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An analysis of sensory-specific satiation: food liking, food wanting, and the effects of distraction

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Abstract

Sensory-specific satiation is the transient loss of reward value of a recently eaten food versus recently uneaten foods. In this study, participants (n = 70 young women and men with healthy body weight) were randomised to eat a fixed portion of either cream cheese bagel or chocolate chip brioche for breakfast. They were also randomised to one of four 'mindset' manipulations (attention, distraction, eating rate, and control). Before and after their meal, participants tasted and evaluated the two foods for desire to eat (a measure of the momentary reward value of the food) and liking (the momentary pleasantness of the taste of the food). Consistent with sensory-specific satiation, desire to eat and liking decreased more for the eaten food than for the uneaten food. Furthermore, there was a sensory-specific effect for food wanting (calculated as desire to eat minus liking). Analyses ruled out floor effects on liking which could have biased results in favour of finding a sensory-specific effect on wanting. To our knowledge this is the first study to demonstrate clearly that sensory-specific satiation comprises a sensory-specific decrease in wanting as well as liking. Further results showed that rated hunger predicted wanting but not liking, and that meal enjoyment (experienced food reward) and post-prandial fullness independently predicted meal satisfaction. A notable effect of mindset was that distraction compared with control almost completely abolished sensory-specific satiation, indicating the involvement of explicit memory processes in this phenomenon.

Key words

Food reward; Liking; Wanting; Sensory-specific satiation; Distraction; Satisfaction

Highlights

- Sensory-specific satiation comprises decreased food liking and food wanting
- Distraction during eating reduces sensory-specific satiation
- Hunger (the absence of fullness) affects wanting but not liking
- Liking and hunger predict meal enjoyment
- Meal enjoyment and post-meal fullness predict meal satisfaction

1. Introduction

Previously we described a model of food reward in which food reward is determined independently by hunger and food liking (Rogers & Hardman, 2015). We defined food reward as the value of a food to the individual at the moment of ingestion. We demonstrated that hunger (primarily, the absence of fullness) does not affect liking (Rogers & Hardman, 2015), but instead exerts its motivational effects via a second component of food reward that, in line with Berridge (1996) and Berridge & Robinson (2003), we called food wanting. We used ratings of desire to eat the food in question and ratings of the pleasantness of its taste (implying taste, flavour and texture) to measure, respectively, food reward and food liking. We argued that there is no obvious direct measure of wanting, as this component of food reward is not experienced separately, at least not consciously so, from desire to eat. Participants can, though, separate the pleasantness of the taste of a food in their mouth (liking) from their desire to taste, chew and swallow it (desire to eat it) (Rogers & Hardman, 2015). An extreme example of this dissociation is that food can taste pleasant even when one is uncomfortably full.

Our measure of wanting is, therefore, desire to eat minus liking (Rogers & Hardman, 2015). In other words, in our model of food reward we define wanting as essentially not being liking. In applying this logic to separate liking and wanting it is important that the desire to eat and liking rating scales have equivalent properties, especially in respect of the potential for scores to change. For example, a desire to eat rating scale anchored with the words 'very weak' to 'very strong', differs from a liking rating scale anchored with the words 'very unpleasant' to 'very pleasant' (e.g., Rolls, Rowe, & Sweeney, 1981; Brunstrom & Mitchell, 2006) in the likely range of scores obtained. The liking scale ranges from negative to positive liking, whereas the desire to eat scale ranges from the absence of a desire to eat to a very strong desire to eat. Essentially, the midpoint of the liking rating scale is equivalent to the zero point (very weak) on the desire to eat scale. Consequently, changes in absolute scores, for example from before to after eating a food, may underestimate the change that occurs in liking for the food compared with the change that occurs in desire to eat it. In turn, this would cause our method for estimating wanting (desire to eat minus liking) to overestimate the change in wanting that occurs from before to after eating the food. Accordingly, in our research, including the present study, we use the same anchors ('not at all' and 'extremely') for the desire to eat and liking rating scales. Furthermore, for liking we include an instruction to focus attention on pleasantness of the food in the mouth, as our previous results indicate that when making this judgement at least some participants appear to confuse the pleasantness of the taste of a food with the pleasantness of eating it (Rogers & Hardman, 2015). The latter is affected by both liking and hunger/fullness (Mela & Rogers, 1998) and therefore is approximately equivalent to desire to eat (i.e., it is an expression of food reward).

The present research had three primary aims. The first, and main, aim was to test whether wanting is decreased in sensory-specific satiation¹. The phenomenon of sensory-specific satiation is the decrease in reward value across a meal of the eaten food compared with the relative preservation of the reward value of uneaten foods (Rolls et al., 1981; Rolls et al., 1984; Hetherington, Rolls, & Burley, 1989). Sensory-specific satiation is evident for at least 1 - 2 hours after eating (Hetherington, et al., 1989; Weenan, Stafleu, & de Graaf, 2005). Classically, sensory-specific satiation is viewed primarily in terms of decreased liking (Rolls, Rolls, Rowe, & Sweeney, 1981; Hetherington, Rolls, & Burley, 1989; Hetherington, & Havermans, 2013), but it is conceivable that decreased wanting also contributes to sensory-specific (e.g., Havermans, Janssen, Giesen, Roefs, & Jansen, 2009; Rogers & Hardman, 2015). However, as far as we are aware, no study has demonstrated unambiguously that wanting decreases more during a meal for the eaten food than for uneaten foods. For example, the measures that Havermans et al. (2009) used did not clearly separate

