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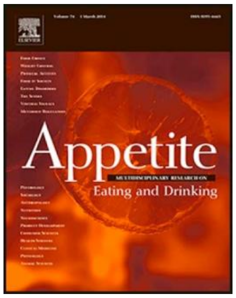

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Food reward: what it is and how to measure it

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Highlights

Food reward was measured by ratings of desire to eat a portion of a tasted food

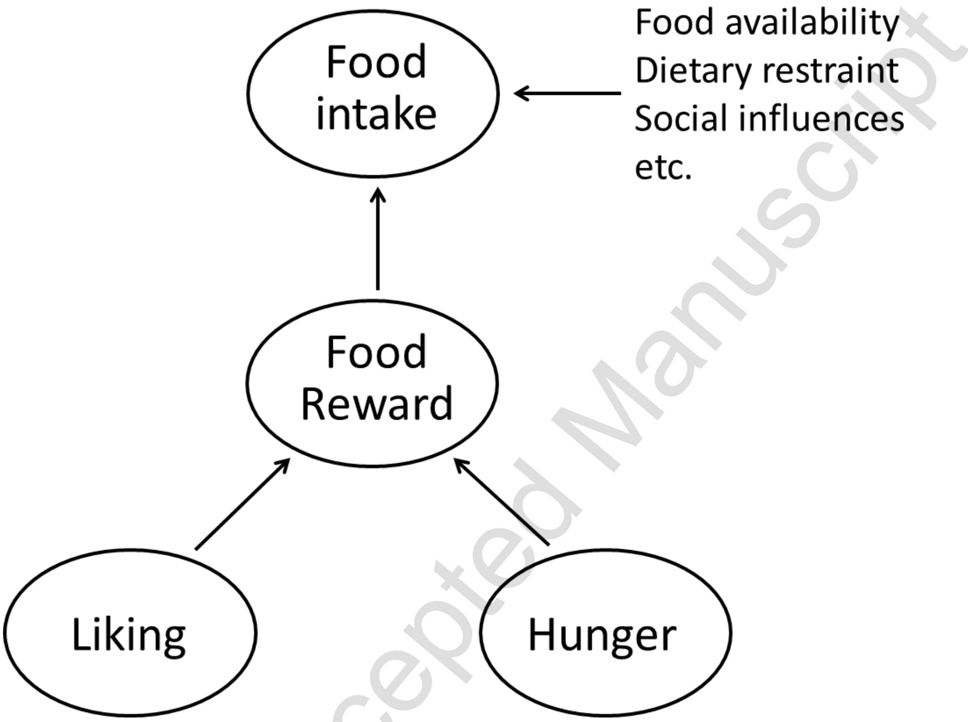
We defined liking as pleasantness of the taste of food, not pleasantness of eating

Liking for recently uneaten foods changed little with hunger/fullness

Hunger and liking were found to contribute largely independently to food reward

Desire to eat ratings better predicted food intake than did a work-for-food measure

Graphic Abstract



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Abstract

We investigated the contribution of hunger and food liking to food reward, and the relationship between food reward and food intake. We defined liking as the pleasantness of taste of food in the mouth, and food reward as the momentary value of a food to the individual at the time of ingestion. Liking and food reward were measured, respectively, by ratings of the pleasantness of the taste of a mouthful, and ratings of desire to eat a portion, of the food in question. Hunger, which we view as primarily the absence of fullness, was rated without food being present. Study 1 provided evidence that hunger and liking contribute independently to food reward, with little effect of hunger on liking. Food intake reduced liking and reward value more for the eaten food than uneaten foods. The results were ambiguous as to whether this food-specific decline in reward value ('sensory-specific

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satiety') involved a decrease in 'wanting' in addition to the decrease in liking. Studies 2 and 3 compared desire to eat ratings with work-for-food and pay-for-food measures of food reward, and found desire to eat to be equal or superior in respect of effects of hunger and liking, and superior in predicting ad libitum food intake. A further general observation was that in making ratings of food liking participants may confuse the pleasantness of the taste of food with the pleasantness of eating it. The latter, which some call 'palatability,' decreases more with eating because it is significantly affected by hunger/fullness. Together, our results demonstrate the validity of ratings of desire to eat a portion of a tasted food as a measure of food reward and as a predictor of food intake.

Keywords: Food reward; Hunger; Liking; Desire to eat; Food intake; Wanting

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Introduction

This paper describes an approach to measuring food reward in humans using participant ratings of 'desire to eat.' At first sight this might appear naïve when compared with, for example, intake, choice, work-for-food and reaction time tests or measurement of brain activity; however our studies demonstrate the utility and validity of desire to eat as a measure of food reward. In particular they show that desire to eat a portion of a tasted food is: (1) influenced independently by hunger and food liking, and (2) performs better than work-for-food and pay-for-food measures in predicting food intake.

Definitions of hunger, liking, food reward and food intake, and their interrelationships

The original starting point for the studies described in this paper was the question "Does food taste better when one is hungry compared with when one is full?" (We assume that taste here is understood in the general sense, and so also includes, flavour, texture, etc.) When we ask this question in English to English-speaking people – friends, strangers, classes of psychology undergraduate students, and colleagues – almost everyone answers yes (it does). But we also find that it is easy to the turn this ready agreement about an everyday 'fact' of eating into disagreement with the following example: "When you have eaten a really large meal, for example Christmas (or Thanksgiving) dinner, does the food now not taste good, or rather is it that you are simply too full to eat more? Indeed, perhaps it is somewhat frustrating that there is plenty of nice-tasting food left to eat, but you are too full to eat it." The change of mind occurs because the example clarifies the meaning of 'taste better' by making a distinction between how pleasant food tastes in the mouth (our meaning, and also what we define here as liking) and how pleasant it is to eat that food (Rogers, 1990; Rogers & Blundell, 1990; Mela & Rogers, 1998; *cf.* Mook, 1987), which we suggest is influenced both by liking and hunger/fullness.

Encouraged by these initial observations, we set out to formally investigate the relationship between hunger and liking and how they in turn relate to food reward. The result is the three studies that we report here. In designing them we had in mind the model depicted in Figure 1. We were also cognisant of the importance of defining terms unambiguously (Salamone & Correa, 2013), and we have done that below and in summary in Table 1. The question about whether there is an effect of hunger on liking is depicted in Figure 1 by the question mark on the line going from the hunger oval to the liking oval.

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Hunger and liking in turn determine food reward, and food reward influences how much is eaten. To be clear, in relation to this model we define liking as 'the pleasantness of the taste, flavour, etc.' of food in the mouth. This is different from, for example, Berridge (1996) who equates liking with palatability, which he defines as 'the hedonic component of food reward . . . (that) results from a central integrative process that can incorporate aspects of not only taste, but of the physiological state and the individual's associative history' (p 2). Young (1967), among others, gives a very similar definition of palatability. In this sense, palatability could be said to be experienced as the pleasantness of eating (above), and therefore not what we call liking, which we propose may not be very much affected by hunger, although is modifiable via association between a food's taste and its post-ingestive consequences (Scalfani & Ackroff, 2004; Brunstrom, 2007; Yeomans, 2012). We suggest that, although liking is usually experienced as part of the pleasantness of eating, it can be evaluated separately, simply by directing attention to 'tasting' rather 'eating.' Indeed, as our results indicate (Study 1), at least some participants probably interpret even the question 'How pleasant is this food?' as meaning taste pleasantness.

We do not, however, equate pleasantness of eating to food reward because, like Berridge (1996), we can conceive of influences on food reward independent of a 'hedonic component.' Perhaps there are effects (via 'wanting' in Berridge's model) of, for example, hunger and the energy density of food on food reward at least partly separate from their effects on the pleasantness of eating. Also there might be significant dissociation between pleasantness of eating and food reward (i.e., ingestion with diminished pleasure) in emotional eating, compulsive eating and binge eating. In the context of our model we define food reward as representing the momentary value of a food to the individual at the time of ingestion. It follows that food reward accumulates over a meal (each mouthful eaten is separately rewarding) so that total food reward will be greater for a large versus small meal of the same food, and also, as described later, greater for a more varied meal.

We view food reward as the final common pathway through which hunger and liking influence food intake. Note, however, that food intake is not the same as food reward (*cf*. Berridge 1996), otherwise there would be no need for a food reward component in the model. The model in Figure 1 seems plausible, at least to us. Eating is more rewarding if one is hungry and it is more rewarding if the food tastes good. Intake, however, is subject to additional influences. For example, dieting or serving a small portion puts a ceiling on the

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amount eaten – in which case the eater is likely to experience the food as 'moreish' because without satiation eating remains rewarding (Rogers & Smit, 2000).

Relationships between hunger, liking, food reward and food intake

We propose that all four components in the model depicted in Figure 1 can be measured directly and simply. Specifically, ratings of hunger, food liking, and desire to eat that food, provide measures of, respectively, hunger, food liking and food reward, and intake of that food from an unlimited portion (in practice a portion larger than participants are able to eat) provides the measure of food intake. Two other measures of food reward that have been used are an instrumental response, on for example a progressive-ratio schedule, and asking about the amount that the participant is willing to pay to have access to a fixed portion of the food (e.g., Epstein, Truesdale, Wojcik, Paluch & Raynor, 2003; Brunstrom & Rogers, 2009; Havermans, Janssen, Janneke, Giesen, Roefs & Jansen, 2009; Hardman, Herbert, Brunstrom, Munafo & Rogers, 2012), and we also included variants of these measures in two of the current experiments.

