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Large portions encourage the selection of palatable rather than filling foods¹⁻³

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1 Abstract

2 **Background:** Portion size is an important driver of larger meals. However, effects on food
3 choice remain unclear.

4 **Objective:** Our aim was to identify how portion size influences the effect of palatability and
5 expected satiety on choice.

6 **Methods:** In Study 1 adult participants ($n= 24$, 87.5% female) evaluated the palatability and
7 expected satiety of five lunch-time meals and ranked them in preference. Separate ranks were
8 elicited for equicaloric portions from 100 to 800 kcal (100-kcal steps). In Study 2 adult
9 participants ($n= 24$, 75% female) evaluated nine meals and ranked 100-600 kcal portions in three
10 contexts, believing that (a) the next meal would be at 19:00, (b) they would receive only a bite of
11 one food, and (c) a favorite dish would be offered immediately afterwards. Regression analysis
12 was used to quantify predictors of choice.

13 **Results:** In Study 1 the extent to which expected satiety and palatability predicted choice was
14 highly dependent on portion size ($P < 0.001$). With smaller portions, expected satiety was a
15 positive predictor, playing a role equal to palatability (with 100 kcal portions expected satiety $\beta =$
16 0.42 and palatability $\beta = 0.46$). With larger portions, palatability was a strong predictor (600 kcal
17 portions, $\beta = 0.53$) and expected satiety was a poor or negative predictor (600 kcal portions, $\beta = -$
18 0.42). In Study 2 this pattern was moderated by context ($P = 0.024$). Results from scenario (a)
19 replicated Study 1. However, expected satiety was a poor predictor in both scenario (b) (expected
20 satiety was irrelevant) and scenario (c) (satiety was guaranteed), and palatability was the primary
21 driver of choice across all portions.

22 **Conclusions:** In adults, expected satiety influences food choice, but only when small equicaloric
23 portions are compared. Larger portions not only promote the consumption of larger meals but
24 they encourage adoption of food choice strategies motivated solely by palatability.

25 **Key words:** Portion size, expected satiety, food choice, dietary decisions

26 **Introduction**

27 The term ‘unhealthy’ is often applied to energy-rich foods that increase both energy intake (1)
28 and the risk of obesity (2). Studies have also shown that dietary decisions are affected by
29 emotions (3) and that social and contextual factors affect people in different ways (4, 5). These
30 observations highlight potential triggers that can inform targeted strategies to promote ‘healthier’
31 dietary choices (6). The study of unhealthy dietary choices has also benefited from the
32 introduction of various imaging technologies. These advances are important because they can
33 help to expose underlying neurobiological processes (7, 8). In other studies, researchers have
34 focused on specific affective and orosensory characteristics of foods. Palatability is often
35 considered and particular emphasis has been placed on the role of fats, sugars, and salt, because
36 these ingredients are associated with foods that are especially energy dense (9, 10). One
37 possibility is that humans are drawn to energy dense foods because they offer protection from
38 starvation. However, energy density is not the sole determinant of energy content – amount or
39 ‘portion size’ also plays a role. This distinction between total calories and energy density is
40 critical, yet very often these variables are confused or conflated in studies suggesting that energy
41 dense or ‘high calorie’ foods promote unhealthy dietary decisions (11, 12).

42 The term ‘food choice’ can refer to ‘what’ and ‘how much’ a person goes on to consume.
43 Here, it is used to refer to the type of food that is chosen rather than its quantity. Two previous
44 studies have considered whether energy density remains a predictor of food choice after
45 controlling for the energy content of foods. Remarkably, when relatively small (400 kcal or less)
46 equicaloric portions were compared at lunchtime, low energy-dense foods were chosen over
47 those with a higher energy density (13, 14). This appears to be because, calorie-for-calorie, lower
48 energy-dense foods are expected to deliver a far greater reduction in our desire for food between
49 meals (hereafter referred to as ‘expected satiety’) (15). Evidence that non-human animals find

50 satiation and satiety reinforcing is general weak (16) (although low doses of cholecystokinin
51 may condition flavor preferences (17)). The reason for this discrepancy remains unclear but it
52 may be linked to an ability to plan for the future that is especially evident in humans.