¹Here, we use the term sensory-specific satiation (e.g., Weijzen et al. 2009), rather than the more common term sensory-specific satiety, because (1) the phenomenon that this describes is the decline in reward value of a food or drink *during* its consumption, and (2) in the current study participants were instructed to eat a fixed portion of food rather than to eat ad libitum to satiety.

wanting from liking. Furthermore, in our previous research a baseline difference in desire to eat the eaten and uneaten foods potentially confounded our calculation of changes in wanting (Rogers & Hardman, 2015; Study 1). In the present study we aimed to avoid this confound, whilst nonetheless ensuring that the foods differed sufficiently to generate a sizeable sensory-specific satiation effect. The foods we served were cream cheese bagel and chocolate chip brioche, primarily on the basis that one is a savoury food and the other a sweet food. Together with this, we chose breakfast as the meal-time for the study because, at least in the UK, these foods are similarly appropriate as a main or sole item for this meal.

As well as measuring liking and desire to eat, we measured hunger and fullness before and after meal and meal enjoyment and meal satisfaction. Here our purpose and second aim was to test a model of meal satisfaction, which we developed in previous research modelling data on the evaluation of a variety of meals and snacks (Shahrokni, Ferriday, Motou, Brunstrom, & Rogers, 2018). In that study, participants tasted the foods but did not eat them. We found that liking predicted expected meal enjoyment, and in turn that expected meal enjoyment and expected fullness after eating predicted expected meal satisfaction. In the present study, participants rated meal enjoyment and meal satisfaction after actual rather than imagined consumption of the food in question, albeit only one food (either bagel or brioche). We found that the terms meal satisfaction and meal enjoyment are readily understood by participants (Rogers, Ferriday, Jebb, & Brunstrom, 2016; Shahrokni et al., 2018). Satisfaction is a term used widely in consumer psychology and everyday life, meaning for example 'the act of fulfilling a need, desire, or appetite, or the feeling gained from such fulfilment' (Vocabulary.com). Previously, we operationalised meal enjoyment as reflecting the experience of food reward, compared with desire to eat which we operationalised as reflecting the anticipation of food reward (Rogers & Hardman, 2015).

Our third aim was to test the effects of different 'mindsets' during eating on meal enjoyment, meal satisfaction, and sensory-specific satiation. These mindsets were attention (whilst eating, focus on the taste of the food), distraction (whilst eating, focus on planning a holiday), pause (pause for 10 seconds between mouthfuls) and control (no mindset instruction). The attention and distraction mindsets were designed to have a similar, positive valence. These mindset manipulations were based on findings that focusing on the oro-sensory qualities of food may enhance the pleasure of eating (food reward) (Cornil & Chandon, 2016; Rogers 2018), and that distraction can reduce fullness (e.g., Oldham-Cooper, Hardman, Nicoll, Rogers, Brunstrom, 2011), whereas reducing eating rate can increase fullness (e.g., Robinson, Almiron-Roig, Rutters, De Graaf, Forde, Tudur Smith, Nolan, & Jebb, 2014; Ferriday, Bosworth, Lai, Godinot, Martin, Martin, Rogers, & Brunstrom, 2015). Furthermore, at least one previous study found that distraction reduced sensory-specific satiation (Brunstrom & Mitchell, 2006). Our interventions were simple, verbal instructions such that they could, if desired, be readily applied in everyday life settings. Unfortunately, because testing was curtailed by COVID-19 lockdown in the UK, we were not able to achieve our target number of participants for the mindset comparisons.

1.1 Hypotheses

Our main hypothesis for this study was that both liking and wanting (desire to eat minus liking) would decrease more for the eaten than the uneaten food. That is, sensory-specific satiation comprises decreased liking and decreased wanting. A second hypothesis was that hunger, but not liking, would predict wanting. A third hypothesis was that liking for the eaten food and hunger would predict meal enjoyment, and a fourth was that meal enjoyment and post-meal fullness would predict meal satisfaction. Hunger in these analyses was measured at baseline, before participants were presented with any food samples. A fifth hypothesis was that sensory-specific satiation would generalise, such that consumption of bagel would cause a greater reduction in desire to eat savoury than sweet foods, with consumption of brioche having the opposite effect.

We also carried out exploratory analyses (1) to test whether a 'floor effect' for liking might bias results in favour of finding a sensory-specific effect on wanting, and (2) to test the effects of mindset on

sensory-specific satiation, and other outcomes, including meal duration, fullness, meal enjoyment and meal satisfaction.

2. Methods

2.1 Participants

The participants were recruited via social media posts and by word of mouth in which the study was described as ‘the breakfast foods study’. Eligibility criteria included age ≥ 18 years, not having food allergies or intolerances, willing not to eat breakfast on the morning of the study, and willing to eat the study foods (cream cheese bagel and chocolate chip brioche). In total, 70 participants (49 women) were recruited and completed the study. We planned to test 96 participants, based on $n = 24$ for each of the attention, distraction, eating rate and control mindset conditions, however COVID-19 lockdown in the UK (beginning 16th March, 2020), prevented us recruiting and testing the final 26 participants. With 70 participants the study is very well powered to detect sensory-specific satiation effects, which is the main focus of the present article. For example, in a previous study on sensory-specific satiation we observed large effect sizes of $d = 1.24$ and $d = 0.86$ for desire to eat and liking measures, respectively (Rogers and Hardman, 2015; Study 1).