Of course hunger, etc. ratings have been used routinely in studies of human appetite, and desire to eat ratings have been included in many of those studies dating from research by one of us (Rogers & Blundell, 1979). It is appears though that, in the absence of knowing what is on offer to eat, the experience of appetite that a participant communicates via a desire to eat rating differs little or not at all from the experience of appetite that they communicate via a hunger rating. This is supported by the high correlation between hunger and desire to eat ratings.[1] It is also consistent with the model shown in Figure 1, in that without knowing what food is on offer, or better, seeing and tasting it, liking can have no effect separate from hunger on desire to eat. Further, ratings of hunger and fullness are (negatively) correlated, which is to be expected if a major stimulus for hunger is the absence of fullness (Stricker, 1984; Rogers, 1999). However, the experience of hunger would appear to be influenced by more than (stomach/gut) fullness, including post-absorptive effects of

[1] Whether or not participants had recently eaten, their hunger and desire to eat ratings made on a 100 mm line scale with no food present were highly correlated, r = 0.82 (L. A. Kyle and P. J. Rogers, unpublished data). A correlation of < 1 might be expected merely on the basis of error of judgement. So, for example, this was not different from the correlation (r = 0.85) between successive hunger ratings (made 5 minutes apart with no intervening eating or food exposure). The correlation between successive hunger and desire eat ratings, also made 5 minutes apart, was r = 0.78.

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nutrients (Sakata, Fujimoto, Ogata, Koyama, Fukagawa, Sakai &Tao, 1996) and the memory of recent eating (Higgs & Donohoe, 2011). When we asked participants informally about what caused them to rate their hunger as they did, as well as referring to feeling full or empty, they also frequently mentioned how long ago they last ate, how large their last meal was, and whether or not it was currently close to a time that they would usually expect to eat.[2] On the basis of these considerations and our aim to test the model depicted in Figure 1, we instructed our participants to taste (and swallow) a bite of the food in question and then rate their liking for the food (pleasantness of its taste) and their desire to eat the entire portion (e.g., slice of pizza) presented. Hunger at 'baseline' was rated before this exposure to the food.

Study 1

In the first study participants rated their hunger and their liking and desire to eat pasta in tomato sauce before and after eating a meal of the same food. They also rated their liking for and their desire to eat three other foods (uneaten except for small bites). This enabled us to investigate the extent to which changes in liking and desire to eat might differ for uneaten and recently eaten foods (Rolls, Hetherington & Burley, 1988; Hetherington, Rolls & Burley, 1989). We also investigated the phrasing of the liking question. This is because, as described above, we were concerned that the simple question 'how pleasant is this food' (e.g., Cabanac 1971; Cabanac & Duclaux, 1970), or even 'how pleasant is the taste of this food' (e.g., Rolls et al., 1988; Hetherington et al., 1989) might be mistaken for how pleasant is it to eat this food, or at least partly 'contaminated' by the latter. Evidence for this comes from previous studies showing larger individual differences in decreases in taste pleasantness than in eating pleasantness across a meal (Rogers & Blundell, 1990; Mela & Rogers, 1998). To investigate these individual differences further we divided participants in the present study into 'no decrease' and 'decrease' in liking groups, based on their answer to a question about how their liking for the foods compared before and after eating the

[2] Consistent with hunger being the absence of fullness we observed a high correlation between pre-meal hunger and fullness ('how full do you feel') ratings of r = -0.86. However, the correlation was only r = -0.44 when the question was 'how full does your stomach feel' (L. A. Kyle, C. A. Hardman and P. J. Rogers, unpublished data). A possible explanation for this difference is that when directed to rate their stomach fullness raters do exactly that, but when the question is less focussed (just fullness) they also factor in the timing and size of their last meal, etc. as they do when rating their hunger.

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meal. We also challenged decrease-group participants to reflect on their past experience of appetite after eating a particularly large meal (see above), and whether this might cause them to re-evaluate their experience.

Our hypotheses for this study were as follows. (1) Participants will show the least decline in liking from before to after eating when instructed to focus on the pleasantness of the taste of the food in the mouth. (2) While some participants will claim a substantial decrease in liking (decrease group) after the meal, their decreases in both hunger and desire eat will be equivalent to those reported by participants claiming little or no decrease in liking. (Such a result would indicate that participants in the decrease group failed to separate pleasantness of taste from pleasantness of eating when making their liking ratings. This is because our model predicts that desire to eat will be affected by liking and hunger. With an equivalent decrease in hunger, a greater decrease in liking should, if genuine, be accompanied by a greater decrease in desire to eat.) (3) Changes in liking and desire to eat from before to after the meal will be greater for the eaten food than the uneaten foods. (4) Rated hunger and food liking (pleasantness) will contribute independently to desire to eat.

Methods

Participants

Participants were recruited by advertising for volunteers for a ‘Study on rating the pleasantness of different types of food’ on noticeboards around the University of Bristol and by word of mouth. The incentive offered for taking part was that the study involved consuming pleasant tasting food. None of the participants was currently dieting or had a history of disordered eating. In total 48 participants (24 women) were recruited and completed the study.

The procedures for this and the other two studies described here were approved by the University of Bristol, Faculty of Science Human Research Ethics Committee. Informed consent was obtained from all participants for their participation in the studies.

Design

The participants were randomised to three groups with the constraint that there would be equal numbers of women and men in each group. The groups differed as to the wording of the scale used for the assessment of food liking (Scale A, pleasantness of the

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food; Scale B, pleasantness of the taste of the food; Scale C, pleasantness of the taste of the food, ignoring how much is wanted and what it would be like to eat it; see below for full details). The order of presentation of the foods for the liking and desire to eat tests (see below) were balanced across rating scale group and gender.

Foods

The foods for the liking and desire to eat tests were as follows. 50 g pasta in tomato sauce (Sainsbury's penne pasta and Dolmio sun-dried stir-in tomato sauce, cooked according to packet instructions and served hot; 67 kcal), 12 cheese biscuits (McVitie's Mini Cheddars; 18.8 g, 101 kcal), 3 sweet biscuits (Sainsbury's sweetmeal digestives; 37.5 g, 184 kcal), and 5 squares of milk chocolate (Sainsbury's milk chocolate; 31.3 g, 168 kcal). These foods were served, on a white plate, one food at a time. The amounts served gave the appearance of similar volumes on the plate. For the lunch meal the pasta in tomato sauce was served in a white bowl. Women received 400 g (536 kcal) and men 500 g (670 kcal). Participants were asked to eat all of their meal, if they wished to do so. We termed the pasta in tomato sauce the 'eaten' food, and the other foods the 'uneaten' foods.

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Measures

Participants rated their hunger on a 100-mm horizontal line scale presented on paper accompanied with the printed instruction 'Please indicate how hungry you feel right now by making a vertical line on the scale at the appropriate point.' The left hand end of the line was anchored with the words 'NOT AT ALL' and the right hand end was anchored with 'EXTREMELY'.

For the liking and desire to eat ratings participants were instructed to take a bite of the food and rate its pleasantness, and then rate their desire to eat the remaining portion. The order in which the sweet and savoury foods were tasted and rated was counterbalanced across gender and liking scale group. The liking and desire to eat scales were presented similarly to the hunger scale and anchored with the words 'NOT AT ALL' (left hand end) and 'EXTREMELY' (right hand end). The instructions for the different liking scales were as follows: (A) 'Please rate the pleasantness of this food', (B) 'Please rate how pleasant this food tastes in your mouth RIGHT NOW,' (C) 'Please rate how pleasant this food tastes in your mouth RIGHT NOW? When making this judgement, IGNORE how much or

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little of the food you want to eat, and what it would be like to chew and swallow it – JUST FOCUS PURELY ON HOW IT TASTES IN YOUR MOUTH.' For the desire to eat rating the instructions were 'Now look at the remaining food on the plate. How strong is your desire to eat, that is, to taste, chew and swallow, the rest of this food RIGHT NOW?'

Shortly after the participant had completed the final rating the Experimenter thanked her/him for their participation and, after a short preamble about the study (without stating its hypothesis), asked them "Did you think that the food tasted less good when you were fuller (after the meal)?" She recorded the participant's response (no or yes). For participants who responded yes, she explained "Our hypothesis is that after eating a meal our ratings of hunger should decrease because we are more full, but our actual liking for the taste of the food shouldn't change. For example, at Christmas dinner you may find yourself very full and unable to eat anymore, but be annoyed because you wish you could continue to eat as the food still tastes really good." And then she asked "Does this make you change your mind (about your experience)?" and recorded the participant's response (no or yes).

Procedure

Participants were instructed not to consume any food or energy-containing beverages within the 3 hours before their scheduled arrival for testing. They were tested individually, starting at either 12:00h, 13:00h or 14:00h. Each test session lasted 50 minutes and involved (1) a baseline hunger rating (no food present), (2) ratings of liking and desire to eat two savoury and two sweet foods, (3) consumption of a lunch (one of the savoury foods, tomato in pasta sauce, time allowed 10 minutes), (4) hunger rating (no food present), (5) ratings of liking and desire to eat the four foods, (6) 10-minute break, (7) hunger rating (no food present), (8) ratings of liking and desire to eat the four foods, (9) brief, structured interview, (10) height and weight measured, and (11) participant debriefing. This schedule generated data on hunger, liking and desire to eat timed (start of data collection) at 5 minutes before and 1 and 15 minutes after consumption of lunch.

Data analysis

The dependent variables were hunger, liking and desire to eat. Responses to the interview question "Did you think that the food tasted less good when you were fuller?"

