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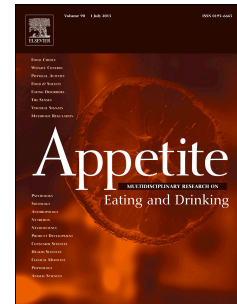
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1 **An acute bout of cycling does not induce**
2 **compensatory responses in pre-menopausal women**
3 **not using hormonal contraceptives**

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30

31 **Abstract**

32 There is a clear need to improve understanding of the effects of physical activity and
33 exercise on appetite control. Therefore, the acute and short-term effects (three days)
34 of a single bout of cycling on energy intake and energy expenditure were examined in
35 women not using hormonal contraceptives. Sixteen active ($n = 8$) and inactive ($n = 8$)
36 healthy pre-menopausal women completed a randomised crossover design study with
37 two conditions (exercise and control). The exercise day involved cycling for one hour
38 (50% of maximum oxygen uptake) and resting for two hours, whilst the control day
39 comprised three hours of rest. On each experimental day participants arrived at the
40 laboratory fasted, consumed a standardised breakfast and an *ad libitum* pasta lunch.
41 Food diaries and combined heart rate-accelerometer monitors were used to assess
42 free-living food intake and energy expenditure, respectively, over the subsequent
43 three days. There were no main effects or condition (exercise vs control) by group
44 (active vs inactive) interaction for absolute energy intake ($P > 0.05$) at the *ad libitum*
45 laboratory lunch meal, but there was a condition effect for relative energy intake ($P =$
46 0.004 , $\eta_p^2 = 0.46$) that was lower in the exercise condition (1417 ± 926 kJ vs. $2120 \pm$
47 923 kJ). Furthermore, post-breakfast satiety was higher in the active than in the
48 inactive group ($P = 0.005$, $\eta_p^2 = 0.44$). There were no main effects or interactions ($P >$

49 0.05) for mean daily energy intake, but both active and inactive groups consumed less
50 energy from protein ($14 \pm 3\%$ vs. $16 \pm 4\%$, $P = 0.016$, $\eta_p^2 = 0.37$) and more from
51 carbohydrate ($53 \pm 5\%$ vs. $49 \pm 7\%$, $P = 0.031$, $\eta_p^2 = 0.31$) following the exercise
52 condition. This study suggests that an acute bout of cycling does not induce
53 compensatory responses in active and inactive women not using hormonal
54 contraceptives, while the stronger satiety response to the standardised breakfast meal
55 in active individuals adds to the growing literature that physical activity helps
56 improve the sensitivity of short-term appetite control.

57

58 **Keywords:** Food intake; Energy expenditure; Appetite; Active; Inactive, Exercise.

59 **Introduction**

60 As a readily modifiable component of energy balance, exercise is a commonly
61 promoted strategy for weight management. While some have questioned the role of
62 exercise (without dietary restriction) as a means of eliciting weight loss (1), exercise
63 appears to play an important role in the prevention of initial weight gain and the
64 promotion of successful weight loss maintenance (2). However, it is becoming clear
65 that marked heterogeneity exists in body mass responses to exercise (and other
66 lifestyle, pharmacological and surgical) interventions designed to promote weight loss
67 (3). High inter-individual variability could be explained by physiological and
68 behavioural compensatory responses in energy intake and/or non-exercise energy
69 expenditure (4).

70 Based on the work of Jean Mayer (5), research has started to examine how
71 habitual physical activity moderates the sensitivity of short-term appetite control. A J-
72 shaped relationship between physical activity and energy intake has been proposed

73 (6), with high levels of habitual physical activity associated with stronger homeostatic
74 appetite control while low levels of physical activity are thought to be associated with
75 dysregulated appetite (7). Despite this, few studies have directly compared the effects
76 of acute exercise on appetite between active and inactive individuals (8-14), and
77 studies typically only examine the impact of a bout of exercise on appetite and food
78 intake at the subsequent meal or over the remainder of the day (8, 9, 12, 13, 15). This
79 is of importance as a 'lag' in corrective responses elicited by acute energy deficit or
80 surfeit has been noted. For example, Bray et al. (16) reporting that compensatory
81 changes in EI are evident 2-5 days after dietary manipulation of energy intake, while
82 Edholm (17) also reported a 2-day lag between increased daily energy expenditure
83 and subsequent increases in daily energy intake. However, a corrective lag in energy
84 intake or energy expenditure has not always been reported when one component of
85 energy balance is perturbed (18).

