‘|’ on the line that represents how pleasant you find the odour.’

Olfactory Threshold Test

The odour used for the threshold test was *isoamyl acetate*, a food associated (smell of banana/pear) odour used frequently in olfactory food related work (Albrecht et al., 2009; Stafford, Tucker & Gerstner 2013), which was diluted in propylene glycol. The odourant was prepared using eleven 250ml squeeze bottles(CJK Packaging, UK), in 16 dilution steps, starting at 0.06% (Step 1) with each successive step diluted by a factor of two, to the lowest (Step 16). All chemicals were supplied by Fisher Scientific (UK). Prior to the start of testing, participants were familiarized with the odour of the strongest concentration, by squeezing the bottle under the participant’s nose (~2cm) and gently waving it between each nostril to ensure optimal inhalation. The experimenter wore cotton gloves (Boots, Portsmouth) to reduce any cross contamination of odours. To test for olfactory threshold, participants were presented with three bottles (2 of which were blanks, containing the dilutant only) at the weakest concentration. Following presentation of the last bottle of the triplet (counterbalanced), participants were asked which bottle contained the odour (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 (higher) concentration step being presented. Participants threshold was established when they had made three consecutive correct responses. The method of threshold testing used was similar to a previous study (Lam, Sung, Abdullah, & van Hasselt, 2006).

Procedure

All testing took place on the University's department of psychology. Participants were instructed not to consume anything (apart from water) within two hours of their appointed time, since this may have affected their sense of smell and taste. Upon arrival, participants provided informed consent and then completed a questionnaire concerning how many hours it had been since their last meal. Next, they were instructed to smell the bottle (labelled odour A) and rate the pleasantness on the VAS. Following this, depending on their assigned condition, they consumed their small confectionary food. Once this was finished, they were instructed to smell the bottle (labelled odour B) and rate the pleasantness on the VAS. Next, they completed the olfactory threshold test. To avoid possible demand characteristics, participants were given a debriefing collectively when all data collection was completed.

Data Analyses

The pleasantness ratings were analysed using a repeated measures ANOVA with the within-subjects factor of Time (Baseline/Test) and between-subjects factor of Condition (Control/Low Association/High Association). Planned pairwise comparisons were completed with Bonferroni adjustment for multiple comparisons. The threshold data were analysed using a Univariate ANOVA with the between-subjects factor of Condition (Control/Low Association/High Association).

Results

Olfactory Specific Satiety

Analyses revealed no main effect of Condition, $F(1, 91) = 0.47$, $p = .63$, but there was a significant main effect of Time, $F(1, 91) = 6.65$, $p = .012$, $\eta^2 = .07$, with pleasantness ratings decreasing from baseline (M = 58.9, SE = 1.8) to test (M = 54.4, SE = 1.9). There was also a Condition x Time interaction, $F(1, 91) = 6.28$, $p = .003$, $\eta^2 = .12$. Planned comparisons demonstrated that in agreement with our prediction, significant reductions in pleasantness were found for those in the High association ($p < .001$), but not for either the Low ($p=.42$) or Control ($p=.27$) groups (Figure 1).

-Insert Figure 1 About Here-

Olfactory Threshold

There was no effect of Condition for olfactory threshold, $F(2, 89) = 0.82$, $p = .44$, $\eta^2 = .018$ (Table 2).

Correlations

To explore the extent to which sensitivity to the test odour might relate to OSS, we computed a change in pleasantness rating (baseline less test ratings), where higher resultant scores would represent decreases in pleasantness; this was then correlated this with olfactory threshold scores, and completed this separately for each of the three groups. None of these correlations were significant ($r<0.3$, $p>0.1$).

