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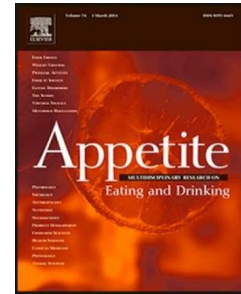
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1 **Food reward: what it is and how to measure it**

2

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14 **Highlights**

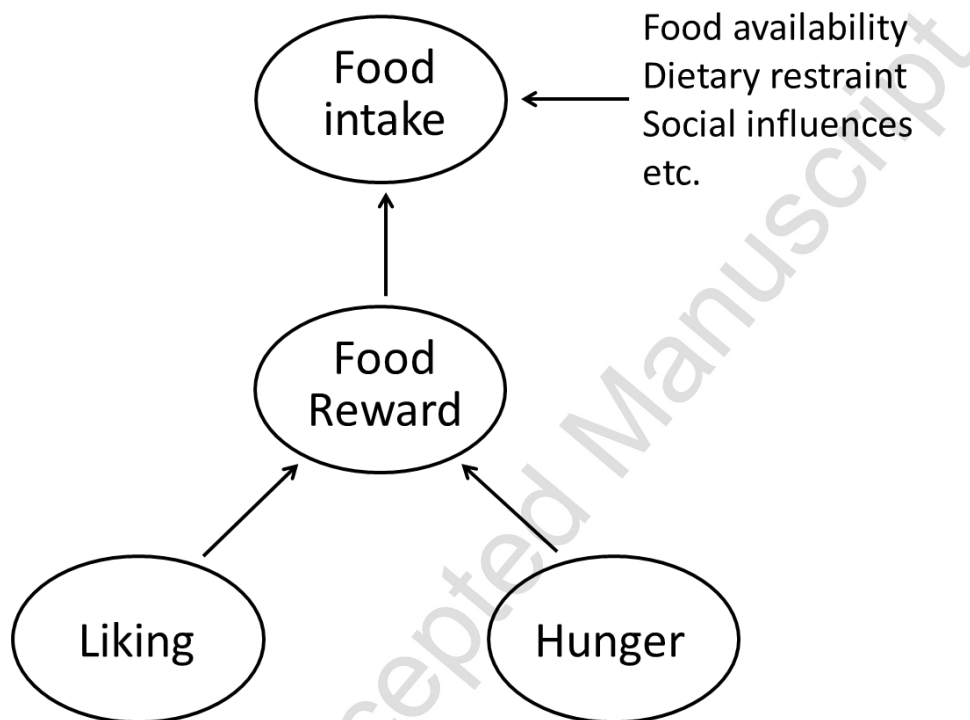
15 Food reward was measured by ratings of desire to eat a portion of a tasted food

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

17 Liking for recently uneaten foods changed little with hunger/fullness

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

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

20 **Graphic Abstract**

21

22 **Abstract**

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

33 satiety') involved a decrease in 'wanting' in addition to the decrease in liking. Studies 2 and  
34 3 compared desire to eat ratings with work-for-food and pay-for-food measures of food  
35 reward, and found desire to eat to be equal or superior in respect of effects of hunger and  
36 liking, and superior in predicting ad libitum food intake. A further general observation was  
37 that in making ratings of food liking participants may confuse the pleasantness of the taste  
38 of food with the pleasantness of eating it. The latter, which some call 'palatability,'  
39 decreases more with eating because it is significantly affected by hunger/fullness. Together,  
40 our results demonstrate the validity of ratings of desire to eat a portion of a tasted food as a  
41 measure of food reward and as a predictor of food intake.

42

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

## 44 Introduction

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

52

### 53 *Definitions of hunger, liking, food reward and food intake, and their interrelationships*

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

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

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

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

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

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

110

### 111 *Relationships between hunger, liking, food reward and food intake*

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

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

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<sup>1</sup> 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  $r = 0.78$ .

135 nutrients (Sakata, Fujimoto, Ogata, Koyama, Fukagawa, Sakai & Tao, 1996) and the memory  
136 of recent eating (Higgs & Donohoe, 2011). When we asked participants informally about  
137 what caused them to rate their hunger as they did, as well as referring to feeling full or  
138 empty, they also frequently mentioned how long ago they last ate, how large their last meal  
139 was, and whether or not it was currently close to a time that they would usually expect to  
140 eat.<sup>2</sup> On the basis of these considerations and our aim to test the model depicted in Figure  
141 1, we instructed our participants to taste (and swallow) a bite of the food in question and  
142 then rate their liking for the food (pleasantness of its taste) and their desire to eat the entire  
143 portion (e.g., slice of pizza) presented. Hunger at 'baseline' was rated before this exposure  
144 to the food.