The study was approved by the School of Psychological Science Research Ethics Committee Committee, University of Bristol. Informed consent was given by all participants prior to their participation in the study.

2.2 Study design and randomisation

Participants were randomised to one of 16 ($2 \times 2 \times 4$) groups, namely eaten food (bagel or brioche), tasted food (bagel first or brioche first), and mindset condition (attention, distraction, eating rate or control). Randomisation was done by an investigator (PJR) not involved in testing participants using an online randomisation tool (<https://www.sealedenvelope.com/simple-randomiser/v1/lists> accessed 31st January 2020) to assign 96 participant ID numbers equally to the 16 groups (6 per group). Participants were assigned their ID number in order of arrival for testing. Group allocation was concealed from the experimenter assigning the ID number.

2.3 Materials

The foods were cream cheese bagel (137 g, 383 kcal, served as two halves) and chocolate-chip brioche (105 g, 379 kcal, served as 3 buns). These were, respectively, a non-sweet food (5.9 g sugar per 100 g) and a sweet food (19.4 g sugar per 100 g), which also differed in other respects in taste and in texture. Separate 5 g samples of each of these foods were served for evaluation of liking and desire to eat, before and after serving the full portion. The samples were labelled A or B according to which was to be tasted first. Participants were also served with 350 ml tap water. Further details of the foods are provided in Supplementary Materials (Tables S1 and S2).

Each participant was given an A4-sized printed response booklet labelled with their ID number. This booklet contained step-by-step instructions for the test session and rating scales for food liking, desire to eat, etc (Table 1). There were four versions of the booklet, which differed only in which mindset instruction it included. The written mindset instructions, preceded by the phrase ‘Shortly you will be served with some food and a glass of water’, were as follows.

Attention: ‘Whilst eating your food, think about how it tastes and feels in your mouth and how it feels to swallow it. Make sure to savour and enjoy every mouthful.’

Distraction: ‘Whilst eating your food, think about planning a holiday. Make sure to imagine arriving in your holiday destination and how you would enjoy that moment. Make sure to follow these instructions about imagining your holiday throughout eating your meal.’

Pause: ‘After finishing each bite of food, count slowly from one to ten (10 seconds) before taking the next bite. Make sure to follow these instructions about pausing between bites throughout eating your meal.’

Control: 'Please wait for a few moments.'

2.4 Measures

The primary outcome measures were changes in liking, desire to eat and wanting (desire to eat minus liking) from before to after eating. Other measures were ratings of hunger, fullness, thirst, desire to eat savoury food, desire to eat sweet food, meal enjoyment and meal satisfaction. Ratings were made on 100 mm visual analogue scales. These scales were anchored 'NOT AT ALL' at the left-hand end and 'EXTREMELY' at the right-hand. Wording for each scale is provided in Table 1.

For the purpose of collecting background information, we weighed the participants, measured their height, and asked them to note their gender and age, and to complete the Dutch Eating Behaviour Questionnaire (van Strien, Frijters, Bergers, & Defares, 1986).

Table 1. Wording for 100 mm visual analogue rating scales

Measure	Wording
Liking	How PLEASANT does Food B taste in your mouth right now? When making this judgement, ignore how much or little of the food you want to eat, and what it would be like to swallow it – just focus only on how pleasant it tastes in your mouth
Desire to eat	I have a STRONG DESIRE to eat more of Food B right now
Hunger	I feel HUNGRY
Fullness	My stomach feels FULL
Thirst	I feel THIRSTY
Desire for savoury food	I have a STRONG DESIRE TO EAT SOMETHING SAVOURY
Desire for sweet food	I have a STRONG DESIRE TO EAT SOMETHING SWEET
Meal enjoyment	How much did you ENJOY eating your meal?
Meal satisfaction	How SATISFIED do you feel by the meal you have just eaten?

For liking and desire to eat, the example is for food B.

Procedure

Participants attended for a single test session at our research facility (Nutrition and Behaviour Unit Laboratory, University of Bristol). The test session began between 9 am and 11 am. They had been instructed to miss breakfast that morning, although consumption of water and/or a caffeine-containing drink was permitted.

Two experimenters managed the test session. One was responsible for setting out the response booklets before the arrival of the participants, then during the test session they were based in a kitchen adjacent to the test room. They prepared and served the food from this kitchen. The other experimenter directed and oversaw the activities in the test room. In the test room each participant was seated singly at a table arranged within a private booth. In total the test room could accommodate up to four participants in this manner.

