

Bond University  
Research Repository



## Food reward in active compared to inactive men: Roles for gastric emptying and body fat

Horner, Katy M.; Finlayson, Graham S; Byrne, Nuala M.; King, Neil A.

*Published in:*  
Physiology and Behavior

*DOI:*  
[10.1016/j.physbeh.2016.04.009](https://doi.org/10.1016/j.physbeh.2016.04.009)

*Licence:*  
CC BY-NC-ND

[Link to output in Bond University research repository.](#)

*Recommended citation(APA):*  
Horner, K. M., Finlayson, G. S., Byrne, N. M., & King, N. A. (2016). Food reward in active compared to inactive men: Roles for gastric emptying and body fat. *Physiology and Behavior*, 160, 43-49.  
<https://doi.org/10.1016/j.physbeh.2016.04.009>

### General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

For more information, or if you believe that this document breaches copyright, please contact the Bond University research repository coordinator.

1

2 **Title 1: Food reward in active compared to inactive men: Roles for gastric emptying and body**  
3 **fat**

4

5 **Authors:** Katy M Horner<sup>1,2</sup>, Graham Finlayson<sup>3</sup>, Nuala M Byrne<sup>1,4</sup>, Neil A King<sup>1</sup>

6

7 **Departmental and Institutional Affiliations:**

8 <sup>1</sup>School of Exercise and Nutrition Sciences and Institute of Health and Biomedical Innovation,  
9 Queensland University of Technology, Brisbane, Australia

10 <sup>2</sup>Institute of Food and Health, University College Dublin, Dublin 4, Ireland

11 <sup>3</sup>School of Psychology, Faculty of Medicine and Health, University of Leeds, UK

12 <sup>4</sup>Bond Institute of Health and Sport, Faculty of Health Sciences and Medicine, Bond University,  
13 Gold Coast, Australia

14

15 **Running Head:** Food Hedonics, Gastric Emptying, Activity

16

17 **Corresponding Author:**

18 Katy Horner,

19 Institute of Food and Health,

20 University College Dublin,

21 Dublin 4,

22 Ireland.

23 Email: [katyhorner@gmail.com](mailto:katyhorner@gmail.com)

24

25

26

27

28

29 **Abstract**

30 Habitual exercise could contribute to weight management by altering processes of food reward via  
31 the gut-brain axis. We investigated hedonic processes of food reward in active and inactive men and  
32 characterised relationships with gastric emptying and body fat. Forty-four men (Active: n=22;  
33 Inactive: n=22, BMI range 21-36 kg/m<sup>2</sup>; percent fat mass range 9-42%) were studied. Participants  
34 were provided with a standardised fixed breakfast and an ad libitum lunch meal 5h later. Explicit  
35 liking, implicit wanting and preference among high-fat, low-fat, sweet and savoury food items were  
36 assessed immediately post-breakfast (fed state) and again pre-lunch (hungry state) using the Leeds  
37 Food Preference Questionnaire. Gastric emptying was assessed by <sup>13</sup>C-octanoic acid breath test.  
38 Active individuals exhibited a lower liking for foods overall and a greater implicit wanting for low-  
39 fat savoury foods in the fed state, compared to inactive men. Differences in the fed state remained  
40 significant after adjusting for percent fat mass. Active men also had a greater increase in liking for  
41 savoury foods in the interval between breakfast and lunch. Faster gastric emptying was associated  
42 with liking for savoury foods and with an increase in liking for savoury foods in the postprandial  
43 interval. In contrast, greater implicit wanting for high-fat foods was associated with slower gastric  
44 emptying. These associations were independent of each other, activity status and body fat. In  
45 conclusion, active and inactive men differ in processes of food reward. The rate of gastric emptying  
46 may play a role in the association between physical activity status and food reward, via the gut-  
47 brain axis.

48 **Keywords:** liking; wanting; gastric emptying; physical activity.

49

50

51

52

53

54

55

56

57

58

59

60

## 61 **Introduction**

62 Epidemiological studies consistently show that individuals who are physically active are less likely  
63 to gain weight over time [1]. One hypothesis to explain why physical activity is crucial for weight  
64 maintenance is that human physiology is biased towards maintaining energy balance at a high  
65 energy flux (i.e. a high level of energy intake and energy expenditure) [2]. In support of this  
66 hypothesis, in an early study of 213 workers with varying occupations in West Bengal (India),  
67 Mayer [3] demonstrated that energy intake was more closely matched to energy expenditure in  
68 physically active compared to sedentary workers. More recent evidence from both cross-sectional  
69 and longitudinal studies further supports a role for physical activity in improved short-term appetite  
70 control [4], [5], [6], [7], [8]. Blundell [9] termed the sedentary range ‘ the zone of dysregulation’  
71 and proposed that people living in this zone are at a greater risk of overeating due to the lack of  
72 physiological regulation that occurs within this range. The underlying mechanisms however remain  
73 to be fully determined.

74 Day-to-day food intake involves the coordination of both non-homeostatic and homeostatic  
75 signals, including psychological, physiological, behavioural and neural events [10] which interact  
76 to form part of a ‘psychobiological system’ controlling appetite [11]. Food preferences and reward  
77 pathways can exert a strong influence on food intake. Weight control can be enhanced or  
78 undermined by the influence of exercise on hedonic processes of ‘liking’ and ‘wanting’ for food  
79 which in turn alter food preference [12], [13]. For example, the impact of exercise on fat mass loss  
80 has been shown to be diminished in some overweight and obese individuals who exhibit increased  
81 explicit liking and wanting for food (particularly, high fat sweet foods) post-exercise [13].  
82 However, whether food hedonics differ between habitually active versus inactive individuals has  
83 not been examined.

84 Physiological signals arising from the gastrointestinal (GI) tract could also have a  
85 mechanistic role in the influence of physical activity on appetite control [7], [14]. Gut peptides  
86 released from the GI tract and gastric emptying (the rate at which food empties from the stomach)  
87 play an important integrative relationship in the short-term control of food intake [15], and are  
88 altered by physical activity level [16], [17]. We recently observed gastric emptying was faster in  
89 habitually active compared to inactive men and was associated with activity energy expenditure  
90 [17]. A growing body of work has demonstrated interactions between the food reward system and  
91 signals from the GI tract [10], [18], [19], [20], [21]. Therefore, it is possible that signals from the GI  
92 tract could interact with reward signals to influence food intake with habitual physical activity.