86 There is also a paucity of studies focusing specifically on the appetite
87 responses to exercise in women, but existing studies typically reported no changes in
88 hunger and/or energy intake (19). However, whether sex differences exist in the
89 appetitive and body mass responses to exercise has been debated (20), and
90 inconsistency in these sex-based responses may in part relate to the lack of control of
91 appetite-modulating variables such as menstrual cycle, menstrual symptoms or use of
92 hormonal contraceptives. As hormonal contraceptive use is rarely identified, this
93 limits understanding of how such medication moderates the impact of exercise on
94 appetite control. Our previous study examining women taking oral contraceptives (11)
95 demonstrated there were no significant differences in energy intake over the four days
96 in active participants. However, there was a suppression of energy intake on the first
97 day after the exercise experimental day compared with the same day of the control

98 condition in inactive participants. As a follow on, this study aimed to examine the
99 immediate and short-term effects (i.e. subsequent three days) of a single bout of
100 cycling on appetite, energy intake and energy expenditure in physically active and
101 inactive pre-menopausal women not taking hormonal contraceptives.

102

103 **Material and methods**

104 **Participants**

105 Twenty-three healthy pre-menopausal women not taking oral contraceptives
106 volunteered, but seven participants withdrew because of time constraints. Therefore,
107 16 active ($n = 8$; age 21.9 ± 4.0 years; Body Mass Index (BMI) $22.2 \pm 2.0 \text{ kg.m}^{-2}$) and
108 inactive ($n = 8$; age 24.5 ± 3.5 years; BMI $23.0 \pm 3.1 \text{ kg.m}^{-2}$) women completed the
109 study. Participants had regular menstrual cycles (21-35 days), stable body mass (± 2
110 kg during the previous six months), no history of cardiovascular or metabolic
111 diseases, were non-smokers and not taking medication, pregnant or lactating.
112 Participants were blinded to the true purpose of the study (i.e. advertised as effects of
113 food and exercise on mood) to minimise participant-expectancy effects. The study
114 was approved by the Faculty of Health and Wellbeing Research Ethics Committee,
115 Sheffield Hallam University and all participants provided written informed consent.

116 Participants were categorised as active and inactive according to their self-
117 reported weekly physical activity (Godin Leisure-Time Exercise Questionnaire (21)).
118 Active participants engaged in regular exercise and met the minimum PA guidelines
119 (22) whilst the inactive did not. A posteriori analysis of the combined heart rate and
120 accelerometer (Actiheart) data was used to confirm the veracity of the self-reported

121 measure. Calculated Physical Activity Level (PAL) (total daily energy expenditure
122 divided by basal metabolic rate) was 2.04 ± 0.23 (range 1.72-2.30) for the active and
123 1.49 ± 0.16 (range 1.24-1.74) for the inactive group.

124 **Design and procedures**

125 After completing preliminary assessment, participants undertook two, four-
126 day experimental conditions (one laboratory based and 3 free-living days) in a
127 randomised, crossover fashion with approximately four weeks between each condition
128 (participants' menstrual cycle defined exact time). Experimental laboratory days were
129 scheduled on the same day of the week during the early to mid-follicular phase (days
130 5-9) of the menstrual cycle. Participants recorded their food intake for two days
131 before the first experimental condition and replicated this intake before the second
132 experimental condition, and were asked to abstain from caffeine, alcohol and vigorous
133 physical activity 24 hours before each experimental condition.

134 Experimental laboratory days started between 8.00 and 9.30am with
135 participants having fasted for 10-hour overnight (Figure 1). The day commenced with
136 a standard breakfast, followed by either 3 hours of rest (control condition- CON) or
137 two hours of rest separated by one hour of cycling at 50% of maximal oxygen
138 consumption (exercise condition- EX). Following this 3 hour period, participants
139 consumed an *ad libitum* lunch and were then provided with a combined heart rate and
140 accelerometer monitor (Actiheart, Cambridge Neurotechnology, Cambridge, UK) and
141 a food diary that were used to estimate energy intake and expenditure over the
142 following 3 days.

143 Preliminary Assessment**144 Anthropometry**

145 Body mass (model 424; Weylux; Hallamshire Scales Ltd, Sheffield, UK) and
146 stature (Harpenden, Holtain Ltd, Crymmych, Wales) were measured to the nearest
147 0.05 kg and 0.01 m, respectively, and BMI was calculated from the above measures.
148 Percentage body fat was determined via bioelectrical impedance (InBody720,
149 Derwent Healthcare, Newcastle, UK) according to the manufacturer's instructions.
150 These measurements were performed with participants fasted for at least two hours
151 and having refrained from undertaking exercise and voiding beforehand.