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posed at the end of the test session were used to classify participants into Liking group (no decrease and decrease). Mixed factors ANOVA was used to compare the effects of Meal (3 levels: before and 1 and 15 minutes after the meal) on liking (averaged across the four foods) measured by the three different liking scales (Scale: A, B and C). Chi^2 was used to analyse the distribution of Liking group participants in respect of gender and rating scale. Mixed factor ANOVA was used to analyse the effects of Meal (3 levels: before and 1 and 15 minutes after the meal), Food (2 levels: eaten and uneaten) and Liking (2 levels: no decrease and decrease in liking from before to after the meal) on hunger, liking and desire to eat. Scale group was not included as a factor in these analyses. The Greenhouse-Geisser correction was applied where appropriate (fractional degrees of freedom and adjusted *p* values are reported).

We used the variance-partitioning procedure described by Chuah and Mabery (1999) to assess the independent and combined contributions of hunger and food liking to desire to eat after the meal, separately for no decrease and decrease liking groups. The data analysed were ratings averaged across all four foods and across the 1- and 15- minute post meal tests.

All data were normally or near normally distributed. The bivariate correlations between liking and hunger for the no decrease and decrease in liking groups were, respectively, $r = 0.11$ and $r = 0.42$, ruling out collinearity as a problem in the variance partitioning analyses.

Results

Participant characteristics (mean ± SD) were as follows: age, 20.7 ± 1.0 years, weight 68.6 ± 10.9 kg, BMI 22.5 ± 2.8 $kg.m^{-2}$. These characteristics were similar for each of the three groups. The amounts (mean ± SD) eaten in the meal of pasta and sauce were 383 ± 40 g (women, served 400 g) and 472 ± 68 g (men, served 500 g). All but four women and five men ate all of the food served (food remaining for these nine participants was 28-145 g and 88-227 g, respectively).

Figure 2 shows the results for liking before and after the meal measured by the three scales. Liking decreased after the meal (main effect of Meal, $F(1.51,68.2) = 35.97$, $p < .0001$). Neither the magnitude of this decrease (Meal by Scale group interaction, $F<1$) nor the overall magnitude of liking ratings (main effect of Scale group, $F<1$) differed between the

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scales. (For this reason Scale group was not included in subsequent analyses of the hunger, liking and desire to eat data.)

In the debriefing interview at the end of test session 23 participants said no and 25 said yes to the question ‘Did you think that the food tasted less good after you were fuller?’ These no decrease and decrease in liking participants were equally distributed across gender (Chi^2 = 0.75, df = 1, p = .39) and Scale group (Chi^2 = 0.17, df = 2, p = .92). Of the nine participants who did not eat all of their meal, four were in the no decrease group. When questioned further and given the example of feeling very full after a large meal but possibly still finding food just as pleasant tasting, 20 of the 25 decrease group participants revised their response to no decrease.

Results for ratings of hunger, and of liking and desire to eat for the uneaten foods and the eaten food, made before and after the meal are shown separately for the no decrease and decrease groups in Figure 3. Hunger was marginally higher overall in the no decrease group than in the decrease group (main effect of Liking group $F(1,46) = 3.58$, p = .065), but there was a large and equal decrease in hunger for both groups from before to after the meal (main effect of Meal $F(1.60,73.5) = 163.82$, $p < .0001$; Meal by Liking group interaction $F < 1$).

Liking decreased overall from before to after the meal (main effect of Meal $F(1.77,81.6) = 48.70$, $p < .0001$), and it did so more for the eaten food than for the uneaten foods (Meal by Food interaction $F(1.72,79.0) = 21.02$, $p < .0001$). Liking also decreased more for the decrease group than for the no decrease group (Meal by Liking group interaction $F(1.77,81.6) = 5.53$, $p = .007$). Liking for the uneaten foods did not change for the no decrease group (simple main effects analysis: $F(1.84,40.5) = 1.72$, $p = .19$), although it did for the eaten food ($p < .0001$), and for both the uneaten ($p = .0001$) and eaten foods ($p < .0001$) for the decrease group. There was no Meal by Liking group by Food interaction (F < 1).

Desire to eat also decreased overall from before to after the meal (effect of Meal $F(1.70,78.1) = 182.43$, $p < .0001$), and more so for the eaten food than for the uneaten foods (Meal by Food interaction $F(1.64,75.2) = 58.84$, $p < .0001$). However, in contrast to liking, the decrease in desire to eat did not differ between the no decrease and decrease groups (Meal by Liking group interaction $F < 1$). Simple main effects analysis showed that desire to eat decreased both for the uneaten foods ($p < .0001$) and the eaten food ($p < .0001$). There was no Meal by Liking group by Food interaction ($F(1.64,75.2) = 1.28$, $p > .1$).

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Gender was included in exploratory analyses of these data (no gender effects were hypothesised). No significant main effects of gender or interaction effects involving gender were found (*ps* >.05).

The results from the variance partitioning analyses are shown in Figure 4. These demonstrate that hunger and liking independently contributed to the prediction of desire to eat in both the no decrease in liking group and the decrease in liking group. In addition for the decrease in liking group, but not for the no decrease group, shared variance in hunger and liking also contributed to the prediction of desire to eat. Hunger and liking together accounted for more than half of the variance in desire to eat (no decrease group, Total R^2 = .54, p = .0004; decrease group, Total R^2 = .64, $p < .0001$).

Discussion

Contrary to our first hypothesis, the magnitude of the decrease in food liking from before to after the meal did not differ between the three liking rating scales. This result is helpful in suggesting that, in the absence of coaching participants to the hypothesis under test and the expected result, little more can be done to assist them in making a distinction between the experience of the taste of a food separate from the experience of eating (tasting, masticating and ingesting) that food. The decrease in liking was, however, relatively small, at least for the uneaten foods (Figure 3). Across all participants it was reduced immediately after the meal (573 kcal eaten) by an average of only 7 mm on the 100-mm scale, whilst hunger was reduced by 48 mm. This preservation of liking for uneaten food after eating has been observed in various previous studies (e.g., Hetherington et al., 1989; Epstein et al., 2003; Brunstrom & Mitchell, 2006; Havermans et al., 2009). Why, therefore, is the idea that 'food tastes better when we are hungry' so salient? Two, not mutually exclusive, explanations are first that the statement is made with reference to liking for recently eaten rather than uneaten food, and second that there is confusion of the pleasantness of the taste of food with the pleasantness of ingesting food.

Again, consistent with many previous findings (e.g., Rolls et al., 1988; Hetherington et al., 1989; Epstein et al., 2003; Brunstrom & Mitchell, 2006; Havermans et al., 2009) and our third hypothesis, we observed a larger decrease in rated liking for the eaten food than the uneaten foods. This phenomenon has been termed 'sensory-specific satiety' (Rolls et al.,

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1988), and it appears to involve habituation, some loss of taste intensity and 'top-down' influences (Brunstrom & Mitchell, 2006; Hetherington & Havermans, 2013; Wilkinson, 2013; Wilkinson, Hinton, Fay, Rogers & Brunstrom, 2013). Notably, in the present study liking for the eaten food decreased even when participants were explicitly asked to focus just on the pleasantness of the taste of the food. Furthermore, the decrease was substantial. Across all participants it was 26 mm, which is actually at least as large if not larger than in the studies cited above.

At the same time, it has to be cautioned that the decrease in liking may have been exaggerated here, and in earlier studies. Despite what we believed to be clear instructions, it may be that (many) participants failed in the rating task to separate their experience of the taste of the food from their experience of eating the food. This possibility is supported by the finding in the interview that slightly over half of the participants said that the food tasted less good after the meal (no distinction was made between the uneaten and eaten food in this questioning). Correspondingly, and unlike the no decrease participants, their liking ratings for all of the foods decreased from before to after the meal. However 80% of these participants revised their response to no decrease after further questioning. Of course, it is possible that the responses in the interview of the no decrease and decrease participants reflect a genuine difference in experience of liking, and that those in the decrease group who revised their response on further questioning did so because they felt obliged to agree with our hypothesis. Against this however, and consistent with our second hypothesis, is the observation that, while the decrease in liking group showed a greater decline in rated liking from before to after the meal, their hunger and desire to eat decreased to the same extent as the no decrease group. This suggests similar experiences of the effects of food ingestion on appetite in these groups (and meal intake did not differ between no decrease and decrease in liking groups; 581 and 565 kcal respectively). Put more specifically, as desire to eat appears to be affected by liking and hunger (see above), with an equal decrease in hunger, a greater decrease in liking should, if it was genuine, be accompanied by a greater decrease in desire to eat, but this was not observed.

So our explanation for the liking ratings and initial interview responses of the decrease group participants is their relative failure to separate the pleasantness of the taste of food in the mouth from the pleasantness of eating. A large majority though were apparently able to recognise this distinction when pressed further in the interview. That left

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five participants confirming their initial response. It may be that they were unwilling to admit to a poor judgement. Or perhaps more likely they brought to mind their experience of the eaten food when responding, for which, consistent with sensory-specific satiety and confirmed by the liking ratings made by the no decrease participants, there was a real decrease in taste pleasantness.

The results of the variance partitioning analysis supported our fourth hypothesis that hunger and liking contribute independently to food reward, as measured by desire to eat ratings (Figure 4). Note that the statistical method identifies the unique contribution of each predictor variable (liking and hunger) to the independent variable (desire to eat), separately from any shared contribution (liking to hunger link). In relation to the latter, there is partial support for our second hypothesis that hunger does not affect liking, in that at least for the no decrease in liking group there was no shared contribution of hunger and liking to desire to eat. For the decrease group, however, there was a shared contribution, which suggests that, in addition to the independent contributions of hunger and liking to food reward, hunger also affects food reward by increasing liking. The reverse influence of liking on hunger ratings is conceivable (e.g., Yeomans, 1996), but would not have occurred here because participants rated their hunger before they were presented with the food for rating liking and desire to eat. Although an effect of hunger on liking might be expected, as discussed below, there are reasons to believe that this may be a spurious result arising from the failure on the part of some participants to separate taste and eating pleasantness, despite our attempt to help them do this.