93 However, to the best of our knowledge, associations between hedonic processes of food reward and  
94 gastric emptying have not been previously investigated in humans.

95           Examining the relationships between gastrointestinal signalling and psychological processes  
96 involved in the control of food intake could improve the understanding of mechanisms involved in  
97 the impact of habitual physical activity on energy balance. In the current study, we aimed to 1)  
98 examine whether food preferences and implicit and explicit hedonic processes of ‘liking’ and  
99 ‘wanting’ differ between active and inactive men, and 2) determine whether gastric emptying  
100 predicts differences in food hedonics, with and without adjusting for body fat. As fat mass has been  
101 shown to correlate with eating behaviour and hedonic processes in overweight and obese  
102 individuals [22], [23], differences in body composition could be a confounding factor when  
103 comparing food reward between active and inactive individuals. Adjusting for body fat will allow  
104 effects of physical activity to be explored while controlling for fat mass.

105

106

107

108

## 109 **Materials and Methods**

110

### 111 **Design**

112 Participants in this between groups design study undertook two separate test mornings one week  
113 apart: (1) body composition and energy expenditure assessment and 2) appetite behaviour/gastric  
114 emptying assessment. Measures including body composition (assessed by air displacement  
115 plethysmography), energy expenditure (activity energy expenditure assessed by accelerometry,  
116 resting energy expenditure by indirect calorimetry) and gastric emptying (assessed by <sup>13</sup>C-octanoic  
117 acid breath test) were taken as previously reported [17].

### 118 **Participants**

119 Forty-four men were studied. The sample size (n=22 Active and n=22 Inactive) was selected to  
120 detect a minimum 10% difference between groups for the main GE outcome measure [24].  
121 Inclusion criteria were: male, aged 18-55 yrs, BMI 18-40 kg/m<sup>2</sup>, weight stable (< ±4 kg change over  
122 last 6 months), no history of GI surgery or disorder, non-diabetic, no medical conditions and not  
123 taking medication known to influence gastric emptying or appetite, willing to consume study test  
124 breakfast and lunch meals and not a heavy smoker (<10 per day). Participants were classified based  
125 on their self-reported physical activity patterns over the last 6 months as either inactive (undertaking  
126 ≤1 structured exercise session per week and not engaged in strenuous work) or active (undertaking  
127 ≥4 structured exercise sessions per week). Individuals who did not fit either category were  
128 excluded. One exercise session was defined as at least 40 minutes of moderate to high intensity  
129 activity [4]. The study was conducted according to the guidelines laid down in the Declaration of  
130 Helsinki and ethical approval was granted by Queensland University of Technology Research  
131 Ethics Committee. All participants provided written informed consent.

132

### 133 **Appetite Behaviour and Gastric Emptying Assessment Day Protocol**

134 Participants attended the laboratory after a 12-hour overnight fast, and having avoided alcohol and  
135 strenuous exercise for 24 hours. Participants were provided with a fixed pancake breakfast labelled  
136 with 100mg <sup>13</sup>C-octanoic acid (Cambridge Isotope Laboratories, Andover, USA), and spread with  
137 butter and strawberry jam [1676 kJ (400 kcal); 15g (15%) PRO, 17g (37%) Fat, 48g (48%)  
138 CHO], and a 250ml drink of water. The test meal and drink were consumed within 10 minutes.  
139 Gastric emptying of the meal was assessed by <sup>13</sup>C-Octanoic acid breath test as described [24].  
140 Breath samples were collected in 10ml glass Exetainer tubes (Labco, Buckinghamshire, UK) prior

141 to the breakfast, immediately after, and subsequently every 15 minutes for 5 hours [24]. Data were  
142 analysed according to Ghooos et al. [25] as described [24] and the two main parameters lag time  
143 ( $t_{lag}$ ), reflecting the initial emptying rate, and half time ( $t_{1/2}$ ) were used in the present analyses.  
144 Participants remained in the laboratory in sedentary activities throughout the test morning. A lunch  
145 meal was served 5h after breakfast in the laboratory.

146

### 147 **Subjective Appetite Sensations and Test Meal Palatability**

148 Subjective appetite sensations were measured immediately before and after breakfast, and  
149 periodically during the postprandial period using an electronic appetite rating system [26].  
150 Participants were asked to rate feelings of hunger, fullness and desire to eat on 100 mm visual  
151 analogue scales, anchored at each end with the statements “not at all” and “extremely”. Five hour  
152 postprandial area under the curve (AUC) was calculated using the trapezoidal rule.

153 To assess palatability of the test meal, six questions concerning sweet, savoury, tasty,  
154 pleasant, filling and satisfying ratings were assessed on a 100mm scale using an identical electronic  
155 appetite rating system [26] immediately post consumption of the fixed breakfast meal.

156

### 157 **Food Reward Assessment; Preferences, ‘Liking’ and ‘Wanting’**

158 Our operational definition of reward-value is through explicit liking and implicit wanting responses  
159 to high fat versus low fat and sweet versus savoury images of food. Food preferences and ‘liking’  
160 and ‘wanting’ were examined immediately after breakfast consumption (fed state) which was  
161 repeated 5h later prior to lunch (hungry state) using a computer-based procedure - the Leeds Food  
162 Preference Questionnaire (LFPQ, for a detailed description see [27]). The LFPQ has been shown to  
163 demonstrate reliable immediate post-meal changes [27], is sensitive to changes in sensory specific  
164 satiation [28] and is a good predictor of food choice and intake in both laboratory and community  
165 settings [29], [30].

166 The LFPQ included 16 photographic food images administered using experiment software  
167 (E-prime v.1.2, Psychology Software Tools, ND). The foods were organised into separate  
168 categories of high fat savoury (HFSA), low fat savoury (LFSA), high fat sweet (HFSW) and low fat  
169 sweet (LFSW) (**Table 1**).