53 Here, the objective was to determine whether portion size moderates the role of ‘expected
54 satiety’ in food choice. Specifically, we reasoned that the attraction of foods with high expected
55 satiety might diminish when larger energy-matched portions are compared. This is because at
56 larger portion sizes all foods will be expected to reduce the desire to eat between meals, even
57 those that have low expected satiety. Results from two studies are reported that were designed to
58 quantify and expose a potential trade-off between portion size, palatability (participants’
59 acceptance of the taste of the food in question), and expected satiety in food choice. In so doing,
60 our objective was to determine whether larger portions promote the selection of foods based on
61 their hedonic properties, even after controlling for their energy content.

62

63 **Methods**

64 *Participants:* Based on an earlier study (15), in both Study 1 and in Study 2 we recruited twenty-
65 four participants (see **Table 1**) drawn from the staff and student populations of the University of
66 Bristol (United Kingdom). To reduce demand awareness, participants were told that the purpose
67 of the study was to explore ‘The effects of mood on appetite ratings, taste perception and
68 cognitive performance.’ Participants were excluded if they were; i) vegetarian or vegan, ii) not
69 fluent in English, iii) taking any medication that might influence appetite or metabolism (with the
70 exception of oral contraceptive pills) or, iv) allergic or intolerant to any foods. In remuneration
71 for their assistance, all were offered a financial reward or course credits upon completion of the
72 study. Both studies were approved by the University of Bristol Faculty of Science Human
73 Research Ethics Committee.

74
75 *Stimuli:* In Study 1 participants assessed five different meals that are commonly consumed for
76 lunch or at an evening meal in the UK. To extend this range, nine meals were assessed in Study
77 2. The macronutrient composition of these meals was taken from food packaging and is provided
78 in **Supplemental Table 1**. All meals were purchased as pre-prepared ‘ready meals’ and they
79 were sourced from local supermarkets.

80 For each meal, a set of photographs was taken using a high-resolution digital camera.
81 Each meal was photographed on the same white plate (255-mm diameter). Particular care was
82 taken to maintain constant lighting conditions and plate position in each photograph. For each
83 food, picture number 1 showed a 20-kcal portion. With increasing picture number the portion
84 shown increased by 20 kcal (*i.e.*, picture 2 = 40 kcal, picture 3 = 60 kcal, and so on). Each food
85 was photographed 50 times (*i.e.*, maximum portion = 1000 kcal). With meals that comprised
86 more than one food item (*e.g.*, lasagna and peas) the relative ratio of each component of each
87 meal (by weight) was maintained, thereby preserving the same overall macronutrient composition
88 within each set of images. The name of the food was included in the top left-hand corner of every
89 image.

90
91 *Expected satiety:* In each trial one of the test foods was displayed (size = 229 × 200 mm).
92 Respectively, depressing the left and right keyboard arrow-key caused the portion size to
93 decrease and increase. The pictures were loaded with sufficient speed that continuous key
94 depression gave the appearance that the change in portion size was animated. Each trial started
95 with a different and randomly selected portion size. In Study 1 participants were given two
96 instructions; “1. You will be shown some food. Imagine it is lunchtime and no other foods are
97 available. You won’t be eating again until 7pm.” (*i.e.*, no other food is available, either for lunch

98 or between lunchtime and 19:00 later that day) and “2. Use the left and right arrow keys to select
99 the portion size that you would need to stave off hunger until 7pm.”

100 One possibility is that participants find this task difficult if they routinely eat earlier or
101 later than 7pm. To address this potential concern we adopted an alternative approach in Study 2.
102 Based on an earlier study (13) participants were asked to match a common comparison food to
103 each test food. In each trial a fixed 300-kcal portion of a test food was displayed on the left-hand
104 side of the screen. Next to this ‘standard’ a ‘comparison food’ was presented. During each trial,
105 the participant changed the amount of the comparison food. For each standard-comparison pair,
106 the participant was asked to “Change the size of the portion on the right so that both foods will
107 keep you feeling satisfied (stave off hunger) for the same amount of time.” We selected pasta and
108 tomato sauce as a common comparison because pilot work indicated that this food is likely to be
109 highly familiar. In both studies the order of the trials was randomized across participants.
110 Expected satiety and all other measures (described below) were obtained using custom software
111 written in Visual Basic 6.0.