The success of the analysis of the interrelationships between liking, hunger and desire to eat in part derived from procedures that ensured large variability across participants in these ratings. The foods were neither close to ceiling or floor in liking, and the pasta in tomato sauce meal was not so large that it reduced hunger or desire to eat to floor.

A final point for discussion is that it is apparent from Figure 3 that at 5 minutes before the meal desire to eat the pasta in tomato sauce (the food that was subsequently eaten in the meal) was greater than the average desire to eat for the other three foods. On its own, this result is unremarkable in that it can be interpreted as showing merely that pasta in tomato sauce was for these particular participants at that time the more desirable food. However, there was not an equivalent difference in liking. Although liking was greater

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for pasta in tomato sauce, the difference compared with the average liking for the other foods was smaller than for desire to eat. This is not predicted straightforwardly by our model as depicted in Figure 1, because if hunger plus liking equals desire to eat, and by definition hunger does not differ across the foods, then the difference between foods in desire to eat should be equivalent to the difference in liking. A resolution to this problem is that there are one or more other influences on desire to eat that are not depicted in Figure 1. Indeed, we suggest this in relation to our discussion of wanting in the Introduction, where we argue that hunger is but one component of wanting. What may account for the greater desire to eat pasta in tomato sauce at baseline is that this is a savoury food, evaluated at lunchtime following a fast of at least 3 hours. In this context of a meal, rather than a snack, tomato in pasta sauce is more usually eaten and more appropriate (Hirsch, Kramer & Meiselman, 2005) as a first course than two of the three uneaten foods which were sweet (and even the third uneaten food, cheese biscuits, is not typically consumed as a first course). In other words, at a given moment, wanting, and in turn desire to eat (food reward), is also influenced by the usual habit for a meal that consumption of savoury food precedes consumption of sweet food. Liking, on the other hand, is largely independent of this influence, in the same way that it is largely independent of hunger.

As well as providing results on the relationship between hunger and food liking, this study provides preliminary evidence on the validity of desire to eat ratings as a measure of food reward. Both hunger and food liking contributed to desire to eat, which matches the experience that eating is most rewarding when the food tastes good and we are hungry. In the next study we tested the validity of this measure further by comparing its performance with other putative measures of food reward.

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Study 2

On the face of it, the amount of money paid and the amount of work performed to gain access to a commodity ought to be good indicators of its reward value, and both of these measures have been used previously in studies of human eating behaviour. For example, in a study of expected liking and expected satiation as determinants of food utility (food reward) Brunstrom and Rogers (2009) used amount willing to pay ('Imagine you are having this food for lunch today. What is the maximum you would pay for this food?') as the measure of food reward. Epstein et al. (2003) used responding on a progressive-ratio task as a measure of the 'reinforcing value of food.' Later, Havermans et al. (2009) used a very similar task to measure 'food wanting.' In both cases the authors argue that the task measures motivational effects on eating independent of food liking; however, our interpretation (see General discussion) is that performance on these tasks is likely to be affected by how much the food is liked, as well as by hunger/fullness, and therefore they actually measure what we call food reward.

In the present study we devised a simple bar pressing task as a work-for-food measure. With this we included a work-for-money measure to control for possible non-motivational effects on responding (e.g., resulting from the soporific effects of the meal). We predicted that food ingestion would not affect performance on this control measure. We also included a pay-for-food measure. Our objective was to compare the work-for-food and pay-for food measures with desire to eat, as affected by food liking, hunger and food ingestion. We also included a no meal condition to test for possible effects of repeated assessments and/or the passage of time on the various measures. We predicted no substantial change over time in any of the measures for this condition.

Method and materials

Participants

There were 48 participants (24 women). None of these healthy women and men was currently dieting or had a history of disordered eating. They were recruited via advertisements placed on noticeboards around the University of Bristol and by word of mouth. The advertisements were headlined 'Your liking for pizza' and the incentives offered

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for participation were free pizza to eat and the opportunity to win up to £5. All participants who started the study completed it.

Design

The participants were randomised to a group of 32 (meal consumed) and a group of 16 (no meal consumed), with the constraint that within each group there would be equal numbers of women and men. The groups differed as to whether or not they received a pizza meal between the first and second set of hunger, liking and reward measures (see below).

Food

The food was tomato and cheese ('Margherita') pizza (325 g, 2.39 kcal/g; Sainsbury's Supermarkets Ltd, London, UK). It was cooked according to the manufacturer's instructions, cut into 8 equally-sized, triangular slices and served hot. In the meal group, women received 5 slices (485 kcal) of pizza to eat and men received 6 slices to eat (583 kcal). For the liking and food reward tests participants were presented with a single slice of pizza (97 kcal).

Measures

The hunger and desire to eat measures were the same as for Study 1.

All participants received the liking scale with the instructions 'Please rate how pleasant this food tastes 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 chew and swallow it – JUST FOCUS PURELY ON HOW IT TASTES IN YOUR MOUTH' (i.e., the same as scale C in Study 1).

The pay-for-food measure was a 100-mm horizontal line, anchored with 0 p at the left hand end and £2.00 at the right hand end, and £1.00 printed above the line centred at 50 mm.

The work-for-food and work-for-money tasks were programmed using E-Prime 2.0 (Psychology Software Tools, Inc. Sharpsburg, PA, USA), and run on networked PCs with 17-in colour monitors and standard QWERTY keyboards. Instructions were presented in black font on a white background. For the work-for-food task these were as follows. First screen: 'Pizza bar pressing task, please wait for instructions.' Second screen: 'Starting in 30 seconds you will have one minute in which you can earn FOOD (pizza) by pressing the SPACEBAR. The more times you press the more FOOD (pizza) you will earn. The maximum amount you can earn is a whole pizza (8 slices). To maximise what you can earn start bar pressing as soon as you see the red count-down clock appear below. Have your finger ready at the SPACEBAR.' Third screen: 'KEEP PRESSING THE SPACEBAR. The more times you press the more FOOD (pizza) you will earn.' A digital clock displayed the number of seconds remaining. Final screen: 'Thank you for completing the task. Please wait for further instructions from the Experimenter.' Each sentence of these instructions appeared centred on a separate line(s) on the screen. The total number of space bar presses made in the designated 1-minute period was recorded. The work-for-money task was the same as the work-for-food task except that the first screen was headed 'Money bar pressing task', and MONEY (£££££) replaced FOOD (pizza) on the second and third screens. In addition, on the second screen it was stated that 'The maximum amount that you can earn is £5.'

Procedure

As in Study 1, participants were instructed not to consume food or energy-containing beverages within the 3 hours before their scheduled arrival for testing. Again they were tested individually, starting at either 12:00h, 13:00h or 14:00h. The schedule for the 45- to 50-minute test session was as follows: (1) hunger (no food present), (2) taste and swallow a bite of pizza, followed by liking, desire to eat, and the pay-for food, work-for-food and work-for-money measures (pizza slice present throughout), (3) consumption of pizza or wait for 10 minutes (see below), (4) hunger (no food present), (5) taste and swallow a bite of pizza, followed by liking, desire to eat, and the pay-for food, work-for-food and work-for-money measures (pizza slice present throughout), (6) height and weight measured, (7) participants debriefed and rewarded with £5.

To explain the 10-minute wait after the first set of the work-for-food and work-for-money tasks, participants in the no meal condition were told that due to an error the computer had failed to save their data. The Experimenter apologised for this and asked the participant if they would perform the task again if the problem could be remedied. (All participants agreed to this.) The participant was provided with magazines to read (minimal food- and eating-related content) and the Experimenter then left "to fix the problem." She returned 10 minutes later saying that "the programme was working now" and asked the

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participant to complete the hunger, liking and desire to eat ratings and the pay-for-food measure because "how you feel may have changed." She then opened the file for the participant to repeat the work-for-food and work-for-money tasks. In the meal group, after the first set of work-for-food and work-for-money tasks, participants were served with the 5 (women) or 6 (men) slices of pizza they had 'won' and were encouraged to eat all of them – participants were given these amounts regardless of how they performed on the work-for-food task. They were left alone for 10 minutes to eat, after which the Experimenter returned saying that they could repeat the tasks to win more pizza and more money. (The no meal participants were offered pizza after being debriefed and paid.)

Data analysis

We used mixed factor ANOVA to analyse the effects of Meal (2 levels: meal and no meal) and Before/After (2 levels: before and after meal/wait) on hunger and food liking, on the different measures of food reward (desire to eat, etc.) and on responding on the work for money task. We used standard multiple linear regression (Tabachnick & Fidell, 2007) to test for the independent contributions of liking and hunger (predictor variables) to food reward (independent variable). Data for both meal and no meal participants were included in this analysis, which ensured a large range of scores for each of the various measures. All data were normally or near normally distributed. The bivariate correlation between liking and hunger was r = 0.36, ruling out collinearity as a problem in the regression analyses.

Results

Participant characteristics (mean ± SD) were as follows: age, 20.8 ± 0.8 years, weight 71.5 ± 12.4 kg, BMI 23.0 ± 2.4 kg.m^{-2}. These characteristics were similar for the meal and no meal groups, as were the baseline scores for the various outcome measures (Figure 5 and Table 2). All of the participants in the meal group ate all of the pizza served to them.