Discussion

The main study finding was that for those individuals in the High association group only, odour pleasantness ratings decreased significantly between baseline and test. This is consistent with our prediction and related research (E. T. Rolls & Rolls, 1997; Fernandez et al., 2013). Previous work found that a dessert infused with the same versus a different food flavouring was rated as less pleasant (Fernandez et al., 2013). However, since the ratings in that study were for the food itself, we are unsure whether a similar pattern would occur for the odour. Due to the nature of that study, it was also unclear, if ratings for the target odour would have actually declined. The present study has extended our knowledge by demonstrating that pleasantness ratings for an odour associated to an ingested food do indeed decline. The implications are that OSS can be observed with different foods (appetizer/dessert) that contain the same food flavouring (Fernandez et al., 2013) and as seen here, a food with a separate but related food odour. To an extent, the study here also links together two different theories of eating behaviour: SSS/OSS and theories on how we acquire a liking for food flavours. The latter has used elegant paradigms that reveal how we increase the liking for novel food odours that have been paired with the taste of sucrose during conditioning trials (Yeomans & Mobini, 2006). Taken together, this suggests that once we have acquired a preference for odours associated to sweet tasting foods, that such preferences can be altered during mealtimes, depending on odour presentation. This has a number of practical applications. Since experiencing solely the food odour (orthonasal) is an accurate predictor of food consumption (de Wijk et al., 2004), these findings suggest that the re-introduction of a food odour during a meal may decrease the pleasantness and possibly intake of a food associated to that odour. So, although work has shown that environments infused with a food odour *prior* to food being served can lead to subsequent increased consumption to that same food (Fedoroff, Polivy, & Herman, 2003). On the basis of the current work, it seems possible that an environment infused with a food odour *during* food consumption would lead to decreased consumption to that same odour related food. If correct, this could then be used to decrease intake of less healthy foods. For instance a meal comprising of pizza and broccoli could be organised so that part way through the meal, the odour of pizza is infused into the environment. The consequence of this is predicted to decrease preference for pizza whilst not affecting broccoli consumption. Relevant here is the research examining retronasal aroma release (Ruijschop et al., 2009), which has shown that foods that are more solid in structure release more odours than those more liquid. More interestingly, they demonstrated that when participants consumed the same fruit yoghurt drink, less of the drink was consumed when it was accompanied by the odour profile of the solid fruit compared to the odour profile of the liquid drink (Ruijschop et al., 2008). This suggests that foods that release more odour during consumption are more satiating and that this leads to lower intake. However, since that work is based on retronasal olfaction, it is for future research to understand the precise interaction between orthonasal and retronasal processing of odours and their influence on food consumption.

The other main finding was that the observed OSS effects were not dependent on individuals' sensitivity to that odour. Earlier work found that SSS was found irrespective of the smelling ability of participants (Havermans et al., 2010); hence even those with olfactory dysfunction showed a decrease in pleasantness for a food continuously eaten. However, from that study alone, we cannot be sure whether the individuals with olfactory dysfunction may have had some preserved sense of smell for the food odours used in that experiment. Additionally, it was uncertain whether broader differences might be observed with respect to olfactory sensitivity and

OSS for those without olfactory dysfunction. By using a healthy sample of individuals with no known problems with their sense of smell, and testing their threshold sensitivity to the test odour, we were able to explore this question. The finding that olfactory sensitivity did not relate to changes in pleasantness suggests that OSS does not depend on this aspect of olfactory function. This is congruent with physiological research demonstrating that the pleasantness of a food flavour is processed in the orbitofrontal cortex, whereas the (taste) intensity of a flavour is controlled by the rostral insular region (E.T. Rolls, 2005). We also know that varying the intensity of a test food item has little effect on SSS (Havermans, Geschwind, Filla, Nederkoorn, & Jansen, 2009), with the usual decline in pleasantness in both low and high sweet intensity versions. This all implies that SSS/OSS does not rely on the degree to which we detect the actual food odour, but some other aspect presumably more related to flavour hedonics.

In terms of study limitations, it could be contended that Olfactory Specific Satiety has not been fully demonstrated in this study, since we did not measure actual satiety/disposition to consume more of the confectionary food. However, since the pioneering work in this field (B. J. Rolls et al., 1981), the terms SSS/OSS are now generally understood to mean a decline in 'pleasantness' and it is assumed that this decline will also be associated with a reduced willingness to consume that specific food (E.T. Rolls et al., 1997; Raynor & Epstein, 2001). As such, to demonstrate OSS/SSS, research now is centred on reduced pleasantness/hedonics (e.g. Havermans et al., 2010; Fernandez et al., 2012). Additional limitations include the fact that since we tested only one odour, we cannot be certain that the same effect would be found if manipulating a different odour/food relationship (e.g. target odour = chocolate, food consumed = chocolate). It is also uncertain whether the observed effects would also carry over to savoury foods/odours.