112

113 *Food choice:* At the beginning of each trial equal-caloric portions of the test foods were
114 positioned randomly at the bottom of the screen. In Study 1 five boxes were shown spanning the
115 width of the monitor and aligned horizontally in the upper section. From left to right the boxes
116 were labelled ‘1’, ‘2’, ‘3’, ‘4’ and ‘5’ and the instruction “Would you choose this meal for lunch?
117 Place the foods in order of preference (1 = Worst/5= Best)” was presented at the top of the
118 screen. In Study 1 the participants were given the following instructions “Imagine it is lunchtime.
119 You will not eat until 7pm and no other foods will be available. You MUST choose one of these
120 meals for lunch. You MUST eat ALL of this food.” Participants completed their ranking by using
121 the mouse to move the foods into separate boxes. In the first trial 100-kcal portions of the test

122 foods were shown. In subsequent trials the portions increased incrementally by 100 kcal until 800
123 kcal-portions had been evaluated.

124 In Study 2 we repeated this procedure in a ‘standard condition’ with a broader range of
125 nine test foods. With the inclusion of extra test foods we were concerned about the extra burden
126 that this might place on participants. Therefore, the maximum portion size was limited to 600
127 kcal. A further possibility is that the meals differ in their perceived energy content (even though
128 these were matched in each trial). To address this concern, in Study 2 explicit labelling was
129 incorporated, informing the participants that in each ranking task all of the foods contain the
130 same number of calories. In an otherwise identical ‘bite condition’ participants were told, “You
131 are only allowed to taste one food (just a small taster on a teaspoon!) You are not allowed to eat
132 the whole portion.” Finally, in a ‘fullness condition’ they were told “You MUST eat ALL of this
133 food. But IMMEDIATELY after you know you are going to be eating one of your favorite
134 foods.” We reasoned that if expected satiety plays a causal role in food choice then the pattern of
135 results from Study 1 should be preserved in the standard condition, but should be modified by the
136 instructions in the bite and the fullness conditions. This is because fullness can never be achieved
137 in the bite condition and because knowledge that other highly palatable food is available
138 addresses concerns about hunger in the fullness condition. The order of these conditions was
139 counterbalanced across participants. After completing each set of rankings the participants were
140 also asked to provide a rationale for their choices. Specifically, they were asked to select one of
141 the following options in response to the instruction “In this previous section which of the
142 following statements best describes your approach to food choice?” a) "I always selected foods
143 based on how tasty they would be to eat", b) "I always selected foods based on how filling they
144 would be", c) "I started thinking about how tasty they would be to eat but then with larger
145 portions I thought about fullness", d) "I started thinking about fullness but then with larger

146 portions I thought about how tasty they would be to eat", e) "None of the above."

147

148 *Expected palatability:* Participants rated the palatability of the test meals in a randomized order.

149 In each trial a visual-analogue rating scale was presented above a picture of a 300-kcal portion.

150 The rating was headed "How much do you like the taste of this food?" with end anchor points "I

151 hate it" and "I love it." Responses were scored in the range 1 to 100.

152

153 *Familiarity:* Participants were shown 300-kcal portions of each test food in a randomized order.

154 In each trial they selected one of two buttons labelled 'No' and 'Yes' in response to the question

155 "Have you ever eaten this food before?"

156

157 *Procedure:* All data were collected in the Nutrition and Behaviour Unit at the University of

158 Bristol (UK). Test sessions were scheduled between 10:00 and 16:00. In both studies participants

159 completed the measure of food choice, followed by measures of familiarity, palatability, and

160 expected satiety. To characterize trait dietary behaviors the participants were then asked to

161 complete the Three-Factor Eating Questionnaire (TFEQ) (18). Finally, the height and weight of

162 the participants was measured and they were debriefed and thanked for their assistance with the

163 study.

164

165 *Data analysis:* Following a similar strategy (14), for each participant, portion size, and condition

166 (Study 2 only), simultaneous linear regression was used to calculate separate standardized beta

167 coefficients to quantify the role of expected satiety and palatability as independent predictors of

168 ranked food choice. We assessed expected satiety in different ways in Study 1 and Study 2. In

169 Study 1 larger selected portions indicate less expected satiety, whereas in Study 2, larger selected

170 portions suggest greater expected satiety. To promote direct comparison across studies raw
171 expected satiety values from Study 2 were multiplied by -1 and these transformed values were
172 used in the regression analysis. Accordingly, for both studies, a positive beta weight for expected
173 satiety suggests that foods that have high expected satiety also tended to be highly ranked.
174 Similarly, a positive beta weight for palatability suggests that palatable foods tended to be ranked
175 higher. Negative beta weights suggest the converse. For example, a negative expected satiety beta
176 weight suggests that foods that have high expected satiety tended to receive a relatively low
177 ranking. In addition to assessing the independent role of expected satiety and palatability we also
178 sought to quantify the proportion of variance in food choice that is explained by these variables in
179 combination. Therefore, using data from Study 2, for each portion size and each condition, we
180 averaged across participants to calculate a set of mean R^2 values.