152 Submaximal cycling test

153 A submaximal cycling test was undertaken to determine the relationship
154 between oxygen consumption and exercise intensity in order to determine the
155 workload needed to elicit 50% of maximum oxygen uptake during the exercise
156 condition. After 15 minutes of warm-up, participants completed four, 4-min exercise
157 stages at 60 rpm using a Monark cycle ergometer (model 874E, Monark, Sweden).
158 Initial intensity was set according activity status (inactive participants: 60W; active:
159 60 or 90W) with 30W increases at the end of each stage. Oxygen consumption and
160 carbon dioxide production were determined using a breath-by-breath gas analysis
161 system (CPX Ultima, Medical Graphics, Gloucester, UK), which was calibrated
162 before each test using a 3-liter syringe and gases of known concentration. Heart rate
163 was assessed continuously during exercise (Polar F4, Kempele, Finland).

164 Maximal cycling test

165 A maximal cycling test was also undertaken to determine the participants'
166 maximal oxygen consumption in which participants cycled continuously through 3-
167 min stages until volitional exhaustion. Initial exercise intensity was equal to that of
168 the last stage of the submaximal cycling test and workload increased by 30W at the
169 end of each stage. Participants were given strong verbal encouragement throughout
170 and the test which ended when participants could not continue or failed to maintain
171 the pedalling rate for 20 consecutive seconds. Cycling-specific maximal oxygen
172 consumption was confirmed as attained, when two or more of the following criteria
173 were met: heart rate within 15 beats.min⁻¹ of predicted maximum heart rate (205.8-
174 0.685(age)) (23), an increase in oxygen consumption ($\dot{V}O_2$) of less than 100 ml.min⁻¹
175 despite an increase in exercise intensity, and a respiratory exchange ratio (RER)
176 greater than 1.15.

177 Experimental Days**178 Breakfast meal**

179 Upon arrival, participants consumed a breakfast meal comprising a bowl of
180 cereal (CornFlakes, Kellogg's, UK) with fresh semi-skimmed milk (Sainsbury, UK)
181 and a glass of orange juice (Drink Fresh, DCB Foodservice, UK) with a mean energy
182 content of 12.8% from protein, 76.5% from carbohydrate and 9.6% from fat.
183 Breakfast was standardised between conditions, and quantities determined based on
184 individual body mass (23.6 kJ/kg of body mass) (10, 11). Participants ate individually
185 in air-conditioned testing cubicles equipped with Sussex Ingestion Pattern Monitors
186 (SIPM).

187 Exercise and control periods

188 Following breakfast consumption, participants rested for 60 minutes in a
189 seated position. Participants were allowed to read and undertake work in a laboratory
190 devoid of any food-related cues. During CON, participants remained at rest for a
191 further 120 minutes (180 minutes in total). However, during EX, participants cycled
192 at 50% of maximal oxygen consumption for 60 minutes, and then rested for 60
193 minutes (seated devoid of any food-related cues). During the exercise bout and
194 equivalent period of rest during CON, indirect calorimetry was used to estimate
195 energy expenditure (and ensure participants exercised at the target intensity during
196 EX) (24). Expired air was collected (Harvard Apparatus, Kent, UK) and analysed
197 (GIR250 combined O₂/CO₂ gas analyser, Hitech Instruments, Luton, UK) at 15 min
198 intervals using Douglas Bags during the 60 minute period of exercise or rest.

199 Ad libitum lunch meal

200 An *ad libitum* lunch meal was provided to participants after the 180 minute period of
201 rest (CON) or rest/exercise (EX). This was comprised of durum wheat semolina
202 conchiglie pasta (Granaria, Favellatos.r.l, Italy) with tomato and mascarpone cheese
203 sauce (Fratelli Sacla, S.p.A., Asti, Italy). Energy content was 10.1% from protein,
204 67.2% carbohydrate and 22.7% fat, with an energy density of 7.4 kJ/g. Participants ate
205 in isolation and care was taken to standardise the test meals. Food was served to
206 participants on each occasion using the same dinnerware and cutlery, and the same
207 verbal script was used by researcher when interacting with participants. Cooking and
208 cooling times were standardised across conditions and the pasta and sauce meal was
209 served to participants in individual air-conditioned testing cubicles on both
210 experimental days at a temperature of 60-65°C. Participants were instructed to “eat as

211 much or as little as they wanted". The SIPM were used to covertly measure food
212 intake in grams and prompt the participant to call the researcher, by pressing a call
213 button, once at least 300 g of the lunch meal had been consumed. Following this, the
214 researcher would provide a refill to ensure the empty plate was not used as an external
215 cue to end their meal. This step was repeated until participants indicated that they had
216 finished eating.