In conclusion, we found that the pleasantness of an odour declined only when individuals consumed confectionary related to that odour. This decline in odour hedonics was not related to sensitivity to that odour. The nature of these findings encourage future research to understand if odours can be used to inhibit intake of less healthy foods.

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Table 1. Mean (SD) Participant Characteristics Dependent On Group

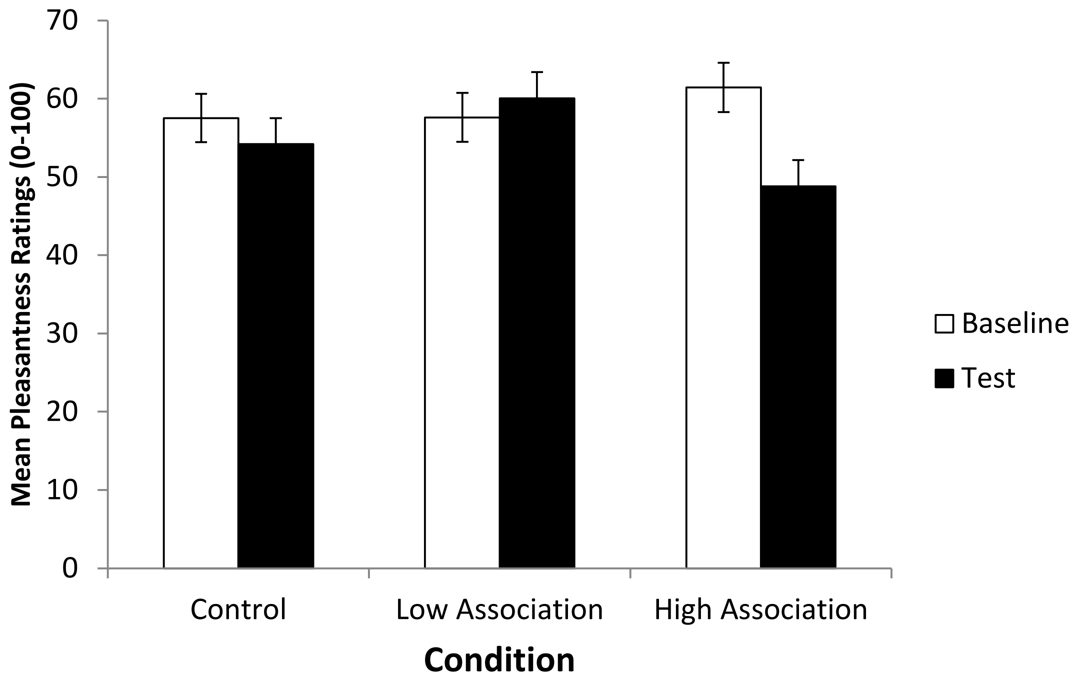
	Group					
	Control (n=32)		**Low Association (n=31)**		**High Association (n=31)**	
	M	**SD**	**M**	**SD**	**M**	**SD**
Age	19.9	1.6	21.0	3.7	19.6	0.7
Hours Since Last Meal	3.3	1.3	2.8	1.1	3.4	1.2
Sex (M:F)	7:25		7:24		10:21	

Table 2. Mean (SEM) Olfactory Thresholds Dependent On Group

	Group					
	Control (n=32)		Low Association (n=31)		High Association (n=31)	
	M	**SE**	**M**	**SE**	**M**	**SE**
Threshold	11.4	0.7	10.4	0.6	10.3	0.7

Legends for figures:

Figure 1. Mean (±SE) Odour Pleasantness Ratings Dependent On Condition


70
60
50
40
30
20
10
0
Mean Pleasantness Ratings (0-100)
Control
Low Association
High Association
Condition
Baseline
Test