181 In a second stage of the analysis beta coefficients were submitted to a repeated-measures
182 ANOVA. For Study 1, two within-subject factors were explored; portion size and predictor type
183 (expected satiety and palatability). For Study 2 we also included condition (standard, bite, and
184 fullness) as a within-subjects factor. *Post-hoc*, the resulting three-way interaction was explored by
185 submitting palatability and expected satiety beta weights to separate repeated-measures ANOVA,
186 with portion size and condition as within-subjects factors. Finally, our null hypothesis was that
187 neither of the predictors play a role in food choice. Therefore, for each portion size, planned *t*-
188 tests were conducted to determine whether sets of beta values deviate significantly from zero.

189 Due to a technical fault, measures of expected satiety were not recorded for one
190 participant in Study 1. This participant was removed from the dataset. Visual inspection of the
191 data from Study 2 suggested that one participant might be an outlier. Therefore, we converted
192 sets of beta values into *z*-scores. In a normal distribution, 99.9% of *z*-scores should lie between -
193 3.29 and 3.29 (19). On this basis data from one participant was omitted from Study 2, leaving 23

194 participants remaining in both studies. Differences were considered significant at $P < 0.05$ and all
195 results are reported as means \pm *SD*. All analyses were conducted using Minitab 16.2.4.

196

197 **Results**

198

199 *Results from Study 1*

200

201 *Participant characteristics:* We were unable to calculate a TFEQ-disinhibition score for two
202 participants who did not complete one question in the disinhibition subscale. Dietary restraint (n
203 = 24, 10.7 ± 5.2), disinhibited eating ($n = 22$, 8.0 ± 3.1), and hunger scores ($n = 24$, 6.8 ± 3.3)
204 were within the normal range (18). Responses in the familiarity task indicated that four
205 participants had never eaten one of the test foods and one had never eaten two of the test foods.

206

207 *Expected satiety and palatability:* **Supplemental Table 2** shows summary values for the
208 expected satiety and palatability of the test foods. For each food, expected satiety is represented
209 by the amount (kcal) that would be required to stave off hunger. Smaller values indicate greater
210 expected satiety.

211

212 *Predictors of food choice:* Standardized beta weights are presented in **Figure 1**. Separate pairs of
213 values are provided for the eight portion sizes (range 100 to 800 kcal). Beta coefficients for
214 expected satiety and palatability differed significantly ($P < 0.001$), indicating that these measures
215 assessed different constructs. We also found a main effect of portion size ($P < 0.001$) and a
216 significant interaction between portion size and predictor type ($P < 0.001$). **Figure 1** shows that
217 for the smallest portion (100 kcal) palatability and expected satiety are both equally good and

218 positive predictors of choice. However, with increasing portion size the role of expected satiety
219 diminished. Indeed, when the largest portions were compared then foods with high expected
220 satiety were less likely to be selected. By contrast, the role of palatability remained reasonably
221 stable across portion sizes. Consistent with this interpretation, for palatability, a significant
222 deviation from zero was observed in beta values across all portion sizes. By contrast, values for
223 expected satiety reached significance only for small (100 kcal; $P < 0.01$ and 200 kcal; $P < 0.05$)
224 and larger portions (500 kcal; $P < 0.01$, 600 kcal; $P < 0.001$, 700 kcal; $P < 0.05$, 800 kcal; $P <$
225 0.01) - with larger portions, expected satiety became a negative predictor.

226

227 *Results from Study 2*

228

229 *Participant characteristics:* Scores for dietary restraint (8.6 ± 5.9), disinhibited eating (8.9 ± 3.6),
230 and hunger (6.2 ± 2.9) were within the normal range (18). Participants were generally familiar
231 with the test foods. However, a larger proportion expressed unfamiliarity than in Study 1. Five
232 participants were unfamiliar with one of the nine test foods, three were unfamiliar with two
233 foods, two were unfamiliar three foods and one was unfamiliar with four of the foods.