145

### 146 **Study 1**

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

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<sup>2</sup> 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.



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

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

177

## 178 Methods

### 179 *Participants*

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

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

189

### 190 *Design*

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

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

198

### 199 *Foods*

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

210

### 211 *Measures*

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

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

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

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

241

#### 242 *Procedure*

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

254

#### 255 *Data analysis*

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

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

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

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

278

## 279 Results

280 Participant characteristics (mean  $\pm$  SD) were as follows: age,  $20.7 \pm 1.0$  years, weight  
281  $68.6 \pm 10.9$  kg, BMI  $22.5 \pm 2.8$  kg.m<sup>-2</sup>. These characteristics were similar for each of the  
282 three groups. The amounts (mean  $\pm$  SD) eaten in the meal of pasta and sauce were  $383 \pm 40$   
283 g (women, served 400 g) and  $472 \pm 68$  g (men, served 500 g). All but four women and five  
284 men ate all of the food served (food remaining for these nine participants was 28-145 g and  
285 88-227 g, respectively).

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

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

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

300 Results for ratings of hunger, and of liking and desire to eat for the uneaten foods  
301 and the eaten food, made before and after the meal are shown separately for the no  
302 decrease and decrease groups in Figure 3. Hunger was marginally higher overall in the no  
303 decrease group than in the decrease group (main effect of Liking group  $F(1,46) = 3.58$ ,  $p =$   
304  $.065$ ), but there was a large and equal decrease in hunger for both groups from before to  
305 after the meal (main effect of Meal  $F(1.60,73.5) = 163.82$ ,  $p < .0001$ ; Meal by Liking group  
306 interaction  $F < 1$ ).

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

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

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

325 The results from the variance partitioning analyses are shown in Figure 4. These  
326 demonstrate that hunger and liking independently contributed to the prediction of desire to  
327 eat in both the no decrease in liking group and the decrease in liking group. In addition for  
328 the decrease in liking group, but not for the no decrease group, shared variance in hunger  
329 and liking also contributed to the prediction of desire to eat. Hunger and liking together  
330 accounted for more than half of the variance in desire to eat (no decrease group, Total  $R^2 =$   
331  $.54$ ,  $p = .0004$ ; decrease group, Total  $R^2 = .64$ ,  $p < .0001$ ).

332

### 333 Discussion

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

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

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

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

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

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

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



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

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

440

441 **Study 2**

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

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

464

465 **Method and materials**466 *Participants*

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

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

473

#### 474 *Design*

475 The participants were randomised to a group of 32 (meal consumed) and a group of  
476 16 (no meal consumed), with the constraint that within each group there would be equal  
477 numbers of women and men. The groups differed as to whether or not they received a pizza  
478 meal between the first and second set of hunger, liking and reward measures (see below).

479

#### 480 *Food*

481 The food was tomato and cheese ('Margherita') pizza (325 g, 2.39 kcal/g; Sainsbury's  
482 Supermarkets Ltd, London, UK). It was cooked according to the manufacturer's instructions,  
483 cut into 8 equally-sized, triangular slices and served hot. In the meal group, women received  
484 5 slices (485 kcal) of pizza to eat and men received 6 slices to eat (583 kcal). For the liking  
485 and food reward tests participants were presented with a single slice of pizza (97 kcal).

486

#### 487 *Measures*

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

489 All participants received the liking scale with the instructions 'Please rate how  
490 pleasant this food tastes in your mouth RIGHT NOW? When making this judgement, IGNORE  
491 how much or little of the food you want to eat, and what it would be like to chew and  
492 swallow it – JUST FOCUS PURELY ON HOW IT TASTES IN YOUR MOUTH' (i.e., the same as  
493 scale C in Study 1).

494 The pay-for-food measure was a 100-mm horizontal line, anchored with 0 p at the  
495 left hand end and £2.00 at the right hand end, and £1.00 printed above the line centred at  
496 50 mm.