170

[Table 1 About Here]

171

172 Using the LFPQ, explicit 'liking' (the conscious feeling of pleasure expected from tasting  
173 each food [27]) was measured by presenting each food image one at a time on the computer screen  
174 and participants were asked to rate their perceived pleasantness of that food on a 100mm visual  
175 analogue scale, anchored at each end with 'not at all' and 'extremely'. Mean ratings for each  
176 category were calculated. A higher score indicates a higher explicit 'liking' for that category.  
177 Implicit wanting was assessed according to each participant's reaction time in selecting a type of  
178 food during each forced choice trial, adjusting for the frequency of selection and overall mean  
179 response time.

180 Preference for fat and sweet/savoury taste were evaluated by computing the fat bias (high fat  
181 > low fat) and the taste bias (sweet > savoury) scores for explicit liking and implicit wanting. The  
182 fat bias was calculated as the mean score for high fat foods minus the mean score for low fat foods.  
183 Thus a positive number indicates a high fat food bias and a negative number a low fat food bias.  
184 The taste bias was calculated as the mean score for sweet foods minus the mean score for savoury  
185 foods. Thus, a positive number indicates a sweet taste bias and a negative number a savoury taste  
186 bias.

187

## 188 **Statistical Analysis**

189 Data are expressed as mean  $\pm$  SEM unless otherwise stated. Differences between active and inactive  
190 groups were assessed by t test. To assess whether differences in percent fat mass (FM) contributed  
191 to these findings, the data were further analysed using ANCOVA, with percent FM as a covariate  
192 and activity status (active or inactive) as the independent factor. Changes from post-breakfast to  
193 pre-lunch were assessed by Repeated Measures ANOVA. Pearson correlation coefficients and  
194 multiple regression analyses were used to determine relationships between gastric emptying lag and  
195 half times, and process of food reward. To examine any influence of percent FM on the  
196 relationships observed, partial correlations were also undertaken controlling for percent FM.  
197 Statistical analysis was performed using PASW Statistics 18.0 (SPSS Inc., Chicago, IL) and Graph  
198 Pad Prism version 6.0 for Mac (GraphPad Software, San Diego, CA, USA). Statistical significance  
199 was set at  $P < 0.05$  unless otherwise stated.

200



## 201 **Results**

### 202 **Participant Characteristics**

203 Mean anthropometric, body composition, energy expenditure and physical activity characteristics  
204 were reported previously [17]. Key anthropometric, body composition and energy expenditure  
205 characteristics are summarised in **Table 2**. No participants were elite athletes. Gastric emptying was  
206 significantly faster in the active compared to inactive group (lag time ( $t_{lag}$ ): active:  $95\pm 13$  and  
207 inactive:  $110\pm 16$  min,  $P < 0.001$ ; half time ( $t_{1/2}$ ): active:  $157\pm 18$  and inactive,  $179\pm 21$  min,  $P <$   
208  $0.001$ ).

209 Both active and inactive groups displayed meal-related oscillations in subjective sensations  
210 of hunger, fullness and desire to eat, but ratings did not differ significantly between active and  
211 inactive groups ( $p > 0.05$ , **Supplementary Figure 1**). Palatability ratings (tasty, savoury, sweet,  
212 pleasant) of the fixed breakfast test meal did not significantly differ between the two groups ( $P >$   
213  $0.05$  for all, **Supplementary Table 1**).

214

215 [Table 2 About Here]

216

217

### 218 **Food Reward; Explicit Liking and Implicit Wanting**

219 Comparison of Active and Inactive men in fed and hungry states

220 Active men showed a lower 'liking' for HFSA, HFSW, LFSW and for foods overall when fed  
221 compared to inactive men (**Table 3**). The lower 'liking' for LFSW and for foods overall remained  
222 significant after adjusting for percent FM (**Table 3**). In the hungry state, there were no significant  
223 differences in 'liking' between active and inactive men. However, active men had a greater implicit  
224 wanting for LFSA foods in both the fed and hungry states compared to inactive men (**Table 3**). This  
225 remained significant after adjusting for percent FM in the fed but not hungry state (**Table 3**).

226

227

228 [Tables 3 and 4 About Here]

229

230

231 Changes over time during the post prandial interval

232 As expected, ratings of liking and wanting assessed by the LFPQ changed over time during the test  
233 morning from breakfast (i.e. fed state) to lunch 5h later (i.e. hungry state). Changes in explicit liking  
234 for all foods and separate food categories from breakfast to lunch are shown in **Figure 1**. Active  
235 men had a greater increase in explicit liking for all food categories combined (assessed by LFPQ)  
236 between breakfast and lunch compared to inactive men ( $F(1, 42) = 4.13, P = 0.048$ ), and  
237 particularly for savoury foods (**Figure 1**). Trends in the differences observed between active and  
238 inactive men remained after adjusting for percent FM (Liking All:  $P = 0.05$ ; Liking LFSA:  $P =$   
239  $0.05$ ; Liking HFSA:  $P = 0.07$ ).

240

241

242

[Figure 1 About Here]

243

244

245 No significant differences in changes in implicit wanting over the postprandial interval were  
246 observed between active and inactive men (**Table 4**).

247

### 248 **Relationship of Food Reward Profiles with Gastric Emptying**

249 Gastric emptying was negatively correlated with the increase in liking for LFSA foods ( $t_{1/2}$ :  $r = -0.34,$   
250  $P = 0.02$ ) and increase in liking taste bias towards savoury foods ( $t_{lag}$ :  $r = -0.30, P = 0.048$ ;  $t_{1/2}$ :  $r = -$   
251  $0.30, P = 0.045$ ) in the post prandial interval between breakfast and lunch. In addition, gastric  
252 emptying was positively correlated with the liking taste bias for savoury foods when hungry ( $t_{lag}$ :  $r$   
253  $= 0.48, P < 0.01$ ;  $t_{1/2}$ : **Figure 2a**) and the average (average of fed and hungry states) liking taste bias  
254 ( $t_{lag}$ :  $r = 0.44, P < 0.01$ ;  $t_{1/2}$ :  $r = 0.36, P = 0.02$ ). These correlations indicate faster gastric emptying  
255 was associated with greater liking for savoury foods. Liking fat bias was not significantly correlated  
256 with gastric emptying ( $P > 0.05$  for all).