The timeline for the test session is summarised in Fig. 1. Full details are as follows. (1) Participants provided their signed informed consent to take part in the study and confirmed that they had not eaten breakfast. (2) They rated their hunger, fullness, thirst, desire to eat savoury food and desire to eat sweet food. (3) They were served the 5 g samples of the foods, labelled A and B. They tasted and rated their liking for food A and then their desire to eat more of food A, followed by the same procedure for food B. They

swallowed the food samples after tasting them. (4) They were told they would shortly be served with some food, and that they should follow the printed instructions whilst consuming the meal. These instructions, reproduced above in Section 2.3, comprised the mindset manipulation. (5) Participants were served a full portion of food A or food B, and a glass of tap water (350 ml). They were asked to eat all the food, and drink as much or as little of the water as they wished. If they were unable to eat all the food, the amount remaining was removed and weighed. The duration of eating was timed using a stopwatch. (6) They were served with fresh samples of foods A and B and again rated their liking for and desire to eat these foods. (7) They rated their hunger, fullness, thirst, desire to eat savoury food, desire to eat sweet food, and meal enjoyment and satisfaction. (8) They completed the DEBQ and noted their gender and age. (9) They were weighed and their height measured. (10) They confirmed their consent for the use of their data. (10) Finally, participants were thanked for taking part in the study and offered a choice of snacks to take away. The whole test session lasted approximately 30 minutes.

Fig. 1. Timeline for the 30-minute, test session. Participants ($n = 70$) were randomised to one of the four mindset conditions and to eat a full portion of either bagel or brioche. The order in which samples of bagel and brioche were tasted was balanced across participants in the respective mindset and eaten food groups. DEBQ = Dutch Eating Behaviour Questionnaire (van Strien et al., 1986).

2.5 Data analysis

The responses on the visual analogue scales were measured in mm from left hand end of the line (= zero). Changes in liking, desire to eat and wanting (desire to eat minus liking) were calculated by subtracting post-eating from pre-eating scores for these variables. Therefore, a reduction in, for example, desire to eat from before to after eating is represented by a negative desire to eat score.

Data analysis was carried out using IBM SPSS Statistics 24 (IBM Corporation, Armonk, NY, USA). We calculated summary information (mean $\pm$ SD) for participants' age, body weight and body mass index (BMI), and for hunger, fullness and thirst measured immediately before the first food samples were served. We also calculated summary information for the various outcome variables, including desire to eat, liking, wanting, and for the amounts of bagel and brioche consumed.

We conducted two-factor mixed measures ANOVAs to test the effects of tasted food (bagel versus brioche, within subjects factor) and eaten food (bagel versus brioche, between subjects factor) on changes in desire to eat, liking and wanting (after minus before eating ratings). A sensory-specific effect is demonstrated by a significant tasted food by eaten food interaction.

We carried out analyses to test whether a 'floor effect' for liking might bias results in favour of finding a sensory-specific effect on wanting. We reasoned that participants making relatively low ratings of liking for the eaten food at baseline might show at most only relatively small decreases in liking for this food, which would result in a sensory-specific effect on desire to eat being attributed to a sensory-specific effect on wanting (because wanting is desire to eat minus liking). We did this by creating eaten food and uneaten food variables for change in desire to eat, change in liking and change in wanting. Sensory-specific effects are demonstrated by differences (paired) between eaten food and uneaten food for these measures. We calculated effect sizes (Cohen's d) for these differences and compared them against zero using one-sample t -tests. We did this analysis for (1) all participants ($n = 70$), (2) participants with a baseline liking score for the

eaten food of > 60 mm (n = 50), and (3) participants who finished the food offered (n = 47; such participants might be expected to show greater decline in liking than those who did not eat the whole portion).

We conducted a two-factor mixed measures ANOVA to test the effect of eaten food (bagel versus brioche, between subjects factor) on desire to eat savoury food ratings and desire to eat sweet food ratings (within subjects factor).

We used the variance-partitioning procedure described by Chuah and Maybery (1999) to assess the independent and combined contributions of hunger and food liking to food wanting, and similarly to assess the contributions of hunger and food liking to meal enjoyment, and in turn the contributions of meal enjoyment and fullness to meal satisfaction.

Finally, we conducted single factor ANOVAs followed by Bonferroni corrected paired comparisons to test the effects of mindset (attention versus distraction versus pause versus control, between subjects factor) on sensory-specific effects on desire to eat, liking and wanting (after minus before eating ratings for the eaten food minus the uneaten food), meal duration, eating rate (g/minute and kcal/minute), changes in hunger and fullness from before to after eating, meal enjoyment and meal satisfaction.

3. Results

3.1 Participant characteristics

The participants were 49 women (27 ate brioche) and 21 men (10 ate brioche), aged 20.5 ± 1.1 years (mean $\pm$ SD). Their body weight was 68.5 ± 14.7 kg and their BMI was 22.8 ± 3.5 kg/m². Their DEBQ restrained eating, emotional eating and external eating scores were 2.5 ± 0.8 , 2.4 ± 0.8 and 3.6 ± 0.6 , respectively. The ratings made at the start of the test session showed that participants were on average moderately hungry (60 ± 23 mm) and moderately thirsty (63 ± 15 mm).

3.2 Baseline desire to eat, liking and wanting, and amounts of the eaten food consumed

The results in Table 2 show that before eating (baseline) scores for desire to eat, liking and wanting were very similar for bagel versus brioche, and also very similar for which food (bagel or brioche) was randomly designated the eaten versus uneaten food.