497 The work-for-food and work-for-money tasks were programmed using E-Prime 2.0  
498 (Psychology Software Tools, Inc. Sharpsburg, PA, USA), and run on networked PCs with 17-in  
499 colour monitors and standard QWERTY keyboards. Instructions were presented in black font  
500 on a white background. For the work-for-food task these were as follows. First screen: 'Pizza  
501 bar pressing task, please wait for instructions.' Second screen: 'Starting in 30 seconds you

502 will have one minute in which you can earn FOOD (pizza) by pressing the SPACEBAR. The  
503 more times you press the more FOOD (pizza) you will earn. The maximum amount you can  
504 earn is a whole pizza (8 slices). To maximise what you can earn start bar pressing as soon as  
505 you see the red count-down clock appear below. Have your finger ready at the SPACEBAR.’  
506 Third screen: ‘KEEP PRESSING THE SPACEBAR. The more times you press the more FOOD  
507 (pizza) you will earn.’ A digital clock displayed the number of seconds remaining. Final  
508 screen: ‘Thank you for completing the task. Please wait for further instructions from the  
509 Experimenter.’ Each sentence of these instructions appeared centred on a separate line(s)  
510 on the screen. The total number of space bar presses made in the designated 1-minute  
511 period was recorded. The work-for-money task was the same as the work-for-food task  
512 except that the first screen was headed ‘Money bar pressing task’, and MONEY (£££££)  
513 replaced FOOD (pizza) on the second and third screens. In addition, on the second screen it  
514 was stated that ‘The maximum amount that you can earn is £5.’

515

#### 516 *Procedure*

517 As in Study 1, participants were instructed not to consume food or energy-containing  
518 beverages within the 3 hours before their scheduled arrival for testing. Again they were  
519 tested individually, starting at either 12:00h, 13:00h or 14:00h. The schedule for the 45- to  
520 50-minute test session was as follows: (1) hunger (no food present), (2) taste and swallow a  
521 bite of pizza, followed by liking, desire to eat, and the pay-for food, work-for-food and work-  
522 for-money measures (pizza slice present throughout), (3) consumption of pizza or wait for  
523 10 minutes (see below), (4) hunger (no food present), (5) taste and swallow a bite of pizza,  
524 followed by liking, desire to eat, and the pay-for food, work-for-food and work-for-money  
525 measures (pizza slice present throughout), (6) height and weight measured, (7) participants  
526 debriefed and rewarded with £5.

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

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

543

#### 544 *Data analysis*

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

554

#### 555 Results

556 Participant characteristics (mean  $\pm$  SD) were as follows: age,  $20.8 \pm 0.8$  years, weight  
557  $71.5 \pm 12.4$  kg, BMI  $23.0 \pm 2.4$  kg.m<sup>-2</sup>. These characteristics were similar for the meal and no  
558 meal groups, as were the baseline scores for the various outcome measures (Figure 5 and  
559 Table 2). All of the participants in the meal group ate all of the pizza served to them.

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

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

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

574

## 575 Discussion

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

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

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

597 decreases in ratings of the pleasantness of the taste of a food from before to immediately  
598 after eating a substantial amount of that food are within the range of those reported  
599 previously in comparable studies (e.g., Hetherington et al., 1989; Brunstrom & Mitchell,  
600 2006; Havermans et al., 2009). Why the decrease in liking was smaller in the present study  
601 compared with Study 1, is not entirely clear. The energy content of the pizza meal was only  
602 marginally smaller than that of the pasta in tomato sauce meal eaten in Study 1 (534 versus  
603 573 kcal), and the starting level of liking and the decline in hunger from before to after  
604 eating was similar in the two studies (Figures 3 and 5). The energy density (pizza 2.39 kcal/g,  
605 pasta in tomato sauce 1.34 kcal/g) , and thus volume, of the two meals did differ however;  
606 so perhaps eating rate was faster in Study 2, resulting in shorter oral exposure time. In turn,  
607 with less oral exposure during eating there may have been less habituation and/or less  
608 diminution of taste intensity (see previous Discussion above) and consequently a smaller  
609 decline in the pleasantness of the taste of the pizza. Consistent with the smaller decline in  
610 liking, desire to eat pizza in this study also decreased less from before to after eating than  
611 did desire to eat pasta and tomato sauce in Study 1 (Figure 3 and Table 2).