257 Implicit wanting taste bias was not associated with gastric emptying ( $P > 0.05$  for all).  
258 However, implicit wanting fat bias was positively correlated with gastric emptying when fed ( $t_{1/2}$ :  $r$   
259  $= 0.37$ ,  $P = 0.01$ ), and 5-hours later when hungry ( $t_{lag}$ :  $r = 0.31$ ,  $P = 0.04$ ;  $t_{1/2}$ : **Figure 2b**) and the  
260 average implicit wanting fat bias ( $t_{1/2}$ :  $r = 0.40$ ,  $P < 0.01$ ). These findings collectively indicate  
261 slower gastric emptying was associated with greater implicit wanting for high fat foods.

262 To examine any influence of body composition on the relationships observed, partial  
263 correlations were also undertaken. The significant correlations reported between food reward  
264 profiles and gastric emptying remained significant after controlling for body composition (BMI or  
265 percent FM) ( $P < 0.05$  for all).

266

267 [Figure 2 About Here]

268

269

270

271 Regression analysis revealed associations of gastric emptying  $t_{1/2}$  with liking taste bias and  
272 implicit wanting fat bias were independent of each other and activity status (gastric emptying  $t_{1/2}$   
273 Model Adjusted  $R^2 = 0.37$ ,  $p < 0.01$ ; activity status  $\beta = 0.37$ ,  $P < 0.01$ ; liking taste bias  $\beta = 0.30$ ,  $P$   
274  $= 0.02$ ; wanting fat bias  $\beta = 0.28$ ,  $P = 0.03$ ). When BMI or percent FM were included in the same  
275 model, they did not contribute to any of the variance (BMI  $\beta = 0.01$ ,  $P = 0.99$ ; percent FM  $\beta = 0.00$ ,  
276  $P = 0.99$ ) and the observed associations remained significant, indicating they were independent of  
277 body fat.

## 278 Discussion

279 This is the first study to compare measures of food reward and gastric emptying between active  
280 versus inactive individuals. Our results demonstrate that food reward differs between active versus  
281 inactive men and suggests that gastric emptying could have a mechanistic role in ‘liking’ and  
282 ‘wanting’ processes of food reward.

283 Using a computer based assessment procedure, we observed that both explicit ‘liking’ and  
284 implicit ‘wanting’ differed between active and inactive men. Firstly, active men displayed a lower  
285 explicit liking for HFSA, LFSW and foods overall and showed a greater implicit wanting for LFSA  
286 in the fed state, compared to inactive men. Elevated ‘liking’ and ‘wanting’ for energy dense foods  
287 are considered psychological markers in individuals who are susceptible to overconsumption [31]  
288 and involve both conscious (subjective, explicit) and subconscious (automatic, implicit) processes  
289 [27], [32]. Indeed, one salient characteristic of individuals who binge eat appears to be the persistent  
290 preference for sweet foods in the presence and absence of hunger, which has been demonstrated  
291 under both laboratory and free-living conditions [33], using identical methodology as the present  
292 study. Dalton et al. [34] reported that binge eaters had a greater explicit ‘liking’ for HFSA foods  
293 and a greater implicit wanting for sweet foods in the fed state compared to non-binge eaters,  
294 suggesting these characteristics may represent a marker for susceptibility to overeat. The hedonic  
295 characteristics observed in binge-eaters are in contrast to the active individuals in our study. The  
296 hedonic characteristics observed in the active individuals including lower liking for foods and a  
297 greater implicit wanting for LFSA foods in the fed state could be one potential factor contributing to  
298 improved appetite and body weight regulation that has previously been documented in more active  
299 individuals [1], [3], [4], [6], [9].

300 We further observed that active men had a greater increase in ‘liking’ for all foods, in  
301 particular savoury foods between breakfast (fed state) and lunch (hungry state - 5h after breakfast)  
302 This is suggestive of a more sensitised appetite system in active compared to inactive men. ‘Liking’  
303 for food has previously been shown to be greater when individuals are in a hungry (3-4 hours  
304 postprandial) versus fed state [27], whereas this effect is reduced in individuals with higher binge  
305 eating scores [35]. The greater increase in liking of savoury foods observed between the fed and  
306 hungry states in active individuals may indicate that hedonic responses function more in response to  
307 nutritional need-state in habitual exercisers compared to inactive individuals.

308 Interestingly, when compared to savoury foods, liking for sweet foods increased to a lesser  
309 extent between the fed (post-breakfast) and hungry (pre-lunch) state and this was apparent in both  
310 active and inactive men. It has previously been shown that ‘liking’ for sweet foods does not  
311 increase to the same extent as fatty foods in hungry compared to fed conditions [27]. Moreover,

312 following a 24h fast, Cameron et al. [36] reported that ‘liking’ for savoury foods was greater in the  
313 hungry versus fed state, whereas ‘liking’ for sweet foods was unchanged. While historically,  
314 hedonic processes have been viewed as a function of nutritional need-state [27] - whereby in a state  
315 of depletion, the hedonic response (experienced palatability or pleasure) to foods is enhanced and  
316 when replete, the hedonic effect is reduced [37] - it is increasingly recognised that palatable sugar-  
317 and fat-rich foods can override satiation and promote overeating [38]. Hedonic responses to  
318 palatable sweet foods may therefore be less dependent on sensations of satiation and satiety than  
319 savoury foods. This may in part explain the blunted change in liking for sweet foods between the  
320 fed (post-breakfast) and hungry (pre-lunch) state that we and others [27], [36] have reported.

321 As could be expected, body composition differed significantly between active and inactive  
322 men and therefore could provide one plausible mechanism for the differences in food reward  
323 observed. Indeed, after adjusting for body fat, no significant differences in hedonic processes were  
324 observed in the hungry state between active and inactive groups, while in the fed state the higher  
325 liking for HFSA foods observed in inactive individuals no longer remained significant. This  
326 suggests that factors other than physical activity status, including body fat may contribute to  
327 hedonic processes in the hungry state and liking for high-fat foods in the fed state. Others have  
328 recently reported positive relationships between fat mass and wanting for high fat foods in  
329 particular, in overweight and obese individuals [22]. Nevertheless, the majority of differences  
330 observed between active and inactive men in the present study including liking for foods overall,  
331 liking for LFSW foods and implicit wanting for LFSA foods in the fed state, along with increases in  
332 liking for foods overall and LFSA foods in the postprandial interval, remained significant after  
333 adjusting for differences in body fat. These findings suggest physical activity status influences these  
334 hedonic processes, independent of body fat.