217 **Hunger ratings and satiety**

218 Throughout the laboratory period of EX and CON, ratings of perceived hunger
219 were assessed using visual analogue scales (VAS) (Figure 1). The VAS were 100-mm
220 in length preceded by the question "how hungry do you feel?" and anchored at each
221 end by "not at all hungry" and "very hungry". Participants were unable to refer to their
222 previous ratings when completing each VAS. The use of VAS for the measurement of
223 subjective appetite has previously been shown to be valid and reproducible (25).

224 The suppression of hunger per calorie of intake for the breakfast meal was
225 calculated using the satiety quotient (SQ) (26). As the SQ reflects the capacity of a
226 meal to modulate the strength of postprandial satiety, the SQ was calculated for CON
227 only (as the exercise bout of EX will have independently influenced hunger and SQ
228 ratings). The SQ was calculated using the following formula based on the hunger
229 ratings before, immediately after and 30, 60, 90, 120, 150 and 180 minutes post-
230 consumption, with a higher SQ indicative of a greater satiating efficiency:

$$\text{SQ (mm/kcal)} = \frac{(\text{rating before eating episode} - \text{rating after eating episode})}{\text{energy of the food consumed}} \times 100$$

231 Free-living energy expenditure and energy intake

232 Following completion of the *ad libitum* lunch meal, participants were provided
233 with a dietary record and a combined accelerometer and heart rate monitor (Actiheart,
234 Cambridge Neurotechnology, Cambridge, UK) to measure free-living food intake and
235 energy expenditure, respectively, for the remainder of the experimental day and over
236 the subsequent three days. Participants received guidance on how to complete the diet
237 diary, and were instructed to weigh and record all items consumed. In cases where
238 weighing was not possible (e.g. eating at a restaurant), participants were asked to use
239 standard household measures to estimate portion sizes. Dietary data was analysed
240 using NetWisp software (3.0; Tinuviel, Warrington, UK) to estimate energy and
241 macronutrient intake. During the same period, participants wore a combined
242 accelerometer and heart rate monitor on their chest using electrocardiogram (ECG)
243 electrodes (E4 T815 Telectrode, Surrey, UK). These monitors recorded activity every
244 15s and participants were instructed to wear the device at all times. A revised
245 branched group calibration equation (27) was used to convert heart rate and
246 accelerometer data to energy expenditure.

247 Statistical analyses

248 All analyses were undertaken with SPSS for windows (22.0, Chicago, IL).
249 Histograms and Shapiro-Wilk tests were used to check for normal distribution whilst
250 Levene's and Mauchly's tests were used to check for homogeneity of variance and
251 sphericity, respectively. Relative energy intake (REI) was calculated as the difference
252 between lunch energy intake and the net exercise-induced energy expenditure
253 (exercise condition) or the resting energy expenditure (control condition).

254 Independent Student's t-tests and a Welch's t-test were used to assess between
255 group differences for participants' characteristics and relative exercise intensity,
256 respectively. Two-way mixed-design factorial ANOVAs (Group \times Time of day) and
257 (Group \times Condition) were used to examine the SQ and experimental day's lunch
258 energy intake, respectively. Three-way mixed-design factorial ANOVAs (Group \times
259 Condition \times Time) were used to analyse subjective hunger ratings, daily energy intake
260 and energy expenditure and macronutrient intakes. In the latter analyses energy intake
261 on the experimental day was calculated by summing participants' energy intake
262 throughout the day (breakfast + *ad libitum* lunch + remainder of experimental day).
263 However, the same formula was not applied to macronutrient intake because the
264 macronutrient values for breakfast and lunch of the experimental day were fixed.
265 Therefore, macronutrient intake for the experimental day is limited to the free-living
266 period of that day (i.e. remainder of the experimental day).