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

616

### 617 **Study 3**

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

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

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

647

648 Method and materials

649 *Participants*

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

655

656 *Design*

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

660



661 *Foods*

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

671

672 *Measures*

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

689

690 *Procedure*

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

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

699

#### 700 *Data analysis*

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

708

#### 709 *Results*

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

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

725 Height and desire to eat (33% of variance accounted for), but not weight and desire to eat  
726 (24% of variance accounted for), were slightly superior to gender and desire to eat in  
727 predicting food intake. The prediction was further improved to 36% with the inclusion of  
728 portion size tolerance in the model (Table 6).

729

## 730 Discussion

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

746 Overall, the best model only accounted for a third of the variance in food intake.  
747 While desire to eat was the variable that contributed most to this prediction, a possible  
748 limitation is that this measure is based on evaluation of a single bite of the food in question,  
749 which may only imperfectly anticipate food reward experienced across the whole meal.  
750 Notwithstanding this limitation, it is also clear that desire to eat was superior to other  
751 measures that might be expected to predict food intake, including, as described above,  
752 dietary restraint and eating disinhibition (Rogers, 1999; Bryant et al., 2007). Additionally,  
753 there will be error associated with these various measurements which will reduce their  
754 predictive power. Error might result from, for example, inattention of participants when  
755 completing ratings or questionnaire items. And, of course, there will be factors that

756 influenced intake that we did not measure. One of these, which could have a large effect in  
757 test meal studies, is plans for future eating. So in the present study a participant might  
758 restrain her consumption despite her strong desire to eat the food and her generally low  
759 dietary restraint, because she does not want to 'spoil her appetite' for meal she has been  
760 invited to at her favourite restaurant later the same day. Equally, another participant, even  
761 though not rating the food as particularly desirable, might take the opportunity to eat as  
762 much of it as they can in order to save on the cost of their next meal. In the first instance  
763 eating in the test meal is curtailed by anticipation of maximising the reward value of the  
764 next meal, whilst in the second instance the dominant driver of intake is instrumental rather  
765 than currently experienced food reward. Such is the potential complexity of predicting  
766 individual food intake decisions in a laboratory setting, and presumably in real life too.

767

## 768 **General discussion**

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

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

789 An advantage of our desire to eat measure is that it is simply made. Certainly, it is  
790 less time-consuming and involved than the work-for-food measure, which arguably requires  
791 a work-for-something-else task to control for non-specific effects of eating on performance,  
792 In any case the work-for-food task failed to predict food intake. Work-for-food tasks have  
793 been investigated in previous studies. For example, Epstein et al. (2003) argued that their  
794 task measured ‘the reinforcing value of food,’ although in their discussion they equate this  
795 with wanting, citing Robinson and Berridge (1993) and Berridge (1996). Havermans et al.  
796 (2009) used a similar task to Epstein et al. (2003) and they also advocated it as a measure  
797 food wanting, and others have developed tasks that they also describe as measuring  
798 wanting (e.g., Finlayson et al., 2008). In our model (Figure 1) hunger could be conceptualised  
799 as part of a wanting component of a more comprehensive model. That is, hunger increases  
800 wanting, and so food deprivation can be used to manipulate food wanting, but we suggest  
801 that it is not possible, or at least very difficult, to measure wanting separately from food  
802 reward (*cf* Berridge, 1996; Havermans, 2011). This is because, in contrast to liking (the  
803 pleasantness of the taste of food), there is no clearly identifiable experience of wanting  
804 separate from food reward. Merely asking how much do you want some of this food now  
805 (e.g., Finlayson et al., 2008; Lemmens, Schoffelen, Wouters, Born, Martens, Rutters,  
806 Westerterp-Plantenga, 2009) does not direct participants to ignore liking as an influence on  
807 their desire for the food. This is also the case for the tasks described in the three studies  
808 cited above, which are summarised in Table 7. The nature of these tasks is that performance  
809 will be affected by both liking and wanting – therefore, they measure food reward rather  
810 than food wanting. Havermans et al. (2009) acknowledge this possibility: “To assess  
811 wanting, the participants in the present study repeatedly had to decide to obtain further  
812 points, or not. It is possible that participants factored in their momentary liking of the  
813 chocolate milk or chips in making these deliberate decisions” (p 225). Nevertheless, to the  
814 extent that reward minus liking equals wanting (*cf*. Figure 1), it is sufficient to measure food  
815 reward and food liking to be able to estimate the contribution of changes in food wanting to  
816 increases or decreases in motivation to eat. In this respect the present studies, and previous  
817 studies (e.g., Hetherington et al., 1989), including those by Epstein et al. (2003) and

818 Havermans et al., (2009) summarised in Table 7, indicate that food intake causes only a  
819 small decrease in liking for uneaten foods,<sup>3</sup> relative to the decrease in food reward.