234

235 *Expected satiety and palatability:* **Supplemental Table 3** shows summary values for expected
236 satiety and palatability. For expected satiety, each value represents the amount (kcal) of
237 comparison food (pasta) that would be needed in order for the test food (300 kcal portion) and the
238 comparison food to have the same expected satiety. Therefore, larger values indicate greater
239 expected satiety.

240

241 *Predictors of food choice:* Our analysis revealed a significant two-way interaction between

242 predictor type (palatability/expected satiety) and portion size ($P < 0.001$). However, we also
243 found a significant three-way interaction between predictor type, portion size, and condition ($P =$
244 0.024), showing that the interaction between predictor type and portion size was moderated by
245 the type of instruction that was given to the participants. *Post-hoc* analyses of expected satiety
246 beta weights revealed a main effect of portion ($P < 0.001$) and a main effect of condition ($P <$
247 0.001). The interaction between portion and condition failed to reach significance ($P = 0.10$).
248 Consistent with our planned analysis, this suggests that the role of expected satiety was
249 moderated by the specific instructions in the ranking tasks.

250 The same *post-hoc* analysis of palatability beta weights revealed a main effect of
251 condition ($P = 0.002$) and a significant interaction between condition and portion size ($P = 0.03$).
252 Again, this shows that the instructions influenced the role of palatability. Standardized beta
253 weights are presented in **Figure 2**. Separate values are provided for each condition. Respectively,
254 Panels A, B, and C show beta weights for the standard, bite, and fullness condition.

255 As in Study 1, we identified mean beta values that deviate significantly from zero. The
256 pattern of results in **Figure 2** can be interpreted as follows. As in Study 1, when the entire portion
257 was expected and no other food was available (standard condition), expected satiety played a
258 significant role in food choice, but only when smaller portions (400 kcal or less) were compared
259 (**Panel A**). As the role of expected satiety diminished with portion size the importance of
260 palatability increased. By contrast, when the portion size was restricted (bite condition; **Panel B**)
261 or when the test food was to be followed by a favorite food (fullness condition; **Panel C**), then
262 expected satiety played a minor role in food choice and, irrespective of portion size, choice was
263 motivated primarily by palatability.

264 Finally, we evaluated the extent to which measures of palatability and expected satiety
265 can explain variance in food choice in combination. Separate mean R^2 values are provided in

266 **Table 2.** The variance explained by the regression models is fairly constant, both across
267 conditions and portion sizes, with one exception. In the standard condition R^2 values increase
268 from 0.39 to 0.58 across the portions tested. Across conditions, approximately 50% of the
269 variance in food choices is explained by a combination of variability in palatability and expected
270 satiety.

271
272 *Self-reported determinants of food choice:* **Table 3** provides a summary of responses. As
273 anticipated, in the standard condition most participants (60.9%) reported prioritizing fullness with
274 smaller portions and then palatability with larger portions. However, a modest proportion
275 (34.8%) also indicated the converse. In the bite condition the majority of participants prioritized
276 palatability (69.6%). Finally, in the fullness condition many participants (56.5%) reported that
277 they prioritized palatability with smaller portions and fullness with larger portions. Other
278 participants were distributed relatively evenly across other response options.

279

280 **Discussion**

281 Together, these findings highlight an added complexity to food choice. In particular, they
282 show how the role of palatability and expected satiety can be isolated and quantified, and how
283 their importance varies with portion size and context. The pattern of results in Study 1 broadly
284 coincides with those in the standard condition of Study 2. Across a range of portion sizes,
285 palatability remained a consistent and positive predictor of food choice. By contrast, expected
286 satiety was favored, but only when small portions were compared.

287 In these studies no foods were consumed - choice was based solely on the visual
288 characteristics of the foods. However, this is how decisions are normally made. Rather than
289 opening packets and/or tasting individual foods in a supermarket, restaurant, or even at home,

290 people tend to decide what to eat before a meal begins (20). Brain imaging studies indicate that
291 stimulus value is coordinated in the orbitofrontal cortex (21). In the case of food, short-term
292 interests in palatability (enjoyment) are tempered by cognitive inhibition that takes the form of
293 dietary restraint and longer-term concerns about health (encoded in the dorsolateral prefrontal
294 cortex) (7). This idea extends beyond the neurocognitive domain and is highlighted in numerous
295 studies that focus on the competition between immediate enjoyment and inhibitory control.
296 Accordingly, overeating and ‘unhealthy’ food choices are thought to occur because foods are
297 ‘hyper palatable’ (22) or because decisions are impulsive (23), or as a result of hyper- (24) or
298 hypo-sensitivity (25) to the immediate reward experienced by eating. Our data suggest that in
299 addition to these short- and long-term considerations, choice is also influenced by expected
300 satiety (a ‘medium term’ meal-to-meal concern) – in other words, the capacity of a food to
301 promote satiety between meals. More generally, and consistent with this proposition, palatability
302 is sometimes a poor predictor of actual food choice (26-28).