267 Post hoc tests were performed using Bonferroni adjustments. Standardised
268 mean difference effect sizes (Cohen's *d*) were calculated by dividing the mean
269 difference by the pooled standard deviation whereas partial eta squared (η_p^2) were
270 calculated by dividing the sum of squares of the effect by the sum of squares of the
271 effect plus the sum of squares of the error associated with the effect (28). All
272 outcomes are presented as means and standard deviations (mean \pm SD) unless
273 otherwise stated. Statistical significance was accepted as $P < 0.05$.

274

275 Results

276 Baseline characteristics and relative exercise intensity during EX

277 Participant characteristics are presented in Table 1. While there were no differences in
278 age ($t(14) = -1.38, P = 0.188, d = -0.74$), stature ($t(14) = 0.77, P = 0.454, d = 0.41$),
279 body mass ($t(14) = -1.44, P = 0.888, d = -0.08$) and BMI ($t(14) = -0.64, P = 0.534, d =$
280 -0.34) between groups, active participants had greater $\dot{V}O_{2\max}$ (mean difference = 12.7
281 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; $t(14) = 7.53, P < 0.001, d = 4.03$) and lower percentage of body fat
282 (mean difference = -9.3%; $t(14) = -3.69, P = 0.002, d = -1.97$) than inactive
283 participants. By design, relative exercise intensity during EX did not differ between
284 active and inactive groups ($50.1 \pm 2.1\%$ vs. $55.2 \pm 9.5\%$ of $\dot{V}O_{2\max}$, respectively;
285 $t(7.69) = -1.50, P = 0.17, d = -0.80$). However, exercise-induced energy expenditure
286 during EX was higher in the active group than the inactive group (mean difference =
287 335 kJ; 95% CI 95 to 576 kJ, $t(14) = 2.99, P = 0.01, d = 1.60$).

288 Hunger, satiety quotient and laboratory *ad libitum* energy intake

289 Hunger changed over time ($F(3.1, 43.5) = 44.623, P < 0.001, \eta_p^2 = 0.76$) but there
290 were no differences between conditions ($F(1, 14) = 0.002, P = 0.962, \eta_p^2 < 0.01$) or
291 groups ($F(1, 14) = 0.112, P = 0.743, \eta_p^2 = 0.01$) (Fig. 2).

292

293 Satiety quotient decreased over time ($F(2, 29) = 13.609, P < 0.0001, \eta_p^2 = 0.49$), and
294 was higher in the active than inactive group ($14.7 \pm 4.3 \text{ mm}\cdot\text{kcal}^{-1}$ vs. 7.7 ± 4.1
295 $\text{mm}\cdot\text{kcal}^{-1}$, $F(1, 14) = 11.031, P = 0.005, \eta_p^2 = 0.44$) (Figure 3) but there was no
296 time*group interaction ($F(2, 29) = 0.716, P = 0.501, \eta_p^2 = 0.05$).

297

298 There were no differences between conditions ($F(1, 14) = 1.962, P = 0.183,$
299 $\eta_p^2 = 0.12$), groups ($F(1, 14) = 2.311, P = 0.151, \eta_p^2 = 0.14$), or a group*condition
300 interaction ($F(1, 14) = 0.599, P = 0.452, \eta_p^2 = 0.04$) for absolute energy intake (Table
301 2), however, there was a condition effect for relative energy intake ($F(1,14) = 11.735,$
302 $P = 0.004, \eta_p^2 = 0.46$) which was lower in EX than CON (1417 ± 926 kJ vs. $2120 \pm$
303 923 kJ, respectively).

304 **Free-living daily energy and macronutrient intakes**

305 Due to an incomplete food diary, one participant in the inactive group was excluded
306 from the analyses, therefore analyses were made with 8 active and 7 inactive
307 participants per group. There were no differences between days ($F(3, 39) = 0.943, P =$
308 $0.429, \eta_p^2 = 0.07$), conditions ($F(1, 13) = 0.399, P = 0.538, \eta_p^2 = 0.03$), groups ($F(1,$
309 $13) = 1.506, P = 0.241, \eta_p^2 = 0.10$) or interactions (all $P > 0.622$) for daily energy
310 intake on the free-living days (Figure 4). There was a condition effect for the
311 percentage of energy consumed from protein ($F(1, 13) = 7.644, P = 0.016, \eta_p^2 = 0.37$)
312 and carbohydrates ($F(1, 13) = 5.887, P = 0.031, \eta_p^2 = 0.31$), such that participants
313 consumed more carbohydrates and less protein during EX than CON (CHO: $53 \pm 5\%$
314 vs. $49 \pm 7\%$; Protein: $14 \pm 3\%$ vs. $16 \pm 4\%$, respectively). There were no differences
315 for fat intake (all $P > 0.106$).