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

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

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<sup>3</sup> 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).

835 in liking for recently eaten foods. However, might there be more to sensory-specific satiety  
836 than a decrease in liking with eating? Our results in Figure 3 (summarised in Table 7) show  
837 that the difference in the decrease in desire to eat (food reward) between the eaten and  
838 uneaten foods is greater than the difference in the decrease in liking between the eaten and  
839 uneaten foods. In so far as food reward minus food liking equals food wanting (above) and it  
840 can be accepted that the scaling of the liking and desire to eat ratings is comparable (the  
841 format, 100 mm lines anchored with 'not at all' and 'extremely,' was the same for both  
842 measures), this suggests a substantial decrease in wanting contributing to sensory-specific  
843 satiety.<sup>4</sup> However, this result is in large part accounted for by a greater desire to eat for the  
844 eaten than the uneaten foods at baseline which, as we suggested in the discussion of Study  
845 1, might be explained by the greater appropriateness of the to-be-eaten (pasta in tomato  
846 sauce) food for a meal or the first course of a meal, compared with the uneaten foods  
847 (cheese biscuits, sweet biscuits, milk chocolate). Therefore, it is unclear from this evidence  
848 whether or not a decrease in wanting is part of sensory-specific satiety. Although  
849 Havermans et al. (2009) argue that it is, again there is a caveat because their work-for-food  
850 task may not have been a pure measure of wanting (above). Further studies based on our  
851 model of desire to eat minus liking equals wanting, but balancing eaten and uneaten foods  
852 across participants, would help determine the relative contributions of changes in liking and  
853 wanting to sensory-specific satiety. Functionally, food-specific loss of reward value (sensory-  
854 specific satiety) serves to encourage variety seeking (Hetherington & Havermans, 2013).

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

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

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

864         Although not part of the present studies, it is also appropriate here to consider  
865 briefly the relationship between obesity and food reward. Evidence of reduced striatal  
866 dopamine receptor availability and dopamine release associated with overeating and  
867 obesity have been interpreted as a cause of overeating (Wang, Volkow, Logan, Pappas,  
868 Wong, Zhu, Netusil & Fowler, 2001; Geiger, Haburcak, Avena, Moyer, Hoebel & Pothos,  
869 2009; see also Stice, Spoor, Bohon, Veldhuizen & Small, 2008; Johnson & Kenny, 2010).  
870 Overeating, it is argued, occurs as compensation for reduced food reward. However, the  
871 alternative that increased adiposity leads to reduced food reward, seems to us to be more  
872 plausible (Hardman et al., 2012). This can be seen as an adaptive response – with increased  
873 body fat stores there is a relative loss of interest in food (and obtaining and consuming food  
874 is reduced in priority relative to other activities and inactivity), which exerts at least a partial  
875 brake on further increases in weight. This is supported by observations on the dynamics of  
876 food intake and weight gain in rats exposed to ‘cafeteria’ and high-fat diets (Rogers &  
877 Blundell, 1984; Rogers, 1985; Mela and Rogers, 1998), and changes in electrical brain-self  
878 stimulation thresholds in rats withdrawn from drugs of abuse compared withdrawal from a  
879 cafeteria diet (Epstein & Shaham, 2010). Reduced food reward in obesity could, though, be  
880 partially overcome by choosing foods with higher reward value, perhaps foods with even  
881 higher energy density, for example. Furthermore, it may be that a change in wanting is  
882 responsible for altered food reward in obesity, as there do not appear to be weight-related  
883 differences in food liking (e.g., Mela, 2006).