Both hunger and pizza liking decreased in participants who ate (meal group), but remained unchanged in the participants who did not receive a meal (Meal by Before/After interaction: hunger $F(1,46) = 58.27$, $p < .0001$; liking $F(1,46) = 9.31$, $p = .038$; Figure 5). In the meal group, the decrease in hunger ratings was much greater than the decrease in liking ratings (-45.8 ± 3.3 mm versus -11.9 ± 3.0 mm).

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Food reward was reduced after consumption of the pizza meal compared with no meal (Table 2). Of the three measures of food reward, desire to eat showed the most reliable decrease, and the work-for-food measure the least reliable decrease after the meal versus no meal. Responding on the monetary reward task was unaffected by eating or waiting for the equivalent period (Table 2).

Table 3 shows that both hunger and liking predicted desire to eat and responding on the work-for-food task. Neither hunger nor liking predicted the amount of money participants indicated they were willing to pay for the food (and neither predicted performance on the monetary reward task: total variance accounted for = 2.9%, $p > .1$).

Discussion

Consistent with our predictions for this study, hunger, liking and the three measures of food reward all decreased after eating pizza, but did not change if nothing was eaten. Also as we predicted, there was no change in responding on the work-for-money task after the meal compared with not eating, ruling out the possibility that the decrease in performance on the work-for-food task was due to for example sleepiness, or to a general decrease in motivation, occurring as a consequence of food intake.

Of the three food reward measures, desire to eat showed statistically the most reliable decrease from before to after eating. Both hunger and food liking affected desire to eat and responding on the work-for-food task (50% of variance accounted for). This confirms the construct validity of desire to eat and the work-for-food tasks as measures of food reward as defined by our model (Figure 1). In contrast the pay-for-food measure was only weakly predicted by hunger and food liking (19% of variance accounted for), indicating that this is a less useful measure of food reward. A problem inherent in the pay-for-food measure is that responses may be to an extent constrained by knowledge of the retail price of the item in question. That is, irrespective of their current motivation towards the food, participants may resist indicating a higher (or lower) amount than the amount they might typically expect to pay for the food. Whatever the explanation, it is the case that the pay-for-food measure performed least well in reflecting current hunger and food liking.

It is worth noting that the decrease in liking for the pizza after eating pizza was small compared with decrease in hunger, and moreover smaller than the decrease in liking for pasta in tomato sauce after eating pasta in tomato sauce in Study 1 (Figures 3 and 5). These

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decreases in ratings of the pleasantness of the taste of a food from before to immediately after eating a substantial amount of that food are within the range of those reported previously in comparable studies (e.g., Hetherington et al., 1989; Brunstrom & Mitchell, 2006; Havermans et al., 2009). Why the decrease in liking was smaller in the present study compared with Study 1, is not entirely clear. The energy content of the pizza meal was only marginally smaller than that of the pasta in tomato sauce meal eaten in Study 1 (534 versus 573 kcal), and the starting level of liking and the decline in hunger from before to after eating was similar in the two studies (Figures 3 and 5). The energy density (pizza 2.39 kcal/g, pasta in tomato sauce 1.34 kcal/g) , and thus volume, of the two meals did differ however; so perhaps eating rate was faster in Study 2, resulting in shorter oral exposure time. In turn, with less oral exposure during eating there may have been less habituation and/or less diminution of taste intensity (see previous Discussion above) and consequently a smaller decline in the pleasantness of the taste of the pizza. Consistent with the smaller decline in liking, desire to eat pizza in this study also decreased less from before to after eating than did desire to eat pasta and tomato sauce in Study 1 (Figure 3 and Table 2).

The present results suggest that desire to eat is superior as a measure of food reward to the pay-for-food and work-for-food measures. The question remains, however, whether any of these measures can predict actual food intake. This was investigated in the next study.

Study 3

In this study participants completed measures of food reward based on tasting a mouthful of a 98 g portion of a food (cheese sandwiches) before being served a large portion of that food to consume ad libitum. This was the first part of a procedure that also investigated predictors of food choice. The results of this second aspect of the study, which are not directly relevant to the present discussion of components of food reward, will be reported elsewhere. Regarding the relationship between food reward and food intake we expected a positive correlation. Additionally, however, we predicted that the amount eaten would probably be affected by other influences. For example, participants with higher concern about their body shape/weight might restrain their intake. Actual body size will also influence intake, in that, larger people require more food to remain weight stable than do smaller people. The measures of food reward are, however, likely to be largely insensitive to

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differences in energy requirements, as the procedure is based on evaluating a fixed portion of food. As we tested both women and men in this study, our planned analysis included gender with the reward measure as predictors of food intake on the basis that gender would account for variance in intake related to both to body size and dietary restraint (on average, women are smaller than men and display greater dietary restraint).

We also included measures of dietary restraint and eating disinhibition and a measure of maximum tolerated portion size in the study. We hypothesised that the latter might be relevant because in the intake test participants are offered food in excess of what is usually consumed. In this situation greater tolerance to large portions might be expected to predict greater intake. In exploratory analyses we included desire to eat with these variables and with height or weight to test whether we could improve the prediction of food intake. Note that because of weight-related restraint, height might be superior to weight as a proxy measure of the effect of energy requirement on food intake. That is, weight could reflect opposing influences on intake – on the one hand a positive influence linked to energy requirement and on the other a negative influence linked to restraint arising from concern about fatness (relatively high weight for height). Lastly, dietary restraint and eating disinhibition, independently of gender, can be expected to predict, respectively, lower and higher food intake in this free-eating situation (Rogers, 1999; Bryant et al., 2007).

Method and materials

Participants

There were 71 participants (50 women). As is the previous two studies, none of these healthy women and men was currently dieting or had a history of disordered eating. They were recruited via advertisements placed on noticeboards around the University of Bristol and by word of mouth. The advertisements were headlined ‘Food Choice Study’ and the incentives offered for participation were free food to eat plus a payment of £7.

Design

In order to increase variance in appetite across participants for regression analysis, we randomised participants to eat breakfast or no breakfast and to ‘early’ and ‘late’ test sessions (see below).

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Foods

The main test food, used for both the food reward and intake tests was cheese sandwiches. A single sandwich consisted of two slices of Kingsmill 50/50 Crusts Away medium slice bread (Allied Bakeries, UK), and 10 g Butterlicious and 1 slice of medium British Cheddar slices (Sainsbury's Supermarkets Ltd., UK). Each sandwich was cut into 8 equal bite-sized pieces. Ten pieces (98 g, 304 kcal) were served for the food reward tests and 50 pieces (490 g, 1520 kcal) were served for the intake test. A glass of water (300 ml) was served with the test meal. Participants also evaluated four other foods in this study (data not reported): tuna and mixed bean salad, cheese and tomato pasta, cheese and onion quiche and pork pie. There was no intake test for these foods.

Measures

Results for the following outcomes are reported here. The hunger and desire to eat measures were the same as for Study 1 and Study 2. The pay-for-food and work-for-food measures were the same as for study 2, except that the scale for the pay-for-food measure ranged from 0 p to £5.00, with £2.50 printed above the line centred at 50 mm, and 'cheese sandwiches' replaced 'pizza' in the instructions for the work-for-food task. The portion size tolerance measure required participants to write in a box the 'maximum number of portions like this you could eat in a single meal'. The reference portion was the portion used in the reward tests, starting at 10 bite-sized pieces and reduced to 9 after tasting for the reward measures (see below). The sandwich meal was weighed before the intake test. Participants were told that their performance on the work-for-food task had earned them the 'maximum portion available.' They were served with the 50 bite-size portion and invited by the Experimenter to 'eat as much as you like,' saying that she would leave them alone for 15 minutes to eat. She returned after 15 minutes to remove the remaining food, which she then weighed out of sight of the participant. Intake to the nearest g was calculated. The Three Factor Eating Questionnaire (Stunkard & Messick, 1985) was used to measure cognitive restraint of eating and eating disinhibition.

Procedure

Participants were instructed either to consume their usual breakfast or to not consume any food or energy-containing beverages from waking until their test session later

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in the day. The hour-long test session began at either 11.30h or 13.00h. Participants were tested individually. The schedule of tests for which results are reported here was as follows: (1) hunger (no food present), (2) taste and swallow one bite-sized piece of sandwich, followed desire to eat, pay-for-food, portion size tolerance and work-for-food measures (sandwich pieces present throughout), (3) sandwich test meal, (4) TFEQ, (5) height and weight measured, (6) participants debriefed and rewarded with £7.

Data analysis

In planned analyses we used standard multiple linear regression (Tabachnick & Fidell, 2007) to test the performance of the various measures of food reward in predicting food intake. We included gender in these analyses as a proxy to control for the effects of weight and dietary restraint on intake (see above). In exploratory analyses we also included cognitive restraint of eating, eating disinhibition, portion size tolerance and height or weight in regression models to investigate whether the prediction of food intake could be improved. All data were normally or near normally distributed.

Results

Participant characteristics and scores for the various outcome measures shown separately for women and men are summarised in Table 4. The men were taller and heavier than the women, and they scored lower on the measure of eating restraint and ate more in the test meal. There were no clear gender differences in the measures of food reward, although on the pay-for-food measure women tended to place a higher value on the cheese sandwiches, whereas the opposite trend was apparent in the work-for-food measure. Portion size tolerance did not differ reliably between women and men. Hunger at the start of the test session was lower in participants who ate breakfast compared with those who did not (58 ± 21 versus 75 ± 14 respectively, $p < .001$). There was a wide range of scores for each of the three measures of food reward, portion size tolerance and test meal food intake.