316

317 **Free-living daily energy expenditure**

318 Due to incomplete heart-rate and accelerometer monitor data in two participants
319 (removed due to skin irritation), analyses are for 7 active and 7 inactive participants.
320 During the three free-living days after the experimental laboratory days, TEE was
321 different between groups ($F(1, 12) = 14.141, P = 0.003, \eta_p^2 = 0.54$), with the active

322 group expending more energy (mean difference = 3527 kJ; 95% CI 2148 to 4906 kJ).
323 This difference is primarily due to a higher PAEE of the active group (active vs.
324 inactive: 5244 ± 1791 kJ vs. 2189 ± 879 kJ; $F(1, 12) = 19.336$, $P = 0.001$, $\eta_p^2 = 0.62$).
325 However, there were no differences in TEE (exercise vs control: 10984 ± 2861 kJ vs.
326 10284 ± 2097 kJ, $F(1, 12) = 2.825$, $P = 0.119$, $\eta_p^2 = 0.19$) and PAEE (exercise vs
327 control: 4034 ± 2338 kJ vs. 3399 ± 1726 kJ, $F(1, 12) = 2.861$, $P = 0.117$, $\eta_p^2 = 0.19$)
328 between conditions during the three days after the experimental days.

329 Discussion

330 This study examined the effects of an acute bout of cycling on the immediate
331 and subsequent free-living energy intake and PAEE in active and inactive pre-
332 menopausal women not using hormonal contraceptives. There were no differences
333 between EX and CON for *ad libitum* lunch intake on the laboratory test days, or daily
334 energy intake and PAEE during the subsequent free-living period. These data
335 therefore suggest that a bout of aerobic exercise does not elicit acute or delayed
336 compensatory in total daily energy intake or PAEE. Interestingly though, active
337 individuals displayed a stronger satiety response to the standardised breakfast meal
338 used during the laboratory test days compared to their inactive counterparts, adding to
339 the growing literature indicating that an individual's habitual physical activity status
340 moderates the sensitivity of short-term appetite control (7).

341 Consistent with previous research (19), the present study failed to observe any
342 acute differences between CON and EX for subjective hunger or absolute energy
343 intake during the *ad libitum* lunch meal. As such, after adjusting for energy expended
344 during the exercise/rest period, lunch REI was lower in the exercise condition. These
345 findings are consistent with a recent meta-analysis indicating that acute bouts of

346 aerobic exercise are effective in inducing acute energy deficits (at the mean or group
347 level, at least) (19). When high intensity exercise is used ($\geq 70\%$ of $\dot{V}O_{2max}$), there is
348 evidence of 'exercise-induced anorexia', such that hunger is transiently suppressed
349 post-exercise (29). However, this effect is not always seen following low intensity
350 exercise (such as that used in the present study).

351 While a 2-5 day 'lag' in energy intake compensation has been noted following
352 dietary perturbations to energy balance (16, 30, 31), whether such corrective
353 responses in energy intake exist after exercise-induced perturbations has received less
354 attention. In the present study, there was no evidence of delayed compensation in
355 energy intake (or expenditure) during the three free-living days subsequent to the bout
356 of cycling used in the present study. However, whether delayed compensation is seen
357 following exercise-induced energy deficits of a greater magnitude, or when repeated
358 exercise-induced energy deficits are induced over consecutive days, is unclear. This is
359 of particular importance given that exercise interventions often report that losses in
360 body mass are lower than would be expected based on objective measures of exercise-
361 induced energy expenditure (32).

362 In agreement with previous studies (7), no difference in absolute EI at the
363 laboratory *ad libitum* lunch meal was seen between the active and inactive individuals
364 following the 60 min bout of cycling (despite a greater exercise-induced energy
365 expenditure in active individuals). However, greater SQ was observed in the active
366 than inactive group following the standardised laboratory breakfast meal, indicating
367 that the meal produced more subjective postprandial satiety in active individuals than
368 inactive individuals. Indeed, this was despite a tendency for high fasting hunger levels
369 in the active group. Using a preload test meal paradigm, active males and females
370 have previously been shown to be better able to adjust energy intake to the energy

371 content of a prior preload than inactive individual (7, 13, 15). Furthermore, medium-
372 term exercise training in previously inactive males and females has been shown to
373 increase hunger in the fasted state and the SQ response to fixed energy meals (33, 34).