303 Note that we are not suggesting that the role of expected satiety implies homeostatic
304 regulation of food intake from one meal to the next. The hypothesis that food choice reflects a
305 motivation to address short-term energy depletion is commonplace in scientific discourse.
306 Indeed, this popular belief probably plays an important role in guiding everyday decisions
307 (people claim the need to eat in order to ‘keep going’ or to ‘maintain energy levels’). In reality,
308 food choice is unlikely to have a meaningful impact because the effect of a single decision will be
309 trivial compared with total energy stores. In a recent theoretical review an analogy is drawn
310 between a saucepan and a bathtub (29). The former represents the energy that might be
311 ‘corrected’ by eating, and the latter, the total energy reservoir held within a typical person. We
312 calculate that if a 65kg person decided to skip a 500-kcal meal then this might generate only a
313 0.4% deficit. Therefore, there is little reason to fine tune food choice in order to achieve precise

314 energy balance from one meal to the next. Instead, all else being equal, people eat and experience
315 ‘hunger’ (desire to eat) primarily in response to emptiness of the gut, and a related capacity to
316 consume more food.

317 One of the advantages of maintaining significant energy reserves is that it enables humans
318 to structure their meal pattern (*e.g.*, breakfast, lunch, and dinner) around other activities. The
319 tendency to limit meal size to avoid the acute physiological and cognitive effects of a large meal
320 (sometimes referred to as an ‘eating paradox’ (30)) has been explored extensively, both in
321 humans and in non-human animals (31). Our data indicate that food choice is also governed by a
322 further consideration –meal patterns tend to be entrained around daily work and social activities.
323 If a poorly satiating meal is consumed then this may risk later distraction caused by hunger (a
324 readiness to consume more food), to the detriment of those other activities. When the timing of a
325 following meal is known and when confronted with smaller-than-normal portions, then foods will
326 be chosen that are particularly satiating, *i.e.*, those that limit the distraction that might otherwise
327 be experienced between meals. When only a bite of food was offered (bite condition, Study 2) or
328 when unlimited access to a favorite food was permitted (fullness condition, Study 2), then
329 expected satiety was found to be a poor predictor of food choice (**see Figure 2, panels B and C**).
330 Thus, it would appear that both an inability to achieve satiety (bite condition) and the certainty
331 that satiety would be achieved (fullness condition) are sufficient to eliminate a role for expected
332 satiety when prioritizing foods to consume at lunchtime. Recently, we have used informal and
333 semi-structured interview techniques to assess food choices during snacks and around lunchtime.
334 Reliably, participants refer to fullness and, in particular, the need to ensure the absence of hunger
335 between meals (a typical response takes the form, “I just want a healthy and tasty lunch that will
336 fill me up until supper”). This strategy was reflected in the self-report questionnaire and appears
337 to indicate an active ‘defense of meal pattern’ that preserves a capacity to fully engage in other

338 non-food related behaviors between meals. In relation to this idea, it may be relevant that obesity
339 is often associated with a chaotic eating pattern and that short periods of chaotic eating produce
340 an impaired insulin response and an increase in fasting total and LDL cholesterol (32, 33).

341 The findings are also highly relevant to what is commonly referred to as the ‘portion size
342 effect’ - large portions reliably increase food intake, even when the portion that is offered is
343 larger than can be consumed (34). This observation is very robust and has been explored
344 extensively (for excellent recent reviews see (35, 36)). Our findings show that larger portions not
345 only promote increased energy intake but also promote a food-choice strategy that promotes the
346 selection of palatable foods. One of the reasons why this relationship may have been overlooked
347 is because the portion-size effect has tended to be studied in single component meals or otherwise
348 using paradigms that are not optimized to detect and quantify the underlying behavioral
349 economics of food-utility trade-offs in comparisons across different types of meal.