Table 5 shows that of the three measures of food reward, only desire to eat was a significant predictor of food intake. Together, desire to eat and gender accounted for 28% of the variance in food intake. In the exploratory analyses neither restraint nor disinhibition added to the prediction of food intake, with or without gender included (results not shown).

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Height and desire to eat (33% of variance accounted for), but not weight and desire to eat (24% of variance accounted for), were slightly superior to gender and desire to eat in predicting food intake. The prediction was further improved to 36% with the inclusion of portion size tolerance in the model (Table 6).

Discussion

Desire to eat but not the other measures of food reward, the pay-for-food measure and work-for-food measure, predicted the amount of food consumed in the test meal. This adds to the demonstration of the validity and usefulness of desire to eat as a measure of food reward. The prediction of food intake was improved by including a proxy for body size, namely gender or height, in the regression model. Gender might be expected to also account for at least part of the effect of dietary restraint on food intake, but gender was not a better predictor of food intake than was height. Moreover, although women, as expected, scored higher on cognitive restraint of eating than men, restraint was not found to predict food intake. This lack of effect of restraint on intake could be due to the fairly restricted range of restraint scores in this sample. Current dieters were excluded as participants and the mean and standard deviation of cognitive restraint of eating scores were lower, for example, than for the scores of a combined sample of 'free eaters' and dieters described by Stunkard and Messick (1989). The same holds for eating disinhibition – the present sample of participants scored relatively low on this dimension. Portion size tolerance, on the other hand, did add marginally to the prediction of food intake in this ad libitum eating situation.

Overall, the best model only accounted for a third of the variance in food intake. While desire to eat was the variable that contributed most to this prediction, a possible limitation is that this measure is based on evaluation of a single bite of the food in question, which may only imperfectly anticipate food reward experienced across the whole meal. Notwithstanding this limitation, it is also clear that desire to eat was superior to other measures that might be expected to predict food intake, including, as described above, dietary restraint and eating disinhibition (Rogers, 1999; Bryant et al., 2007). Additionally, there will be error associated with these various measurements which will reduce their predictive power. Error might result from, for example, inattention of participants when completing ratings or questionnaire items. And, of course, there will be factors that influenced intake that we did not measure. One of these, which could have a large effect in test meal studies, is plans for future eating. So in the present study a participant might restrain her consumption despite her strong desire to eat the food and her generally low dietary restraint, because she does not want to 'spoil her appetite' for meal she has been invited to at her favourite restaurant later the same day. Equally, another participant, even though not rating the food as particularly desirable, might take the opportunity to eat as much of it as they can in order to save on the cost of their next meal. In the first instance eating in the test meal is curtailed by anticipation of maximising the reward value of the next meal, whilst in the second instance the dominant driver of intake is instrumental rather than currently experienced food reward. Such is the potential complexity of predicting individual food intake decisions in a laboratory setting, and presumably in real life too.

General discussion

Taken together, the results of these studies support the validity of rated desire to eat as a measure of food reward. The third study demonstrates its predictive validity – desire to eat predicted food intake. Studies 1 and 2 demonstrated its construct validity, in that desire to eat was influenced independently by hunger and food liking, which is in line with its face validity – our desire to eat is stronger if we are hungry and we like the food on offer. It is important to note that our procedure required participants to taste and swallow a bite of a portion of the food in question so that their rating would be based on their current momentary experience of eating the food. We did not test the alternative of asking participants to imagine and rate their desire to eat (and food liking) based on viewing a picture of the food, but that is likely to yield less valid data. This is because such data will depend on the accuracy of the participant's recall of their experience of eating the food or a similar food previously, and in the same or similar motivational state. Nonetheless, whatever the actual procedure, desire to eat rated at the beginning of a meal anticipates food reward, and this might not fully accurately predict food reward as experienced across the whole meal. Perhaps the food is found to be more filling (reduces hunger more rapidly) than expected, for example. This may be a further reason why desire to eat is a considerably less than perfect, albeit highly significant, predictor of food intake. We plan to investigate the utility of ratings of 'eating enjoyment' made after eating a whole portion or ad libitum

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as a further measure of food reward. Whereas desire to eat measures anticipated food reward, eating enjoyment can be seen as retrospective food reward.

An advantage of our desire to eat measure is that it is simply made. Certainly, it is less time-consuming and involved than the work-for-food measure, which arguably requires a work-for-something-else task to control for non-specific effects of eating on performance, In any case the work-for-food task failed to predict food intake. Work-for-food tasks have been investigated in previous studies. For example, Epstein et al. (2003) argued that their task measured 'the reinforcing value of food,' although in their discussion they equate this with wanting, citing Robinson and Berridge (1993) and Berridge (1996). Havermans et al. (2009) used a similar task to Epstein et al. (2003) and they also advocated it as a measure food wanting, and others have developed tasks that they also describe as measuring wanting (e.g., Finlayson et al., 2008). In our model (Figure 1) hunger could be conceptualised as part of a wanting component of a more comprehensive model. That is, hunger increases wanting, and so food deprivation can be used to manipulate food wanting, but we suggest that it is not possible, or at least very difficult, to measure wanting separately from food reward (*cf* Berridge, 1996; Havermans, 2011). This is because, in contrast to liking (the pleasantness of the taste of food), there is no clearly identifiable experience of wanting separate from food reward. Merely asking how much do you want some of this food now (e.g., Finlayson et al., 2008; Lemmens, Schoffelen, Wouters, Born, Martens, Rutters, Westerterp-Plantenga, 2009) does not direct participants to ignore liking as an influence on their desire for the food. This is also the case for the tasks described in the three studies cited above, which are summarised in Table 7. The nature of these tasks is that performance will be affected by both liking and wanting – therefore, they measure food reward rather than food wanting. Havermans et al. (2009) acknowledge this possibility: "To assess wanting, the participants in the present study repeatedly had to decide to obtain further points, or not. It is possible that participants factored in their momentary liking of the chocolate milk or chips in making these deliberate decisions" (p 225). Nevertheless, to the extent that reward minus liking equals wanting (*cf*. Figure 1), it is sufficient to measure food reward and food liking to be able to estimate the contribution of changes in food wanting to increases or decreases in motivation to eat. In this respect the present studies, and previous studies (e.g., Hetherington et al., 1989), including those by Epstein et al. (2003) and

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Havermans et al., (2009) summarised in Table 7, indicate that food intake causes only a small decrease in liking for uneaten foods,[3] relative to the decrease in food reward.

Indeed, Epstein et al. (2003) found a non-significant decrease in liking for chocolate milk from before to after eating a different food (Table 7). The study was probably underpowered to confirm a difference of this magnitude, which is similar to the small decrease in liking for the uneaten foods in our study (Figure 3). Havermans et al. (2009) found that liking for the uneaten food remained unchanged, but their participants consumed a rather small meal. An exception is the study by Finlayson et al (2008) in Table 7, in which participants were required to make ratings based on pictures of foods. The decreases in liking were equal in magnitude to, and highly correlated with (r = 0.87), the decreases in 'explicit wanting' (food reward). This suggests that these measures failed to discriminate between the anticipated pleasantness of the taste of the food and anticipated food reward. Perhaps this is more likely to occur when the food is not tasted because participants generally believe food to taste less pleasant when full (see Introduction), even though they actually experience rather little change.

Collectively, and consistent with previous results (e.g., Rolls et al., 1988; Hetherington et al., 1989) these various studies nonetheless demonstrate a clear decrease

[3] An objection to this conclusion might be that participants interpret liking questions in terms of their general liking for the food in question, rather than their liking for it at the moment of making the rating. In other words, the measure might assess 'trait' rather than 'state' liking. Yeomans and Symes (1999) make a similar argument about palatability. They found that eating caused a greater decrease in ratings of the pleasantness of the taste of a food than in ratings of its palatability (How palatable is this food?), and concluded that a significant proportion of participants rated palatability 'as a constant property of the food' (p 383). Interestingly, this is in contrast to the notion of palatability being a function of both the food and 'intraorganic conditions' (Young, 1967) or 'physiological state' (Berridge, 1996). Either way, our measure of liking asked about pleasantness of the taste of food, not about palatability; moreover with the instruction to rate how pleasant the food tastes RIGHT NOW. Therefore, it is probable that the ratings did indeed reflect state (momentary) rather than trait liking. Perhaps, if anything, the procedures used in our and similar studies (e.g., Epstein et al., 2003; Havermans et al., 2009) tend to overestimate changes in liking with eating because asking participants to make repeated assessments of liking (e.g., at least once before and once after eating) may cue them to expect change, and because of the potential to confuse the pleasantness of the taste of food with the pleasantness of eating it (see above).

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in liking for recently eaten foods. However, might there be more to sensory-specific satiety than a decrease in liking with eating? Our results in Figure 3 (summarised in Table 7) show that the difference in the decrease in desire to eat (food reward) between the eaten and uneaten foods is greater than the difference in the decrease in liking between the eaten and uneaten foods. In so far as food reward minus food liking equals food wanting (above) and it can be accepted that the scaling of the liking and desire to eat ratings is comparable (the format, 100 mm lines anchored with 'not at all' and 'extremely,' was the same for both measures), this suggests a substantial decrease in wanting contributing to sensory-specific satiety. [4] However, this result is in large part accounted for by a greater desire to eat for the eaten than the uneaten foods at baseline which, as we suggested in the discussion of Study 1, might be explained by the greater appropriateness of the to-be-eaten (pasta in tomato sauce) food for a meal or the first course of a meal, compared with the uneaten foods (cheese biscuits, sweet biscuits, milk chocolate). Therefore, it is unclear from this evidence whether or not a decrease in wanting is part of sensory-specific satiety. Although Havermans et al. (2009) argue that it is, again there is a caveat because their work-for-food task may not have been a pure measure of wanting (above). Further studies based on our model of desire to eat minus liking equals wanting, but balancing eaten and uneaten foods across participants, would help determine the relative contributions of changes in liking and wanting to sensory-specific satiety. Functionally, food-specific loss of reward value (sensory-specific satiety) serves to encourage variety seeking (Hetherington & Havermans, 2013).