374 While the underlying mechanisms remain to be determined, the present data
375 support the notion that active individuals have better short-term appetite control than
376 their inactive counterparts, which over the longer-term, may help with body mass
377 regulation. Indeed, while it could be argued that any differences between the active
378 and inactive group may reflect differences in body composition rather than physical
379 activity levels *per se*, these differences in body composition actually serve to further
380 emphasise the importance of physical activity in body mass management. These
381 differences in body composition may be important in the regulation of appetite as fat-
382 free mass, as the main determinant of resting metabolic rate, has recently been shown
383 to play an important role in day-to-day food intake (35). Furthermore, while high
384 levels of habitual activity are thought to improve the sensitivity of short-term appetite
385 control, potentially due to enhanced gut mediated satiety signalling (7), inactivity may
386 amplify hedonic states and behavioural traits favouring overconsumption indirectly
387 through increased adiposity (7). However, further research specifically examining the
388 mechanisms through which habitual inactivity moderates appetite regulation is
389 needed.

390 During the three day free-living period, there were no differences in energy
391 expenditure between EX and CON, suggesting that a single bout of exercise did not
392 alter PAEE over subsequent days. These results are in agreement with our previous
393 studies in men (10) and women taking oral contraceptives (11), suggesting that a
394 single bout of low-intensity cycling does not elicit a transient suppression in hunger,

395 or compensatory changes in daily physical activity energy expenditure, irrespective of
396 habitual physical activity, sex or use of oral contraceptives.

397 While there were no differences in daily energy intake between EX and CON,
398 both active and inactive groups consumed less energy from proteins and more from
399 carbohydrates over the free-living days of EX than during CON. While it is
400 acknowledged that the magnitude of these changes was small, the effect of exercise
401 on dietary macronutrient selection/preference has received little attention. Indeed, as
402 the effect of exercise on food intake has primarily been limited to the subsequent 24-
403 hour period, the impact of long-term exercise training on macronutrient intake
404 remains unclear. The change in macronutrient intake observed here could be
405 explained by participants being motivated to seek specific foods to restore energy
406 stores or preferences for tastes associated with the carbohydrates needed to replenish
407 the glycogen stores (36). The ability of an acute bout of exercise to improve
408 psychological wellbeing (37, 38) could also be related to changes in protein intake.
409 For instance, lower energy intake of protein during the first 10 days of the menstrual
410 cycle (includes period over which the experimental studies were completed) has been
411 associated with higher ratings of wellbeing in healthy women not taking oral
412 contraceptives (39).

413 It should be noted that these findings are in contrast to our previous study in
414 which inactive women taking oral contraceptives demonstrated a suppression of
415 energy intake on the day following exercise (11). Given the study design and the
416 participant characteristics did not differ other than the use of oral contraceptives, it is
417 plausible to suggest that this discrepancy may partially be accounted for by the effect
418 of such medication on appetite. Indeed, in a combined analysis of data from our
419 present and that collected in our previous study (*see supplementary online material*),

420 examination of the total mean energy intake over the 4 days revealed an interaction
421 between activity status and oral contraceptives ($P = 0.038$). Energy intake was higher
422 in inactive women taking oral contraceptives (OC) compared to inactive women not
423 taking oral contraceptives (Non-OC) (9419 ± 939 vs 7543 ± 2312 kJ, respectively; P
424 $= 0.043$), but no difference was seen between OC and Non-OC active women (OC vs
425 Non-OC: 8385 ± 1037 vs 8905 ± 1987 kJ, $P = 0.483$). The mechanisms responsible
426 for this effect remain unclear but highlights future studies should consider OC use as a
427 potential confounding factor. Inactive women energy intake in the present study was
428 lower than that previously seen in our previous study (11), and thus, there may have
429 been a ‘floor effect’ where further reductions in energy intake were not seen. Further
430 research is now required to confirm these findings and determine the precise influence
431 of hormonal contraceptives on exercise-induced compensatory responses.

432 Limitations include participants being young healthy women; therefore
433 findings might not apply to other populations. Ovarian hormones (e.g. estradiol) were
434 not measured in the present study (or our previous study), so their impact on appetite
435 regulation could not be directly assessed. Sample size may have limited the power to
436 detect differences in energy intake during the free-living period of the study and
437 examine for differences between physical activity groups, however, this was due to
438 the highly controlled experimental environment. Moreover, sample size is in the range
439 of similar studies (40, 41, 42). The *ad libitum* test meal was offered at a fixed time to
440 ensure that differences in time did not affect energy intake. Nevertheless, allowing the
441 participants to choose the time of their next meal may have revealed further effects. It
442 is important to be cautious when interpreting free-living energy intake and
443 expenditure data because the available methods are heavily dependent on participants’
444 compliance with instructions. Finally, combined heart-rate and accelerometer data

445 was converted to energy expenditure using a revised branched group calibration
446 equation and not calibrated to each participant individually.