335 Differences in gut physiology could be one potential mechanism contributing to the  
336 differences in food reward we observed between active and inactive individuals in the present  
337 study. The inactive individuals had a slower gastric emptying and slower gastric emptying was  
338 associated with a higher fat mass as we recently reported [17]. A major aim of the present  
339 investigation was to examine potential associations between hedonic processes and gastric  
340 emptying. The phenomenon that information from the gut during a meal leads not only to decreased  
341 hunger and satiation but also to a feeling of reward is certainly not new [39], [40]. However, the  
342 signals and mechanisms involved remain to be fully elucidated. In our cross-sectional analyses of  
343 active and inactive men, we found that faster gastric emptying was associated with greater liking of  
344 savoury food whereas slower gastric emptying was associated with greater implicit wanting for high  
345 fat food. These relationships were independent of each other activity status and body fat and suggest  
346 that gastric emptying may have a mechanistic role in food reward. Our finding that faster gastric

347 emptying was associated with enhanced ‘explicit’ liking for savoury foods and with an increase in  
348 liking for savoury foods between the fed and hungry state is consistent with the view that hedonic  
349 responses to savoury foods may be associated with nutritional-need state i.e. the less food remaining  
350 in the stomach the greater the ‘liking’ for (savoury) foods.

351 Interestingly, in contrast to ‘liking’ for savoury foods and to this view, greater implicit  
352 ‘wanting’ for high fat foods was associated with slower gastric emptying. To the best of our  
353 knowledge relationships between ‘liking’ and ‘wanting’ and gastric emptying have not been  
354 previously documented in humans. However, Miras et al. [41] demonstrated that gastric bypass  
355 altered the reinforcing effects of sweet and fatty candy but not of vegetables, suggesting that gastric  
356 bypass results in the selective reduction of the reward value of a sweet/fat taste [42]. A reduced  
357 hedonic response and preference for high energy/fat foods has been increasingly documented in  
358 animal models and humans after gastric bypass [41], [43], [44] - a procedure which significantly  
359 accelerates the delivery of nutrients to the distal small intestine and alters gut hormone responses,  
360 but this has not been observed after gastric banding [43], [44] - a procedure which does not change  
361 the emptying rate or gut hormonal responses [15]. These alterations in gut physiology specific to  
362 gastric bypass may have a mechanistic role in the reduced hedonic response to high fat foods -  
363 findings which highlight the importance of the gut-brain axis in reward-based eating behaviour [43].

364 Our findings of a faster emptying rate being associated with a reduced implicit wanting for  
365 high fat foods are consistent with these observations after gastric bypass. One explanation may be  
366 that a slower gastric emptying would mean a reduced homeostatic drive and this could provide  
367 more opportunity for hedonic motivation to influence behavior, especially responses to high fat  
368 palatable foods. Additionally, the observed associations could be mediated by changes in gut  
369 hormones or dopamine release, both of which have been associated with the rate of gastric  
370 emptying [19], [45], [46], [47], [48], [49] and also linked to food reward [21]. The rate of gastric  
371 emptying plays an important role in the release of intestinal satiation peptides [49], [50], [51].  
372 Moreover, in animals differences in gastric emptying rate are comparable to differences in  
373 dopamine efflux [45] and evidence suggests that stimulation of the GI tract with nutrients is  
374 sufficient to stimulate the release of dopamine in brain circuits controlling food intake [19]. A  
375 slower emptying rate could contribute to a blunted gut hormone or dopamine release and  
376 impairments in these pathways associated with food reward and control. As such the hedonic  
377 response to food could disrupt or override homeostatic signals of satiety.

378 The limitations of the present study should be considered. Given the cross-sectional nature  
379 of the study, causal relationships between gastric and hedonic responses are not possible to establish  
380 and this is an area that requires further investigation. Moreover, it is important to acknowledge that  
381 a wide range of genetic, environmental, psychological, and physiological factors contribute to the

382 short and long term control of food intake [52]. Gastric emptying and gut hormones have an  
383 integrative relationship in appetite control and gut hormones in turn may influence fatty acid  
384 detection or perception [44]. Characterising a combination of GI factors may therefore provide  
385 further mechanistic insight into differences in food reward with physical activity level. Furthermore,  
386 whether food reward differs between active and inactive men in response to other types of test meal  
387 as a result of sensory-specific satiety or if measured earlier in the postprandial period (e.g. at 3h)  
388 when hunger ratings are lower, is of interest. Findings may also be different in females and this is  
389 another area that requires further study.

390 In conclusion, these data demonstrate that in addition to differences in gastric emptying,  
391 habitual exercisers are characterised by different hedonic responses for high fat or low fat and sweet  
392 or savoury foods, compared to inactive individuals. These processes do not appear to operate  
393 independently. Interactions between the gut and hedonic aspects of appetite control could play a key  
394 role in the impact of habitual exercise on energy balance.

395

#### 396 **Acknowledgements**

397 We are grateful to the participants in the study. This study was supported by a Queensland  
398 University of Technology Postgraduate Research Award (QUTPRA).

399

#### 400 **Financial Support**

401 This study was supported by a Queensland University of Technology Postgraduate Research Award  
402 (QUTPRA).

403

#### 404 **Conflicts of Interest**

405 The authors have no conflicts of interest to disclose.

406

#### 407 **Authorship**

408 KMH, GF, NMB and NAK contributed to the design of the study; KMH collected the data, contributed to  
409 data analysis and drafted the manuscript; GF provided the experimental task, performed data and  
410 statistical analysis and contributed to critical revision of the manuscript. NMB and NAK provided  
411 critical revision of the manuscript. All authors read and approved the final manuscript.