The maintenance or at most small decline in liking for uneaten foods after eating observed in these various studies contradicts the proposal of a general decrease in hedonic response to food stimuli ('alliesthesia,' Cabanac, 1971) as a consequence of food ingestion, unless this is equated to the pleasantness of eating, rather than to the pleasantness of the taste of food (see Introduction). Relatedly, other research suggests that a decrease in liking ('the food stops tasting good' or even 'the food tastes less good') is not a salient reason for ending a meal (Mook and Votaw, 1992; Hardman & Rogers, 2013). Perhaps, at least in part,

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[4] In Study 1 the (mean ± SE) difference in desire to eat from before to 1 and 15 minutes after eating for the eaten foods versus uneaten foods was 29 ± 3 mm. The difference in liking from before to 1 and 15 minutes after eating for the eaten foods versus uneaten foods was 18 ± 3 mm. The difference between these values (wanting), 11 ± 3 mm, was significant, paired-t = 3.11, df = 47, p = .003. The full data are shown in Figure 3 (see also Table 7).

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this is because most meals are composed of a variety of foods and therefore sensory-specific satiety is avoided (*cf.* Hetherington, 1996).

Although not part of the present studies, it is also appropriate here to consider briefly the relationship between obesity and food reward. Evidence of reduced striatal dopamine receptor availability and dopamine release associated with overeating and obesity have been interpreted as a cause of overeating (Wang, Volkow, Logan, Pappas, Wong, Zhu, Netusil & Fowler, 2001; Geiger, Haburcak, Avena, Moyer, Hoebel & Pothos, 2009; see also Stice, Spoor, Bohon, Veldhuizen & Small, 2008; Johnson & Kenny, 2010). Overeating, it is argued, occurs as compensation for reduced food reward. However, the alternative that increased adiposity leads to reduced food reward, seems to us to be more plausible (Hardman et al., 2012). This can be seen as an adaptive response – with increased body fat stores there is a relative loss of interest in food (and obtaining and consuming food is reduced in priority relative to other activities and inactivity), which exerts at least a partial brake on further increases in weight. This is supported by observations on the dynamics of food intake and weight gain in rats exposed to ‘cafeteria’ and high-fat diets (Rogers & Blundell, 1984; Rogers, 1985; Mela and Rogers, 1998), and changes in electrical brain-self stimulation thresholds in rats withdrawn from drugs of abuse compared withdrawal from a cafeteria diet (Epstein & Shaham, 2010). Reduced food reward in obesity could, though, be partially overcome by choosing foods with higher reward value, perhaps foods with even higher energy density, for example. Furthermore, it may be that a change in wanting is responsible for altered food reward in obesity, as there do not appear to be weight-related differences in food liking (e.g., Mela, 2006).

Future studies might also investigate our model in relation to fluid balance. Does thirst, signalled for example by a dry mouth, increase desire for fluid with or without an increase in the pleasantness of the taste of the fluid in the mouth (*cf* Appleton, 2005)? Similarly, does caffeine deprivation increase the reward value of coffee in part due to an increase in pleasantness of the taste of coffee, or in its absence (*cf* Stafford, Wright & Yeomans, 2010)? We predict that taste pleasantness (liking) would remain relatively unaffected by physiological state but, as in the present studies, results will depend on overcoming the challenge of separating pleasantness of taste from pleasantness of ingestion.

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Finally, it is worth restating that in our model (Figure 1) hunger and liking contribute jointly to food reward. This would seem to be consistent with the usual experience of eating – eating is experienced as more rewarding if the food tastes good and we are hungry. It is equally highly rewarding if we are very hungry but the food tastes only moderately good, or if the food tastes very good but we are only moderately hungry. Eating under the latter circumstances might be described as primarily hedonic (i.e., 'hedonic eating' (Lowe & Levine, 2005; Lowe & Butryn, 2007) or as 'eating in the (near) absence of hunger' (French, Epstein, Jeffery, Blundell & Wardle, 2012). To the extent that this describes the predominant influence on food reward as being liking, this seems reasonable. We suggest, however, that the term 'homeostatic eating' (e.g., Lowe & Butryn, 2007) is not an appropriate description of predominantly hunger-driven food reward. This is because there does not seem to be a salient signal related to acute energy balance (Stricker, 1984; Rogers, 1999). Nor is there a good reason to expect there should be, as the amount of energy eaten in a typical meal, or indeed eaten over a typical day, is very small compared with the amount of potential fuel stored in the body of even a lean individual (Mela & Rogers, 1998; Frayn, 2010). By contrast, ingesting a meal does significantly fill the gut and is detected there and post-absorptively. This reduces hunger, and then as the meal is further digested and assimilated hunger rises again (see Introduction). In other words, fluctuation of hunger from the beginning of one meal to the next reflects what is or recently was in the gut, and has little to do with the accompanying small decrease in body energy reserves. This is supported by the observation that eating is reduced by energy intake (even when the manipulation of energy content of the food is disguised, Almiron-Roig, Palla, Guest, Ricchiuti, Vint, Jebb & Drewnowski, 2013), but little affected by an acute bout of exercise (reviewed by Schubert, Desbrow, Sabapathy, & Leveritt, 2013; median energy expenditure 490 kcal). Further, and related to this, the concept of homeostatic eating is not in accord with the observation that we appear to be adapted to eat, within limits, in excess of energy expenditure if the opportunity arises, with only weak feedback from the increase in energy stored (Mela and Rogers, 1998; Rogers, 1999; Wells, 2010; Speakman, 2014). For these reasons, making a contrast between hedonic and homeostatic eating is questionable. By way of example consider someone who has expended 500 kcal since they last ate. They now start to eat again and go on to consume a total of 1000 kcal. Does that mean that the first 500 kcal of that meal was homeostatic eating and the second 500 kcal was hedonic eating? Our answer is no. Rather, their intake reflected, restraint, future eating plans, etc. aside, the reward value of the meal, jointly determined throughout predominantly by their momentary hunger and their momentary liking for the meal.

Conclusions

These studies demonstrate the validity of ratings of desire to eat a portion of a tasted food as a measure of food reward, and that food reward substantially predicts food intake. They further demonstrate independent effects of hunger (determined mainly by the degree of absence of inhibitory signals generated in response to the previous meal) and liking on food reward, and at most a small effect of hunger on food liking in general. There is a greater decrease in liking and reward value for recently eaten food than for uneaten food, but whether a decrease in 'wanting' also contributes to this sensory-specific satiety remains to be elucidated. An additional advantage of desire to eat ratings over most other potential measures of food reward is the procedure's relative simplicity.

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Figure 1. A model of the relationships between food liking, hunger, food reward and food intake. The present studies tested these relationships, including the hypothesis that hunger does not much or at all affect liking, hence the question mark. (Note that the way in which we have conceptualised hunger – as the absence of fullness, and affected by the size of the previous meal, time since last eating, etc. – means that liking cannot be expected to affect hunger.)

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Figure 2. Food liking before and after a meal rated on a 100 mm horizontal line labelled with different instructions. Scale A, pleasantness of the food. Scale B, pleasantness of the taste of the food. Scale C, pleasantness of the taste of the food, ignoring how much is wanted and what it would be like to eat it. See text for full format and wording of these scales. Liking ratings are averaged across four foods, one of which was eaten in the meal.

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Figure 3. Hunger, food liking and desire to eat before and after consuming a meal of pasta in tomato sauce, shown separately for participants claiming no decrease in liking after the meal and those claiming a decrease in liking. Liking and desire to eat are also shown separately for uneaten foods (cheese biscuits, sweet biscuits, milk chocolate) and the eaten food (pasta in tomato sauce).

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Figure 4. Diagrams displaying the variance accounted for in desire to eat by hunger and food liking (averaged across all four test foods and the 1- and 15-minute post meal tests) for participants claiming no decrease in liking after the meal and those claiming a decrease in liking. Note that there is no exact significance test available for the shared contribution of hunger and liking, R^2 = .03 and R^2 = .20 here (Chuah & Mabery, 1999).

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Figure 5. Hunger and food liking before and after consuming a meal of pizza, or waiting for the equivalent period (15 minutes).

Table 1. Definitions of key terms how and they are operationalised in the three studies

Term	Definition	How measured?
Hunger[a]	The absence of fullness, as related to gastrointestinal and post-absorptive signals, and the time since and size of the previous meal	Rating of hunger (made without food being present).
Liking	The pleasantness of taste of food in the mouth. (Note that this is different from the pleasantness of eating, which has often been called ‘palatability’).	Rating of food liking. The participant tastes (and swallows) a bite of a portion of the food in question and then rates their liking for the pleasantness of its taste.
Food reward	The momentary value of a food to the individual at the time of ingestion.	Rating of desire to eat. Having completed the liking rating (as above), the participant rates their desire to eat the entire portion of the food.
Food intake	Food intake is not the same as food reward, as it is subject to additional influences such as dieting and food availability.	Intake of the food from a portion much larger than participant would usually eat.