350 Reviews of food portion sizes often highlight a dramatic increase in serving sizes,
351 particularly those found in fast food restaurants (37). Our findings suggest that larger serving
352 sizes enhance the relative appeal of these foods (for the reasons outlined above). More generally,
353 this trend towards larger portions might represent an example of how food production can
354 become adapted to fundamental principles that govern the economics of food choice (for a related
355 point see (38)). Of course, the converse also applies, if smaller portions are presented, then this
356 may promote the selection of less palatable lower energy-dense foods (consistent with
357 recommendations (39)), and an awareness of this relationship could help to inform the design of
358 diets and commercial products that promote satiety and weight management. Consistent with this
359 proposition, children appear to show a greater preference for lower energy-dense (more satiating)
360 foods when they are presented in smaller portions (40).

361 Finally, there are two broad areas where our research and methods might be applied. First,

362 an opportunity exists to explore individual differences in food choice. The present paradigm is
363 unusual in that it deconstructs food choice on a calorie for calorie basis. In particular, the data
364 indicate that a ‘satiety-to-palatability switch’ occurs as food portions become larger. Although
365 our models account for a large proportion of variance in food choice (roughly 50%) other factors
366 such as perceived healthiness or demographic and economic factors are also likely to play a role
367 (2, 41). Our psychophysical approach would seem well placed to expose very subtle individual
368 differences that promote a positive energy balance over time. A further possibility is that
369 differences in switch point are governed by a weighing up of immediate reward (palatability)
370 against medium-term concerns about a defense of meal pattern. This possibility might parallel
371 individual differences in monetary delay discounting (immediate gratification vs the willingness
372 to wait for a larger reward), a variable that has previously been associated with obesity (42).

373 Second, broadening this work to incorporate different meals and social contexts could be
374 very informative. In particular, our analysis suggests that eating a two-course lunch might have a
375 dramatic effect on priorities in food choice (see **Figure 2, Panel C**), promoting a strategy based
376 almost entirely on palatability. In future it would be interesting to explore how planned inter-
377 meal snacks and other variables moderate food choice in this context.

378

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380 JMB, AJ, AAM, JCWB, and PJR designed research. RLG, CP, and NRE conducted research.
381 JMB analyzed data; JMB and PJR wrote the paper; JMB had primary responsibility for final
382 content. All authors have read and approved the final manuscript.

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Tables**Table 1.** Characteristics of participants in Study 1 and Study 2¹.

	Study 1	Study 2
	(<i>n</i> = 23)	(<i>n</i> = 23)
Females / males, <i>n</i>	20 / 3	18 / 5
BMI, kg/m ²	22.2 ± 1.9	22.6 ± 2.2
Age, y	19.3 ± 1.2	24.5 ± 3.5

¹ Values are means ± SDs

Table 2. Variance in food choice explained by a combination of expected satiety and palatability in Study 2^{1 2}.

Portion size shown (kcal)	Standard ³	Condition	
		Bite ⁴	Fullness ⁵
100	0.39 ± 0.19	0.57 ± 0.24	0.46 ± 0.29
200	0.40 ± 0.20	0.55 ± 0.24	0.51 ± 0.27
300	0.50 ± 0.21	0.52 ± 0.22	0.51 ± 0.21
400	0.50 ± 0.21	0.54 ± 0.23	0.58 ± 0.22
500	0.54 ± 0.20	0.52 ± 0.23	0.50 ± 0.26
600	0.58 ± 0.20	0.55 ± 0.22	0.56 ± 0.24

¹ Values are means ± SDs, $n=23$

² Expected satiety and expected palatability were entered as simultaneous predictors of choice using linear regression. Separate models were calculated for each participant, portion size, and condition.

³ Test foods were ranked by participants assuming it is lunchtime and no other food is available until 19:00.

⁴ Same as the standard condition but participants were told that only a single bite of one test food would be available.

⁵ Same as the standard condition but participants were told to expect a favorite dish after consuming one of the test foods.

Table 3. Self-reported strategies in food choice in Study 2. Values show the percentage of participants ($n=23$) who selected a particular rationale in each condition¹.

Option	Rationale for choosing	Standard (%) ²	Condition	
			Bite (%) ³	Fullness (%) ⁴
1	Palatability with all portions	0.0	69.6	13.0
2	Fullness with all portions	0.0	4.3	13.0
3	Palatability with smaller portions and fullness with larger portions	34.8	13.0	56.5
4	Fullness with smaller portions and palatability with larger portions	60.9	8.7	8.7
5	None of the above	4.3	4.3	8.7

¹ Responses were elicited using a self-report forced-choice questionnaire with five options.