When bagel was the eaten food the amount consumed (mean $\pm$ SD) was 124 ± 27 g (347 ± 75 kcal). Seven of these 33 participants did not consume all their bagel. The minimum amount consumed by any participant was 40 g (113 kcal). When brioche was the eaten food the amount consumed was 84 ± 27 g (289 ± 93 kcal). Fifteen of these 37 participants did not consume all their brioche. The minimum amount consumed by any participant was 34 g (118 kcal). Water intake was similar when bagel (215 ± 89 ml) was the eaten food to when brioche was the eaten food (210 ± 100 ml).

Table 2. Baseline values for desire to eat and liking

	Bagel	Brioche	Eaten food	Uneaten food
Desire to eat, mm	64 ± 26	62 ± 23	65 ± 22	61 ± 27
Liking, mm	68 ± 22	65 ± 19	68 ± 19	65 ± 21
Wanting, mm	-4 ± 13	-3 ± 16	-2 ± 14	-4 ± 16

Data are means $\pm$ SDs. N = 70. Wanting is desire to eat minus liking.

3.3 Sensory-specific satiation

Consistent with our main hypothesis there were significant tasted food by eaten food interaction effects for changes in desire to eat, $F(1,68) = 33.68$, $p < 0.001$, $\eta_p^2 = 0.331$; liking, $F(1,68) = 24.60$, $p < 0.001$, $\eta_p^2 = 0.266$; and wanting, $F(1,68) = 6.97$, $p = 0.010$, $\eta_p^2 = 0.093$. Fig. 2 shows that desire to eat and wanting decreased more for the eaten food (food tasted is the same as the food eaten) than the uneaten food (food

tasted is different from the food eaten). Liking for the eaten food decreased, but essentially it did not change for the uneaten food. The magnitude of these sensory-specific satiation effects (i.e., difference in ratings between eaten food and uneaten food) was similar irrespective of which food, bagel or brioche, was the eaten food (Fig. 2).

There was no significant main effect of eaten food on changes in desire to eat $F(1,68) = 3.08$, $p < 0.084$, $\eta_p^2 = 0.043$, liking ($F < 1$), or wanting $F(1,68) = 1.72$, $p = 0.194$, $\eta_p^2 = 0.025$. There were no significant main effects of tasted food (all F ratios < 1).

The exploratory analyses which excluded participants with potentially small changes in liking for the eaten versus uneaten food, showed that the effect size for the sensory-specific reduction in wanting remained undiminished and statistically significant, whereas the effect sizes for the sensory-specific reduction in desire to eat and liking increased slightly (Table 3). The analyses for all participants in Table 3 essentially replicates the analyses of the results displayed in Fig. 2 which show the sensory-specific effects separately for the two foods (bagel and brioche).

Desire to eat something savoury decreased (after eating minus before eating) more when the eaten food was bagel when it was brioche (-35 ± 5 mm versus -10 ± 5 mm), whereas desire to eat something sweet decreased more when the eaten food was brioche than when it was bagel (-23 ± 4 mm versus -4 ± 5 mm) (desire rating by eaten food interaction: $F(1,68) = 22.34$, $p < 0.001$, $\eta_p^2 = 0.247$.)

Fig. 2. Effects of eating bagel or brioche on desire to eat, liking and wanting for bagel and brioche. Wanting is desire to eat minus liking. Units are mm. Ratings of desire to eat and liking (taste pleasantness) were made on 0-100 mm line scales, anchored 'not at all' and 'extremely'. The eaten food was bagel for 33 participants and brioche for 37 participants.

Table 3. Changes in desire to eat, liking and wanting for the eaten food versus the uneaten food and for the corresponding differences between those foods (sensory-specific effects), for all participants and two sub-samples of the participants

	Desire to eat	Liking	Wanting
All participants			
Eaten food	-37 ± 3	-17 ± 3	-21 ± 3
Uneaten food	-9 ± 4	2 ± 2	-11 ± 3
Difference	-28 ± 5	-19 ± 4	-9 ± 4
	$t(69) = 5.86, p < .001,$ $d = 0.99$	$t(69) = 5.01, p < .001,$ $d = 0.92$	$t(69) = 2.66, p = .010,$ $d = 0.41$
Baseline liking for eaten food > 60 mm			
Eaten food	-43 ± 4	-21 ± 3	-22 ± 3
Uneaten food	-10 ± 4	2 ± 2	-12 ± 4
Difference	-33 ± 5	-23 ± 4	-9 ± 4
	$t(49) = 6.02, p < .001,$ $d = 1.16$	$t(49) = 5.89, p < .001,$ $d = 1.24$	$t(49) = 2.42, p = .019,$ $d = 0.40$
Finishers (consumed the whole portion of the eaten food)			
Eaten food	-42 ± 4	-18 ± 3	-24 ± 3
Uneaten food	-11 ± 4	3 ± 2	-14 ± 4
Difference	-31 ± 5	-21 ± 4	-10 ± 4
	$t(46) = 5.67, p < .001,$ $d = 1.11$	$t(46) = 4.88, p < .001,$ $d = 1.07$	$t(46) = 2.45, p = .018,$ $d = 0.45$

Data are means ± SEs. Units are mm. Ratings of desire to eat and liking were made on 0-100 mm line scales. Wanting is desire to eat minus liking. The statistics, including Cohen's d , are for the difference between the eaten and uneaten foods. This difference represents the sensory-specific effect.