412 **References**

- 413 [1] Hill JO, Wyatt HR (2005) Role of physical activity in preventing and treating  
414 obesity. *J Appl Physiol* **99**, 765-770.
- 415 [2] Hill JO (2006) Understanding and Addressing the Epidemic of Obesity: An  
416 Energy Balance Perspective. *Endocr Rev* **27**, 750-761.
- 417 [3] Mayer J, Roy P, Mitra KP (1956) Relation between caloric intake, body weight,  
418 and physical work: studies in an industrial male population in West Bengal. *Am J Clin*  
419 *Nutr* **4**, 169-175.
- 420 [4] Long SJ, Hart K, Morgan LM (2002) The ability of habitual exercise to influence  
421 appetite and food intake in response to high- and low-energy preloads in man. *Br J*  
422 *Nutr* **87**, 517-523.
- 423 [5] Martins C, Truby H, Morgan LM (2007) Short-term appetite control in response to  
424 a 6-week exercise programme in sedentary volunteers. *Br J Nutr* **98**, 834-842.
- 425 [6] Van Walleghen EL, Orr JS, Gentile CL et al. (2007) Habitual physical activity  
426 differentially affects acute and short-term energy intake regulation in young and older  
427 adults. *Int J Obes* **31**, 1277-1285.
- 428 [7] Martins C, Kulseng B, Rehfeld JF et al. (2012) Impact of Chronic Exercise on  
429 Appetite Control in Overweight and Obese Individuals. *Med Sci Sports Exerc* **45**,  
430 805-812.
- 431 [8] Beaulieu K, Hopkins M, Blundell J et al. (2016) Does Habitual Physical Activity  
432 Increase the Sensitivity of the Appetite Control System? A Systematic Review. *Sports*  
433 *Med*, [In Press].
- 434 [9] Blundell JE (2011) Physical activity and appetite control: can we close the energy  
435 gap? *Nutr Bull* **36**, 356-366.
- 436 [10] Blundell J (1991) Pharmacological approaches to appetite suppression. *Trends*  
437 *Pharmacol Sci* **12**, 147-157.
- 438 [11] Blundell JE, King NA (1996) Overconsumption as a cause of weight gain:  
439 Behavioural-physiological interactions in the control of food intake (appetite). *CIBA*  
440 *Foundation Symposia*, 138-158.
- 441 [12] Finlayson G, Bryant E, Blundell JE et al. (2009) Acute compensatory eating  
442 following exercise is associated with implicit hedonic wanting for food. *Physiol*  
443 *Behav* **97**, 62-67.



- 444 [13] Finlayson G, Caudwell P, Gibbons C et al. (2011) Low Fat Loss Response after  
445 Medium-Term Supervised Exercise in Obese Is Associated with Exercise-Induced  
446 Increase in Food Reward. *J Obes*, pii: 615624.
- 447 [14] Blundell JE, Caudwell P, Gibbons C et al. (2012) Role of resting metabolic rate  
448 and energy expenditure in hunger and appetite control: a new formulation. *Dis Model*  
449 *Mech* **5**, 608-613.
- 450 [15] Horner KM, Byrne NM, Cleghorn GJ et al. (2011) The effects of weight loss  
451 strategies on gastric emptying and appetite control. *Obes Rev* **12**, 935-951.
- 452 [16] Martins C, Kulseng B, King NA et al. (2010) The Effects of Exercise-Induced  
453 Weight Loss on Appetite-Related Peptides and Motivation to Eat. *J Clin Endocrinol*  
454 *Metab* **95**, 1609-1616.
- 455 [17] Horner KM, Byrne NM, Cleghorn GJ et al. (2015) Influence of Habitual  
456 Physical Activity on Gastric Emptying in Healthy Males and Relationships with Body  
457 Composition and Energy Expenditure. *Br J Nutr* **3**, 489-96 .
- 458 [18] Ren X, Ferreira JG, Zhou L et al. (2010) Nutrient Selection in the Absence of  
459 Taste Receptor Signaling. *J Neurosci* **30**, 8012-8023.
- 460 [19] de Araujo IE, Ferreira JG, Tellez LA et al. (2012) The gut-brain dopamine axis:  
461 A regulatory system for caloric intake. *Physiol Behav* **106**, 394-399.
- 462 [20] Tellez LA, Medina S, Han W et al. (2013) A Gut Lipid Messenger Links Excess  
463 Dietary Fat to Dopamine Deficiency. *Science* **341**, 800-802.
- 464 [21] Sun X, Veldhuizen MG, Wray AE et al. (2014) The neural signature of satiation  
465 is associated with ghrelin response and triglyceride metabolism. *Physiol Behav* **136**,  
466 63-73.
- 467 [22] Hopkins M, Gibbons C, Caudwell P et al. (2014) Fasting Leptin Is a Metabolic  
468 Determinant of Food Reward in Overweight and Obese Individuals during Chronic  
469 Aerobic Exercise Training. *Int J Endocrinol*, Article ID 323728, 8 pages, 2014.
- 470 [23] O'Neill BV, Bullmore ET, Miller S et al. (2012) The relationship between fat  
471 mass, eating behaviour and obesity-related psychological traits in overweight and  
472 obese individuals. *Appetite* **59**, 656-661.
- 473 [24] Horner KM, Byrne NM, Cleghorn GJ et al. (2013) Reproducibility of gastric  
474 emptying in overweight and obese males. *Clin Nutr*, **33**, 684-688.
- 475 [25] Ghos YF, Maes BD, Geypens BJ et al. (1993) Measurement of gastric emptying  
476 rate of solids by means of a carbon-labeled octanoic acid breath test.  
477 *Gastroenterology* **104**, 1640-1647.