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



893 Finally, it is worth restating that in our model (Figure 1) hunger and liking contribute  
894 jointly to food reward. This would seem to be consistent with the usual experience of eating  
895 – eating is experienced as more rewarding if the food tastes good and we are hungry. It is  
896 equally highly rewarding if we are very hungry but the food tastes only moderately good, or  
897 if the food tastes very good but we are only moderately hungry. Eating under the latter  
898 circumstances might be described as primarily hedonic (i.e., ‘hedonic eating’ (Lowe &  
899 Levine, 2005; Lowe & Butryn, 2007) or as ‘eating in the (near) absence of hunger’ (French,  
900 Epstein, Jeffery, Blundell & Wardle, 2012). To the extent that this describes the predominant  
901 influence on food reward as being liking, this seems reasonable. We suggest, however, that  
902 the term ‘homeostatic eating’ (e.g., Lowe & Butryn, 2007) is not an appropriate description  
903 of predominantly hunger-driven food reward. This is because there does not seem to be a  
904 salient signal related to acute energy balance (Stricker, 1984; Rogers, 1999). Nor is there a  
905 good reason to expect there should be, as the amount of energy eaten in a typical meal, or  
906 indeed eaten over a typical day, is very small compared with the amount of potential fuel  
907 stored in the body of even a lean individual (Mela & Rogers, 1998; Frayn, 2010). By contrast,  
908 ingesting a meal does significantly fill the gut and is detected there and post-absorptively.  
909 This reduces hunger, and then as the meal is further digested and assimilated hunger rises  
910 again (see Introduction). In other words, fluctuation of hunger from the beginning of one  
911 meal to the next reflects what is or recently was in the gut, and has little to do with the  
912 accompanying small decrease in body energy reserves. This is supported by the observation  
913 that eating is reduced by energy intake (even when the manipulation of energy content of  
914 the food is disguised, Almiron-Roig, Palla, Guest, Ricchiuti, Vint, Jebb & Drewnowski, 2013),  
915 but little affected by an acute bout of exercise (reviewed by Schubert, Desbrow, Sabapathy,  
916 & Leveritt, 2013; median energy expenditure 490 kcal). Further, and related to this, the  
917 concept of homeostatic eating is not in accord with the observation that we appear to be  
918 adapted to eat, within limits, in excess of energy expenditure if the opportunity arises, with  
919 only weak feedback from the increase in energy stored (Mela and Rogers, 1998; Rogers,  
920 1999; Wells, 2010; Speakman, 2014). For these reasons, making a contrast between hedonic  
921 and homeostatic eating is questionable. By way of example consider someone who has  
922 expended 500 kcal since they last ate. They now start to eat again and go on to consume a  
923 total of 1000 kcal. Does that mean that the first 500 kcal of that meal was homeostatic  
924 eating and the second 500 kcal was hedonic eating? Our answer is no. Rather, their intake

925 reflected, restraint, future eating plans, etc. aside, the reward value of the meal, jointly  
926 determined throughout predominantly by their momentary hunger and their momentary  
927 liking for the meal.

928

## 929 **Conclusions**

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

939

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949

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1087 Figure 1. A model of the relationships between food liking, hunger, food reward and food  
1088 intake. The present studies tested these relationships, including the hypothesis that hunger  
1089 does not much or at all affect liking, hence the question mark. (Note that the way in which  
1090 we have conceptualised hunger – as the absence of fullness, and affected by the size of the  
1091 previous meal, time since last eating, etc. – means that liking cannot be expected to affect  
1092 hunger.)  
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1094 Figure 2. Food liking before and after a meal rated on a 100 mm horizontal line labelled with  
1095 different instructions. Scale A, pleasantness of the food. Scale B, pleasantness of the taste of  
1096 the food. Scale C, pleasantness of the taste of the food, ignoring how much is wanted and  
1097 what it would be like to eat it. See text for full format and wording of these scales. Liking  
1098 ratings are averaged across four foods, one of which was eaten in the meal.  
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1100 Figure 3. Hunger, food liking and desire to eat before and after consuming a meal of pasta in  
1101 tomato sauce, shown separately for participants claiming no decrease in liking after the  
1102 meal and those claiming a decrease in liking. Liking and desire to eat are also shown  
1103 separately for uneaten foods (cheese biscuits, sweet biscuits, milk chocolate) and the eaten  
1104 food (pasta in tomato sauce).