3.4 Hunger, liking and wanting

The results for the analysis of the inter-relationships between hunger, food liking and wanting before eating are shown in the left-hand panel of Fig. 3. Hunger, but not liking, predicted wanting. There was essentially no correlation between hunger and food liking (bivariate correlation, $r(68) = 0.12$), and therefore no shared variance in hunger and liking to contribute to wanting ($R^2 < .01$).

3.5 Food satisfaction, meal enjoyment and fullness

The results for the analysis of predictors of meal satisfaction after eating are shown in the right-hand panel of Fig. 3. Hunger and liking measured at the start of the meal independently predicted meal enjoyment measured at the end of the meal, and meal enjoyment and post-meal fullness independently predicted meal satisfaction (all measured at the end of the meal). Again, liking and hunger were unrelated, as were enjoyment and post-meal fullness.

3.6 Mindset – exploratory analyses

The sensory-specific effect on desire to eat and liking, but not wanting, was reduced by the distraction mindset compared with the control condition (Table 4).

Meal duration was increased in the pause condition, significantly so compared with the distraction condition. Eating rate was slowest in the pause condition; significantly slower than in the distraction condition for the weight of food consumed per minute, and significantly slower than in both the distraction and attention conditions for kcals consumed per minute (Table 5).

There was no effect of mindset on hunger, fullness, meal enjoyment or meal satisfaction. (Table 5).

Fig. 3. Left panel: The results are for ratings made before the start of the meal for the eaten and uneaten foods combined. Wanting (mean $\pm$ SD, -3 ± 12 mm) is calculated as desire to eat minus liking (66 ± 16 mm). Hunger (60 ± 23) was rated before the food was presented and tasted. $n = 70$. Right panel: The results are for the eaten food. Liking (68 ± 19) and hunger (60 ± 23) ratings were made before eating (as for the left-hand panel results), and meal enjoyment (60 ± 21), fullness (66 ± 20) and meal satisfaction (60 ± 20) ratings were made after eating. $n = 70$. These analyses used the variance partitioning procedure described by Chuah & Maybery (1999). * denotes $p < .001$.

Table 4. Effects of mindset on sensory-specific satiation¹

	Attention, n = 18	Distraction, n = 17	Pause, n = 18	Control, n = 17	$F(3,66)$, p , η_p^2
Desire to eat, mm	-34 ± 7	$-5^a \pm 9$	-26 ± 12	$-48^b \pm 8$	3.73, 0.015, 0.145
Liking, mm	-22 ± 8	$-4^a \pm 5$	-17 ± 8	$-34^b \pm 7$	2.79, 0.047, 0.112
Wanting, mm	-13 ± 7	-1 ± 5	-9 ± 7	-15 ± 9	0.63, 0.597, 0.028

¹ The data are after minus before eating ratings for the eaten food minus the uneaten food (means $\pm$ SEs).

^{a, b} Means within a row sharing a different superscript letter differ significantly ($p < 0.05$, Bonferroni correction for multiple comparisons applied).

Table 5. Effects of mindset on meal duration, eating rate, hunger, fullness, meal enjoyment and meal satisfaction

	Attention, n = 18	Distraction, n = 17	Pause, n = 18	Control, n = 17	$F(3,66)$, p , η_p^2
Meal duration, minutes	5.54 ± 0.50	4.94 ^a ± 0.36	7.35 ^b ± 0.82	6.26 ± 0.59	3.04, 0.035, 0.123
Eating rate, g/minute	22.0 ± 1.8	22.4 ^a ± 1.9	13.7 ^b ± 1.2	19.5 ± 2.0	4.36, 0.007, 0.167
Eating rate, kcal/minute	64 ^a ± 6	71 ^a ± 5	43 ^b ± 4	61 ± 6	4.83, 0.004, 0.182
Change in hunger, mm ¹	-33 ± 6	-32 ± 8	-32 ± 5	-35 ± 6	0.04, 0.988 0.002
Change in fullness, mm ¹	36 ± 6	40 ± 7	43 ± 4	46 ± 6	0.54, 0.658, 0.024
Meal enjoyment	56 ± 5	64 ± 4	58 ± 5	63 ± 6	0.59, 0.627, 0.026
Meal satisfaction	54 ± 4	59 ± 6	57 ± 6	69 ± 3	1.95, 0.130, 0.083

All data are means ± SEs.

¹ The data are after minus before eating ratings.

^{a, b} Means within a row sharing a different superscript letter differ significantly ($p < 0.05$, Bonferroni correction for multiple corrects applied).

Ratings of meal enjoyment and satisfaction were made shortly after consumption of the meal (Figure 1).

4. Discussion

The present results provide clear support for our first and main hypothesis that sensory-specific satiation comprises a sensory-specific decrease in food wanting as well as a sensory-specific decrease in food liking (the momentary pleasantness of the taste of a food). More precisely, the decreases in wanting and liking for the eaten food were greater than the respective decreases in wanting and liking for the uneaten food (Figure 2 and Table 3). Our approach to unravelling these two components of food reward rests on the measurement of food reward using desire to eating ratings, the measurement of liking using pleasantness of taste ratings, and defining wanting as desire to eat minus liking. Crucially, we took care to rule out truncated ('floor') effects on liking which might have caused our methods to overestimate of the contribution of decreased wanting to sensory-specific satiation. First, in terms of measurement, the anchor points for the desire to eating and liking rating scales were the same ('not all' to 'extremely'). Second, we conducted exploratory analyses excluding participants with low baseline liking for the eaten food and separately excluding participants who did not finish the full portion of the food. These analyses demonstrated robust effects on wanting, undiminished in size compared with that found for all participants.