- 478 [26] Gibbons C, Caudwell P, Finlayson G et al. (2011) Validation of a new hand-held  
479 electronic data capture method for continuous monitoring of subjective appetite  
480 sensations. *Int J Behav Nutr Phys Act* **8**, 57.
- 481 [27] Finlayson G, King N, Blundell J (2008) The role of implicit wanting in relation  
482 to explicit liking and wanting for food: Implications for appetite control. *Appetite* **50**,  
483 120-127.
- 484 [28] Griffioen-Roose S, Finlayson G, Mars M et al. (2010) Measuring food reward  
485 and the transfer effect of sensory specific satiety. *Appetite* **55**, 648-655.
- 486 [29] Griffioen-Roose S, Mars M, Finlayson G et al. (2011) The effect of within-meal  
487 protein content and taste on subsequent food choice and satiety. *Br J Nutr* **106**, 779-  
488 788.
- 489 [30] French SA, Mitchell NR, Finlayson G et al. (2014) Questionnaire and laboratory  
490 measures of eating behavior. Associations with energy intake and BMI in a  
491 community sample of working adults. *Appetite* **72**, 50-58.
- 492 [31] Finlayson G, Dalton M (2012) Hedonics of Food Consumption: Are Food Liking  
493 and Wanting Viable Targets for Appetite Control in the Obese? *Current Obesity*  
494 *Reports* **1**, 42-49.
- 495 [32] Finlayson G, King N, Blundell J (2007) Liking vs. wanting food: importance for  
496 human appetite control and weight regulation. *Neurosci Biobehav Rev* **31**, 987-1002.
- 497 [33] Dalton M, Finlayson G (2014) Psychobiological examination of liking and  
498 wanting for fat and sweet taste in trait binge eating females. *Physiol Behav* **136**, 128-  
499 134.
- 500 [34] Dalton M, Blundell J, Finlayson G (2013) Effect of BMI and binge eating on  
501 food reward and energy intake: further evidence for a binge eating subtype of obesity.  
502 *Obes Facts* **6**, 348-359.
- 503 [35] Dalton M (2013) Biopsychological investigation of hedonic processes in  
504 individuals susceptible to overeating: role of liking and wanting in trait binge eating.  
505 University of Leeds.
- 506 [36] Cameron JD, Goldfield GS, Finlayson G et al. (2014) Fasting for 24 Hours  
507 Heightens Reward from Food and Food-Related Cues. *PLoS ONE* **9**, e85970.
- 508 [37] Cabanac M (1989) Maximization of pleasure, the answer to a conflict of  
509 motivations. *Comptes Rendus de l'Academics des Sciences Serie III* **409**, 397-402.
- 510 [38] Sclafani A (2013) Gut-brain nutrient signaling. Appetition vs. satiation. *Appetite*  
511 **71**, 454-458.

- 512 [39] Berthoud HR (2008) Vagal and hormonal gut-brain communication: from  
513 satiation to satisfaction. *Neurogastroenterol Motil* **20**, 64-72.
- 514 [40] Sclafani A (2004) Oral and postoral determinants of food reward. *Physiol Behav*  
515 **81**, 773-779.
- 516 [41] Miras AD, Jackson RN, Jackson SN et al. (2012) Gastric bypass surgery for  
517 obesity decreases the reward value of a sweet-fat stimulus as assessed in a progressive  
518 ratio task. *Am J Clin Nutr* **96**, 467-473.
- 519 [42] Astrup A (2012) Weight loss produced by gastric bypass surgery: more gut  
520 feelings hit the brain. *Am J Clin Nutr* **96**, 457-458.
- 521 [43] Scholtz S, Miras AD, Chhina N et al. (2013) Obese patients after gastric bypass  
522 surgery have lower brain-hedonic responses to food than after gastric banding. *Gut*. **6**,  
523 891-902.
- 524 [44] le Roux CW, Bueter M, Theis N et al. (2011) Gastric bypass reduces fat intake  
525 and preference. *Am J Physiol Regul Integr Comp Physiol* **301**, R1057-R1066.
- 526 [45] Ferreira JIG, Tellez LA, Ren X et al. (2012) Regulation of fat intake in the  
527 absence of flavour signalling. *J Physiol* **590**, 953-972.
- 528 [46] Vazquez Roque MI, Camilleri M, Stephens DA et al. (2006) Gastric  
529 sensorimotor functions and hormone profile in normal weight, overweight, and obese  
530 people. *Gastroenterology* **131**, 1717-1724.
- 531 [47] Schirra J, Katschinski M, Weidmann C et al. (1996) Gastric emptying and  
532 release of incretin hormones after glucose ingestion in humans. *J Clin Invest* **97**, 92-  
533 103.
- 534 [48] French SJ, Murray B, Rumsey RDE et al. (1993) Is cholecystokinin a satiety  
535 hormone? Correlations of plasma cholecystokinin with hunger, satiety and gastric  
536 emptying in normal volunteers. *Appetite* **21**, 95-104.
- 537 [49] Meyer-Gerspach AC, Wolnerhanssen B, Beglinger B et al. (2014) Gastric and  
538 intestinal satiation in obese and normal weight healthy people. *Physiol Behav* **129**,  
539 265-271.
- 540 [50] Steinert RE, Meyer-Gerspach AC, Beglinger C (2012) The role of the stomach in  
541 the control of appetite and the secretion of satiation peptides. *Am J Physiol*  
542 *Endocrinol Metab* **302**, E666-E673.
- 543 [51] Pilichiewicz AN, Chaikomin R, Brennan IM et al. (2007) Load-dependent  
544 effects of duodenal glucose on glycemia, gastrointestinal hormones,

545 antropyloroduodenal motility, and energy intake in healthy men. Am J Physiol  
546 Endocrinol Metab **293**, 743-753.  
547 [52] de Castro JM (2004) Genes, the environment and the control of food intake. Br J  
548 Nutr **92**, S59-S62.

549

550

551 **Table 1.** Photographic food stimuli used in the food preference and 'liking' and  
 552 'wanting' computer task (grouped by food category)

HFSA	LFSA	HFSW	LFSW
Chips (fries)	Tomatoes	Doughnuts	Jelly beans
Pizza	Chicken	Chocolate	Juice
Meat pie	Rice	Milkshake	Mixed fruits
Swiss cheese	Boiled potatoes	Ice-cream	Apple

553 HFSA, high fat savoury; LFSA, low fat savoury; HFSW, high fat sweet; LFSW, low fat sweet.

554

555 **Table 2.** Participants' anthropometric, body composition and energy expenditure  
 556 characteristics

	Inactive (n=22)		Active (n=22)		P-value
	Mean	SEM	Mean	SEM	
Age (years)	30.5	1.82	29.4	1.67	0.56
Height (m)	1.78	0.02	1.80	0.02	0.55
Weight (kg)	87.1	3.36	79.2	2.50	0.07
BMI (kg/m <sup>2</sup> )	27.4	0.89	24.5	0.55	<b>0.02</b>
Body Composition					
FM (%)	26.2	1.85	14.3	1.24	<b>&lt;0.001</b>
FFM (kg)	63.3	1.74	67.7	1.90	0.10
Activity EE (kcal/day) <sup>1</sup>	525	42	709	51	<b>&lt;0.01</b>
Total EE (kcal/day) <sup>1</sup>	2665	95	2890	92	0.09

557 Values are means ( $\pm$  SEM).

558 <sup>1</sup>Energy expenditure data refers to n=19 in Inactive group.