² Test foods were ranked by participants assuming it is lunchtime and no other food is available until 19:00.

³ Same as the standard condition but participants were told that only a single bite of one test food would be available.

⁴ Same as the standard condition but participants were told to expect a favorite dish after consuming one of the test foods.

Figure headings

Figure 1. Standardized beta coefficients for expected satiety and palatability as predictors of the ranked selection of five foods (Study 1). Separate values are provided for equicaloric portions in the range 100 kcal to 800 kcal. Positive values indicate that a predictor promoted the appeal of a meal. A negative value indicates the converse. Asterisks denote a significant departure from zero (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$). Data are means \pm SEMs, $n = 23$.

Figure 2. Standardized beta coefficients for expected satiety and palatability as predictors of the ranked selection of nine foods (Study 2). Separate values are provided for equicaloric portions in the range 100 kcal to 600 kcal. Positive values indicate that a predictor promoted the appeal of a meal. A negative value indicates the converse. Separate panels show the relative importance of expected satiety and palatability when; (Panel A) participants were told to assume it is lunchtime and no other food is available until 19:00 (standard condition), (Panel B) participants were told that only a single bite of one test food would be available (bite condition), and (Panel C) participants were told to expect a favorite dish after consuming one of the test foods (fullness condition). Asterisks denote a significant departure from zero (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$). Data are means \pm SEMs, $n = 23$.

Online Supporting Material

Supplemental Table 1: Macronutrient composition of the test foods in Study 1 and Study 2. The column headed 'study' indicates whether the food was included only in Study 2 or in both Study 1 and Study 2.

Food type	Carbohydrate g/100 kcal	Protein g/100 kcal	Fat g/100 kcal	Weight g/100 kcal	Study
beef stew and dumplings	8.6	4.9	4.3	67	2
chicken chow mein	11.0	8.1	2.6	124	1, 2
chicken salad	5.8	7.5	5.2	102	2
chicken tikka masala	11.1	4.2	4.3	57	2
fish, chips, and peas	12.4	3.2	3.8	62	1, 2
lasagna and peas	8.9	4.7	4.7	69	1, 2
pepperoni pizza	10.2	4.6	4.4	37	1, 2
sausage, mashed potato, & peas	5.3	5.0	6.4	61	1, 2
spaghetti Bolognese	11.5	5.1	3.76	71	2

Online Supporting Material

Supplemental Table 2: Expected satiety and palatability of 300 kcal portions of the test foods in Study 1. Separate values are provided for each test food¹.

Food type	Expected satiety ² (kcal)	Palatability ³ (0-100 mm)
chicken chow mein	408 ± 231	66 ± 20
fish, chips and peas	561 ± 146	68 ± 22
lasagna and peas	520 ± 154	65 ± 21
pepperoni pizza	451 ± 161	58 ± 27
sausage, mashed potato, & peas	462 ± 173	55 ± 24

¹ Values are means ± SDs, $n = 23$

² Expected satiety was assessed using a method of adjustment. Participants selected an amount that would be needed to stave off hunger between lunchtime and 19:00. Smaller values indicate that a meal had greater expected satiety.

³ Palatability was assessed using a 100-mm visual-analogue scale. Higher values indicate greater palatability.

Online Supporting Material

Supplemental Table 3: Expected satiety and palatability of 300 kcal portions of the test foods in Study 2. Separate values are provided for each test food¹.

Food type	Expected satiety ² (kcal)	Palatability ³ (0-100 mm)
beef stew and dumplings	180 ± 50	62 ± 24
chicken chow mein	304 ± 136	68 ± 21
chicken salad	210 ± 92	59 ± 26
chicken tikka masala	267 ± 141	68 ± 24
fish, chips, and peas	198 ± 68	66 ± 24
lasagna and peas	237 ± 80	72 ± 24
pepperoni pizza	219 ± 56	69 ± 24
sausage, mashed potato, & peas	203 ± 53	80 ± 20
spaghetti Bolognese	250 ± 92	73 ± 19

¹ Values are means ± SDs, $n = 23$

² Expected satiety was assessed using a method of adjustment. Higher values show that a larger portion (kcal) of a common comparison food was needed to match the expected satiety of the test food. Higher values indicate greater expected satiety.

³ Palatability was assessed using a 100-mm visual-analogue scale. Higher values indicate greater palatability.