As we have argued elsewhere (Rogers & Hardman, 2015), asking 'how much do you want to eat this food' (e.g., Finlayson, King, & Blundell, 2008; Lemmens, Schoffelen, Wouters, Born, Martens, Rutters, & Westerterp-Plantenga, 2009; Olsen, Ritz, Hartvig, & Møller, 2011), does not isolate wanting from liking, as 'want' for a food in this sense includes liking – how much we 'want' to eat an offered food is determined jointly by our current hunger and anticipated liking (or momentary liking, if tasted) for the food, in other words its momentary reward value. During eating we typically do not consciously appreciate food liking and wanting separately, rather they are blended in the experience that is described as the pleasure of eating, meal enjoyment, or similar; in other words what we (Rogers & Hardman, 2015), and others (e.g., Berridge, 1996) conceptualise as food reward. Other research indicates that attentional tasks show promise in assessing wanting, although again attention toward food-related stimuli is likely affected by anticipated

liking as well as wanting, and so cannot be said to provide unambiguous evidence for sensory-specific changes in wanting with eating (di Pellegrino, Magarelli, & Mengarelli, 2011; Davidson, Giesbrecht, Thomas & Kirkham, 2018).

Our results indicate that, whilst it is substantial, the contribution of decreased wanting to sensory-specific satiation is about half the size of the contribution made by decreased liking. In turn, the contribution of sensory-specific satiation to overall satiation and satiety could be substantial. On the other hand, it can be at least largely avoided by including a variety of foods (with dissimilar oro-sensory qualities) within the meal. Indeed, it has been argued that the function of sensory-specific satiation is to motivate variety seeking, and thereby potentially improve the nutritional adequacy of individuals' diets (e.g., Hetherington, & Havermans, 2013). The contribution of sensory-specific satiation to food reward via effects on liking and wanting is depicted schematically in Fig. 4. Also depicted in this figure is an effect of hunger on wanting (our second hypothesis). This is based on results of a previous study (Rogers & Hardman, 2015, Study 1), together with the present analysis showing that baseline hunger, but not food liking, predicted wanting (left-hand panel of Fig. 3). It is worth noting that in both these studies baseline hunger was measured in the absence of food, that is, before participants saw or tasted any of the study foods. The dissociation between hunger and liking can also be seen very clearly in other analyses of the present results. Food consumption reduced hunger and increased fullness (Table 5) but liking for the *uneaten* food was unchanged (Figure 2 and Table 3). Wanting for the *uneaten* food, however, was reduced in line with the decrease in hunger/increase in fullness (Figure 2 and Table 3).

There was also support for our third and fourth hypotheses. Hunger and food liking separately predicted meal enjoyment (experienced food reward), and in turn meal enjoyment and post-meal fullness separately predicted meal satisfaction. Post-meal fullness, however, was unrelated to meal enjoyment, which is consistent with the view that fullness per se is not rewarding (Rogers & Brunstrom, 2016; Sclafani & Ackroff, 2004). Arguably, fullness is not inherently rewarding because the goal of eating is the ingestion of nutrients, and fullness inhibits nutrient intake. Rather, fullness accumulating during a meal reduces food reward via its inhibitory effect on wanting (Fig. 4). Nonetheless, consistent with previous results (Shahrokni et al., 2018), fullness did contribute positively to meal satisfaction. We suggest that humans, at least, value post-meal fullness because of the desire not to be distracted unduly by 'hunger' (thoughts of food reward) before the next scheduled opportunity to eat occurs. This primarily explicit motive for feeling full contrasts with the finding of an inverse relationship between food palatability (food reward) and fullness per calorie (Holt, Brand Miller, Petocz, & Farmakalidis, 1995). Therefore, rather than increasing fullness, our favoured strategy for increasing meal satisfaction is to increase eating enjoyment via increased food variety and flavour intensity (Rogers et al., 2016).

Our fifth hypothesis was that sensory-specific satiation would generalise beyond the eaten food, such that consumption of the savoury food (bagel) would cause a greater reduction in desire to eat savoury foods than sweet foods, with consumption of the sweet food (brioche) having the opposite effect. These predictions were fully supported by the results for ratings of desire to eat something savoury and desire to eat something sweet. This demonstrates the generalisation of sensory-specific satiation (loss of reward value) to foods similar in taste to the eaten food. In other words, sensory-specific satiation is aptly named – it is 'sensory-specific', not 'food-specific'. We have also found that sensory-specific satiation generalises from sweet drinks to sweet foods (Rogers et al., 2020).