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1107 Figure 4. Diagrams displaying the variance accounted for in desire to eat by hunger and food  
1108 liking (averaged across all four test foods and the 1- and 15-minute post meal tests) for  
1109 participants claiming no decrease in liking after the meal and those claiming a decrease in  
1110 liking. Note that there is no exact significance test available for the shared contribution of  
1111 hunger and liking,  $R^2 = .03$  and  $R^2 = .20$  here (Chuah & Mabery, 1999).

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1113 Figure 5. Hunger and food liking before and after consuming a meal of pizza, or waiting for  
 1114 the equivalent period (15 minutes).

1115

1116

1117 Table 1. Definitions of key terms how and they are operationalised in the three studies

Term	Definition	How measured?
Hunger <sup>a</sup>	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.

1118 <sup>a</sup>As described in the General discussion, we view hunger as influencing eating via a 'wanting'  
 1119 (Berridge, 1996) component of food reward.

1120

1121 Table 2. Effect of eating and waiting for an equivalent period on three measures of food  
 1122 reward and on performance of a work for money control task  
 1123

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	$F(1,46) < 1$

1124 The data are means ± SEs

1125

1126 Table 3. Hunger and food liking as predictors of three different measures food reward  
 1127

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

1128 The data analysed were hunger, food liking and food reward measured after the meal or  
 1129 rest for all participants (*n* = 48).

1130 <sup>a</sup>Values are standardised coefficients ( $\beta$ ) from standard multiple regression analyses. These  
 1131 values represent the independent contribution of hunger and liking to the respective food  
 1132 reward measure.  
 1133

1134 Table 4. Participant characteristics and scores on the food reward measures, portion size  
 1135 tolerance and test meal food intake shown separately for women and men  
 1136

	Women (n = 50)	Men (n = 21)	<i>p</i> value <sup>c</sup>
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 <sup>-2</sup>	22.5 ± 3.3	22.9 ± 2.2	> .1
Cognitive restraint of eating score <sup>a</sup>	8.4 ± 3.0	5.8 ± 2.7	.007
Disinhibition of eating score <sup>b</sup>	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

1137 Data are means ± SDs

1138 <sup>a</sup>Minimum possible score = 0, maximum possible score = 21

1139 <sup>b</sup>Minimum possible score = 0, maximum possible score = 16

1140 <sup>c</sup>*t*-test (df = 70) comparing women versus men

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1143 Table 5. Food reward and gender as predictors of food (cheese sandwich) intake

1144

Food reward measure	Food intake predictors		Total variance in intake accounted for
	Reward measure	Gender	
Desire to eat cheese sandwiches	0.45 <sup>a</sup> ( $p < .0001$ )	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% ( $p < .023$ )

1145 <sup>a</sup>Values are standardised coefficients ( $\beta$ ) from standard multiple regression analyses. These  
 1146 values represent the independent contribution of food reward and gender to the prediction  
 1147 of food intake.

1148

1149 Table 6. Standard multiple regression of desire to eat, portion size tolerance and height as  
 1150 predictors of test meal food intake  
 1151

	Food intake (g)	Desire to eat	Portion size tolerance	<i>B</i>	<i>SE B</i>	$\beta$	$sr^2$ (unique) <sup>a</sup>
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 $R^2 = .33$							

1152 Data in the left-hand half of the table are zero-order (Pearson) correlations  
 1153 <sup>a</sup>squared semipartial correlations: unique variability = .292, shared variability = .070  
 1154 \*\*\* $p < .001$ , \*\* $p < .01$ , \* $p < .05$ , two-tail  
 1155

Table 7. Summaries of five studies of the effects of eating on hunger, food liking and food reward<sup>a</sup>

Study/Measure	Condition		Methods
	Meal	No meal	
<b>Epstein et al., 2003</b>			
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	
<b>Finlayson et al., 2008</b>			
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) <sup>b</sup> , implicit measure, change from before to after the meal			
savoury food	-126		
sweet food	-568		

<b>Havermans et al., 2009</b>		
Hunger (mm)	Not reported	
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	
<b>Present paper, Study 1</b>		
Hunger (mm), change from before to after the meal	-46	
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	
<b>Present paper, Study 2</b>		
Hunger (mm), change from before to after the meal/no meal	-46	-3
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

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.

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.

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.

<sup>a</sup>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.

<sup>b</sup>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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