[a]As described in the General discussion, we view hunger as influencing eating via a ‘wanting’ (Berridge, 1996) component of food reward.

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Table 2. Effect of eating and waiting for an equivalent period on three measures of food reward and on performance of a work for money control task

Food reward or control measure	Meal, n = 32		No meal (wait), n = 16		Meal/no meal by before/after interaction
	Before	After	Before	After	
Desire to eat pizza, mm (0-100 mm scale)	81 ± 3	48 ± 4	81 ± 4	80 ± 5	$F(1,46) = 54.42$, $p < .0001$
Amount willing to pay for one slice of pizza, pence	65 ± 7	35 ± 7	67 ± 10	68 ± 10	$F(1,46) = 23.95$, $p < .0001$
Work-for-pizza, number of bar presses in 1 min	334 ± 22	243 ± 27	323 ± 31	339 ± 39	$F(1,46) = 10.17$, $p = .0026$
Work-for-money, number of bar presses in 1 min	378 ± 13	378 ± 14	381 ± 18	385 ± 19	$F(1,46) < 1$

The data are means ± SEs

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Table 3. Hunger and food liking as predictors of three different measures food reward

Food reward measure	Food reward measure predictors		Total variance accounted for
	Hunger	Liking	
Desire to eat pizza	0.32[a] (p = .014)	0.49 (p = .0003)	50% (p < .0001)
Amount willing to pay for one slice of pizza	0.27 (p = .088)	0.22 (p > .1)	19% (p = .0010)
Work for pizza	0.28 (p = .026)	0.52 (p = .0001)	50% (p < .0001)

The data analysed were hunger, food liking and food reward measured after the meal or rest for all participants (n = 48).

[a]Values are standardised coefficients (β) from standard multiple regression analyses. These values represent the independent contribution of hunger and liking to the respective food reward measure.

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Table 4. Participant characteristics and scores on the food reward measures, portion size tolerance and test meal food intake shown separately for women and men

	Women (n = 50)	Men (n = 21)	*p* value[c]
Age, years	25.2 ± 5.8	25.6 ± 9.7	> .1
Height, cm	164 ± 5	179 ± 6	< .0001
Weight, kg	60.4 ± 9.1	73.3 ± 8.9	< .0001
BMI, $kg.m^{-2}$	22.5 ± 3.3	22.9 ± 2.2	> .1
Cognitive restraint of eating score[a]	8.4 ± 3.0	5.8 ± 2.7	.007
Disinhibition of eating score[b]	6.6 ± 3.9	5.7 ± 2.0	> .1
Desire to eat cheese sandwiches (0-100 mm scale)	65 ± 23	61 ± 27	> .1
Amount willing to pay for one portion (98 g) of cheese sandwiches, pence	120 ± 72	89 ± 61	.093
Work for pizza, number of bar presses in 1 min	239 ± 118	296 ± 139	.083
Portion size tolerance, maximum number of 98 g portions could eat	2.48 ± 1.93	3.14 ± 2.67	> .1
Test meal food intake, g	110 ± 61	160 ± 112	.018

Data are means ± SDs
[a]Minimum possible score = 0, maximum possible score = 21
[b]Minimum possible score = 0, maximum possible score = 16
[c]*t*-test (df = 70) comparing women versus men

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Table 5. Food reward and gender as predictors of food (cheese sandwich) intake

Food reward measure	Food intake predictors		Total variance in intake accounted for
	Reward measure	Gender	
Desire to eat cheese sandwiches	0.45[a] ($p < .0001$)	0.31 ($p = .003$)	28% ($p < .0001$)
Amount willing to pay for one portion (98 g) of cheese sandwiches	0.13 ($p > .1$)	0.31 ($p = .012$)	9% ($p = .036$)
Work-for-cheese sandwiches	0.17 ($p > .1$)	0.25 ($p = .040$)	11% ($p < .023$)

[a]Values are standardised coefficients (β) from standard multiple regression analyses. These values represent the independent contribution of food reward and gender to the prediction of food intake.

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Table 6. Standard multiple regression of desire to eat, portion size tolerance and height as predictors of test meal food intake

	Food intake (g)	Desire to eat	Portion size tolerance	*B*	*SE B*	β	sr^2 (unique)[a]
Desire to eat	.43***			1.31***	0.35	.38	.136
Portion size tolerance	.37**	.23		9.05*	3.81	.24	.054
Height (cm)	.35**	-.01	.12	3.11**	0.95	.32	.102
				Intercept = -505			
				R^2 = .36[a], p < .0001; adjusted R^2 = .33			

Data in the left-hand half of the table are zero-order (Pearson) correlations
[a]squared semipartial correlations: unique variability = .292, shared variability = .070
***p < .001, **p < .01, *p < .05, two-tail

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Table 7. Summaries of five studies of the effects of eating on hunger, food liking and food reward[a]

Study/Measure	Condition: Meal	Condition: No meal	Methods
Epstein et al., 2003			
Hunger (mm)	17	70	Participants were 17 women, divided between two groups: fasted (n=9) and fed (n=8). The hunger scale was anchored with 'not hungry' and 'hungry,' and the liking scale was anchored with 'aversive' and 'most pleasant.' Food reward was measured using a progressive-ratio task. The food in this task (one of: chocolate snack cakes, chocolate chip cookies, Kit Kat bars, chips/crisps) was different from the meal food (high protein /fibre bar) and the food for the liking task (chocolate milk). Meal size was 700 kcal.
Liking (mm) for uneaten food, change from before to after the meal/no meal)	-9	+3	
Food reward (total number of responses), uneaten food	189	1100	
Finlayson et al., 2008			
Hunger (mm), change from before to after the meal	-72		Participants were 38 women, 25 men. They were tested before and after consuming a meal of pizza ad libitum. Intake was 942 kcal (females) and 1439 kcal (males). Hunger ('How hungry do you feel now?') and liking ('How pleasant would it be to experience a mouthful of this food now?') were measured with 100-mm line scales anchored with 'not at all' and 'extremely.' Food reward was measured in two ways. 1) Ratings of 'How much do you want some of this food now?' anchored with 'not at all' and 'extremely' ('explicit' measure). 2) In a computer-based participants were presented with choices between high and low fat, sweet and savoury foods. They were instructed to select the food they 'most want to eat now.' Time taken to make the choice was designated as a measure of 'implicit wanting.'
Liking (mm), change from before to after the meal			
savoury (non-sweet) food	-37		
sweet food	-16		
Food reward (mm), explicit measure, change from before to after the meal			
savoury (non-sweet) food	-39		
sweet food	-16		
Food reward (ms)[b], implicit measure, change from before to after the meal			
savoury food	-126		
sweet food	-568		

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Havermans et al., 2009			
Hunger (mm)	Not reported		Participants were 48 women, 7 men. They consumed a meal of 250 ml of chocolate milk (215 kcal), after which they were randomly assigned to work for chocolate milk or crisps. Liking ('momentary perceived pleasantness of taste') was measured using a 100-mm line scale anchored 'not at all pleasant' and 'very pleasant.' Food reward was measured using a progressive-ratio task.
Liking (mm), change from before to after the meal			
uneaten food	+2		
eaten food	-10		
Food reward (total number of responses)			
uneaten food	778		
eaten food	194		
Present paper, Study 1			
Hunger (mm), change from before to after the meal	-46		Participants were 24 women and 24 men. They consumed 513 kcal (women) or 632 kcal (men) pasta in tomato sauce. Before and after this meal they evaluated pasta in tomato sauce (eaten food), and cheese biscuits, sweet biscuits and milk chocolate (uneaten foods). Hunger, liking and food reward (desire to eat) were measured on 100-mm line scales anchored 'not at all' and 'extremely.' The data on liking summarised here are averaged across three liking scale groups ('pleasantness of the food,' pleasantness of the taste of the food,' and 'pleasantness of the taste of food ignoring what it would be like to eat it'). The change scores are the mean of 1- and 15-minute post-meal scores minus the pre-meal scores.
Liking (mm), change from before to after the meal			
uneaten foods	-9		
eaten food	-27		
Food reward (mm), change from before to after the meal			
uneaten foods	-23		
eaten food	-52		
Present paper, Study 2			
Hunger (mm), change from before to after the meal/no meal	-46	-3	Participants were equal numbers of women and men in a meal group (n = 32) and a no meal group (n = 16). The meal group consumed 485 kcal (women) or 583 kcal (men) of pizza. The no meal group waited for the equivalent period of time. Both groups evaluated pizza before and after the meal/no meal. Hunger, liking and food reward (desire to eat) were measured on 100-mm line scales anchored 'not at all' and 'extremely.' For liking participants were instructed to rate 'the pleasantness of taste of the food ignoring what it would be like to eat it.' Food reward was also measured using pay-for-food and work-for-food tasks.
Liking (mm), eaten food, change from before to after the meal/no meal	-9	+1	
Food reward, eaten food, change from before to after the meal/no meal			
desire to eat (mm)	-33	-1	
pay-for-food (pence)	-30	+1	
work-for-food (number of bar presses	-91	+16	

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[a]We use food reward in this table to label measures that other authors describe as measures of 'food reinforcement'/'wanting' (Epstein et al., 2003) and 'food wanting' (Finlayson et al., 2008; Havermans et al., 2009) because, as we argue in the main text, a common feature of these measures is that they are likely affected by both hunger and food liking.

[b]Reaction times were faster on the repeat of the task after the meal, however this speeding of responses was greater for sweet foods, which were chosen faster than savoury foods after the meal.

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