Lastly, although there was evidence that 'mindset' did influence behaviour, in that meal duration was increased and eating rate decreased in the pause condition, there were no effects of mindset on hunger, fullness, meal enjoyment or meal satisfaction (Table 5). It is possible that we might have found effects on hunger and fullness, and even meal satisfaction, had we measured these variables later in the postprandial interval. This is based on evidence that memory for recent eating plays a role in guiding food intake at the next meal, and the proposal that increased attention to oro-sensory stimuli associated with eating and/or slowing eating rate may affect memory for recent eating by enhancing encoding of the eaten food (Higgs,

2005; Ferriday et al., 2015). However, early in the post-prandial interval gastrointestinal feedback signals of satiation may overshadow effects of memory for the meal, with memory dominating only later when those signals wane in strength (Brunstrom, Burn, Sell, Collingwood, Rogers, Wilkinson, Hinton, Maynard, & Ferriday, 2012).

In contrast with the lack of, at least, an immediate effect of mindset on fullness etc., there was an effect on sensory-specific satiation, which was reduced in the distraction condition compared with the control condition. Indeed, distraction almost fully abolished sensory-specific satiation (Table 4). This indicates that explicit memory processes are involved in generating sensory-specific satiation. Brunstrom and Mitchell (2016) also found that distraction reduced sensory-specific satiation, albeit less dramatically so than in the present study. Their distracted participants played a computer game (Pong) whilst eating. Outwardly, this procedure might be expected to be the more distracting, nonetheless the large effect in the present study demonstrates that merely asking participants to engage in a non-food-related task during eating is sufficient to abolish sensory-specific satiation. This is potentially significant, as a similar level of distraction whilst eating may be a commonplace experience. Indeed, inadvertently, it may be that there was an unusually high degree of attentive eating in the control condition, as all participants were isolated in a booth without their phones or reading material during testing. This situation is typical for laboratory studies of eating behaviour, which leads to the conclusion that such studies potentially overestimate the size of sensory-specific satiation effects compared with its occurrence in everyday life.

A final point concerning the marked reduction of sensory-specific satiation by distraction is that this result seems hard to reconcile with the conclusion that sensory-specific satiation remains intact in individuals with amnesia (Higgs et al., 2008) who, nonetheless, do not have an explicit memory of recent eating. For example, they fail to show reduced hunger or increased fullness after eating, despite reporting abdominal discomfort (Rozin, et al., 1998; Higgs et al., 2008). This is worthy of further investigation, although of course opportunities to study the effects on amnesia on eating behaviour and associated subjective experiences are rare.

4.1 Conclusions

The present study demonstrates that sensory-specific satiation, the loss of reward value of a recently eaten food versus recently uneaten food, comprises a sensory-specific decrease in food liking (the momentary pleasantness of the food in question) and a sensory-specific decrease in food wanting. We defined wanting as desire to eat minus liking. We took care to rule out floor effects on liking, which could have biased results in favour of finding a sensory-specific effect on wanting. The foods we contrasted, cream cheese bagel and chocolate chip brioche, generated large sensory-specific effects. These effects were all but abolished by distraction during eating, implying the involvement of explicit memory processes in sensory-specific satiation. Further results demonstrated that meal satisfaction is predicted independently by meal enjoyment (experienced food reward) and post-prandial fullness.

Fig. 4. Model depicting proposed positive (+) and negative (-) influences on food reward during a meal. Our previous research showed that food reward predicts food intake (Rogers & Hardman, 2015). The results of the present study demonstrate that sensory-specific satiation reduces food reward via inhibiting both food liking and food wanting. Further results confirm that hunger (the absence of fullness) affects food reward via wanting, without affecting liking. Not shown is a positive feedback effect of food intake on food reward. Consistent with the concept of ‘appetition’ (Sclafani, 2013), recent neuroanatomical and behavioural studies (on mice) have identified vagal gut-to-brain pathways activated by rapid detection of food in the upper gastrointestinal tract during a meal that signal separately food reward, fullness and malaise (Han, Tellez, Perkins, Perez, Qu, Ferreira, Ferreira, Quinn, Liu, Gao, Kaelberer, Bohórquez, Shammah-Lagnado, de Lartigue, & de Araujo, 2018). Within the meal, this positive feedback effect of food intake on food reward might occur primarily via wanting. Additionally, it likely supports flavour-nutrient learning and thereby increases reward value of a food via enduring effects on liking and on wanting (Sclafani, 2013; Han et al., 2018). Also not shown are constraints on food intake such as dietary restraint, competing activities, competing rewards, and the discomfort of fullness (the gastrointestinal tract has a large but finite capacity to accommodate food intake). In humans, food reward is likely represented in the orbital-frontal cortex (Rolls, 2007; 2019). It is worth noting that liking can have a negative value, that is, some foods or potential foods taste unpleasant. This was avoided in the present study by recruiting participants who ‘liked’ and would be willing to eat the study foods. (GI = gastrointestinal.)

Dedication

This paper is dedicated to the memory of Dr Jim Wright. Jim was a friend and mentor to me during my time as a research student, postdoc and lecturer at the University of Leeds, UK. He taught me about the primacy of predicting and measuring behaviour, and about using explanatory concepts parsimoniously. We did not measure food intake behaviour in the present study (although we know from previous results that food reward predicts food intake), nonetheless I hope that Jim would have approved of our research. Peter Rogers.

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Disclosures

The authors have no conflicts of interest to declare in relation to this research.

Data statement

The data from this study are available on request from the Corresponding Author (email: peter.rogers@bristol.ac.uk)

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