559 BMI, body mass index; FM, fat mass; FFM, fat free mass, EE, energy expenditure.

560

561 **Table 3.** Mean ( $\pm$ SEM) explicit liking and implicit wanting in fed (post-breakfast)  
 562 and hungry (pre-lunch 5h later) states for different food categories in active (n = 22)  
 563 compared to inactive (n = 22) men.

	Inactive (n = 22)	Active (n = 22)	Effect of Activity P-value (without adj.)	Main Effect %FM P-value	Effect of Activity after adjustment for %FM P-value
<b>Fed state</b>					
Liking HFSA	35.66 (4.65)	21.86 (4.05)	<b>0.03</b>	0.98	0.09
Liking HFSW	45.51 (4.64)	32.32 (5.03)	<b>0.06</b>	0.99	0.15

Liking LFSA	30.98 (4.05)	25.57 (4.42)	0.37	0.75	0.38
Liking LFSW	55.68 (3.65)	40.61 (4.37)	<b>0.01</b>	0.26	<b>&lt;0.01</b>
Liking All	41.96 (3.34)	30.10 (3.67)	<b>0.02</b>	0.67	<b>0.04</b>
Wanting HFSA	-7.14 (7.05)	-5.47 (7.04)	0.87	0.68	0.70
Wanting HFSW	10.03 (5.34)	-4.30 (7.86)	0.14	0.87	0.22
Wanting LFSA	-27.42 (5.88)	-5.61 (6.33)	<b>0.02</b>	0.35	<b>0.02</b>
Wanting LFSW	24.52 (6.49)	15.38 (6.33)	0.32	0.24	0.13

**Hungry state**

Liking HFSA	62.01 (4.14)	62.5 (4.93)	0.94	0.75	0.79
Liking HFSW	59.72 (4.08)	50.35 (6.42)	0.23	0.39	0.70
Liking LFSA	52.53 (3.65)	60.09 (4.11)	0.18	0.91	0.34
Liking LFSW	56.26 (3.54)	48.95 (3.67)	0.16	0.57	0.15
Liking All	57.63 (2.86)	55.47 (3.48)	0.63	0.78	0.75
Wanting HFSA	27.39 (6.00)	26.79 (7.17)	0.95	0.58	0.69
Wanting HFSW	-9.30 (5.14)	-21.18 (6.85)	0.17	0.19	0.82
Wanting LFSA	-4.06 (3.77)	12.24 (5.99)	<b>0.03</b>	0.51	0.19
Wanting LFSW	-14.03 (4.51)	-17.85 (5.15)	0.58	0.85	0.59

564 All, all categories of food combined; LFSA, low fat savoury; HFSA, high fat savoury, LFSW, low fat  
565 sweet; HFSW, high fat sweet.

566

567 **Table 4.** Mean ( $\pm$ SEM) changes in explicit liking and implicit wanting for different  
568 food categories from fed (post-breakfast) to hungry (pre-lunch 5h later) states in  
569 active (n = 22) compared to inactive (n = 22) men.

	Inactive (n = 22)	Active (n = 22)	Effect of Activity P-value (without adj.)	Main Effect %FM P-value	Effect of Activity after adjustment for %FM P-value
<b>Change from fed to hungry state</b>					
Liking HFSA	26.35 (4.11)	40.64 (5.13)	<b>0.04</b>	0.73	0.07
Liking HFSW	14.22 (4.36)	18.00 (5.26)	0.58	0.33	0.30
Liking LFSA	21.56 (2.87)	34.52 (4.49)	<b>0.02</b>	0.81	<b>0.05</b>
Liking LFSW	0.58 (2.99)	8.34 (5.03)	0.19	0.56	0.17
Liking All	15.68 (2.58)	25.38 (4.02)	<b>0.05</b>	0.48	<b>0.05</b>
Wanting HFSA	34.53 (7.31)	32.27 (5.65)	0.81	0.31	0.41
Wanting HFSW	-19.33 (6.19)	-16.88 (5.18)	0.76	0.11	0.21
Wanting LFSA	23.36 (5.47)	17.85 (5.23)	0.47	0.09	0.10
Wanting LFSW	-38.56 (7.49)	-33.24 (6.15)	0.59	0.31	0.34

570 All, all categories of food combined; LFSA, low fat savoury; HFSA, high fat savoury, LFSW, low fat  
571 sweet; HFSW, high fat sweet.  
572  
573

574 **Figure Legends**

575 Figure 1. Mean changes in explicit liking from breakfast to lunch (5h later) in active  
576 (n = 22) compared to inactive (n = 22) men, as assessed using the LFPQ.  
577 All, all categories of food combined; LFSA, low fat savoury; HFSA, high fat savoury,  
578 LFSW, low fat sweet; HFSW, high fat sweet.  
579 Error bars indicate SEM. \* p < 0.05.

580

581 Figure 2. (a) Scatter plot illustrating slower gastric emptying (i.e. longer gastric  
582 emptying  $t_{1/2}$ ) is associated with greater liking for sweet compared to savoury foods at  
583 pre-lunch. A positive taste bias score = liking for sweet foods > savoury foods. A  
584 negative taste bias score = liking for savoury foods > sweet foods. Partial correlations  
585 showed the relationship remained significant after adjusting for BMI (r = 0.43, P <  
586 0.01) or percent FM (r = 0.38, P = 0.01). Removal of the extreme individual point for  
587 gastric emptying  $t_{1/2}$  (value: 231min) reduced r from 0.43 to r = 0.30, P = 0.04. (b)  
588 Scatter plot illustrating slower gastric emptying ( $t_{1/2}$ ) is associated with greater  
589 implicit wanting for high fat compared to low fat foods at pre-lunch. A positive fat  
590 bias score = wanting for high fat foods > low fat foods. A negative fat bias score =  
591 wanting for low fat foods > high fat foods. Partial correlations showed the  
592 relationship remained significant after adjusting for BMI (r = 0.37, P = 0.01) or  
593 percent FM (r = 0.32, P = 0.04). Removal of the extreme individual point for gastric  
594 emptying  $t_{1/2}$  (value: 231min) increased r from 0.36 to r = 0.43, P < 0.01.  
595 n = 44 for both.

596