447 This study demonstrated that an acute bout of low-intensity cycling did not
448 elicit changes in hunger and lunch energy intake in active and inactive women not
449 using hormonal contraceptives. However, exercise induced a decrease in relative
450 energy intake meaning that an acute energy deficit persisted after lunch. The stronger
451 subjective satiety response to the standardised breakfast meal in active women also
452 supports a growing body of evidence demonstrating more sensitivity in short-term
453 appetite control in habitually active individuals. There were no differences in energy
454 intake and expenditure during the remainder of the experimental day or any of the
455 subsequent three days between conditions. These findings support the use of low-
456 intensity aerobic exercise to induce a short-term negative energy balance in women
457 not taking hormonal contraceptives and a stronger satiety response in active
458 individuals. Together with findings from our previous study, the present study also
459 suggests that future studies should consider OC use as a potential confounding factor.

460

461 **Conflict of interest**

462 None of the authors had any conflict of interest regarding any aspect of this study.

463

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469 **References**

- 470 1. Malhotra A, Noakes T, Phinney S. It is time to bust the myth of physical
471 inactivity and obesity: you cannot outrun a bad diet. *British journal of sports*
472 *medicine* 2015;bjsports-2015-094911.
- 473 2. Foright R, Presby D, Sherk V, et al. Is regular exercise an effective strategy
474 for weight loss maintenance? *Physiology & behavior* 2018.
- 475 3. Rocha J, Paxman J, Dalton C, Winter E, Broom DR. Effects of a 12-week
476 aerobic exercise intervention on eating behaviour, food cravings, and 7-day
477 energy intake and energy expenditure in inactive men. *Applied Physiology,*
478 *Nutrition, and Metabolism* 2016;41(11):1129-36.
- 479 4. King N, Caudwell P, Hopkins M, et al. Metabolic and Behavioral
480 Compensatory Responses to Exercise Interventions: Barriers to Weight Loss.
481 *Obesity* 2007;15(6):1373-83.
- 482 5. Mayer J, Roy P, Mitra K. Relation between caloric intake, body weight, and
483 physical work: studies in an industrial male population in West Bengal.
484 *American Journal of Clinical Nutrition* 1956;4(2):169.
- 485 6. Blundell J. Physical activity and appetite control: can we close the energy
486 gap? *Nutrition Bulletin* 2011;36(3):356-66.
- 487 7. Beaulieu K, Hopkins M, Blundell J, Finlayson G. Does Habitual Physical
488 Activity Increase the Sensitivity of the Appetite Control System? A Systematic
489 Review. *Sports Medicine* 2016:1-23. doi: doi:10.1007/s40279-016-0518-9.
- 490 8. Charlot K, Chapelot D. Energy compensation after an aerobic exercise
491 session in high-fat/low-fit and low-fat/high-fit young male subjects. *British*
492 *Journal of Nutrition* 2013;110(6):1133-42.
- 493 9. Jokisch E, Coletta A, Raynor HA. Acute energy compensation and
494 macronutrient intake following exercise in active and inactive males who are
495 normal weight. *Appetite* 2012;58(2):722-9.
- 496 10. Rocha J, Paxman J, Dalton C, Winter E, Broom D. Effects of an acute bout of
497 aerobic exercise on immediate and subsequent three-day food intake and
498 energy expenditure in active and inactive men. *Appetite* 2013;71:369-78.
- 499 11. Rocha J, Paxman J, Dalton C, Winter E, Broom D. Effects of an acute bout of
500 aerobic exercise on immediate and subsequent three-day food intake and
501 energy expenditure in active and inactive pre-menopausal women taking oral
502 contraceptives. *Appetite* 2015;89:183-91.
- 503 12. Beaulieu K, Hopkins M, Blundell J, Finlayson G. Impact of physical activity
504 level and dietary fat content on passive overconsumption of energy in non-
505 obese adults. *International Journal of Behavioral Nutrition and Physical*
506 *Activity* 2017;14(1):14.
- 507 13. Beaulieu K, Hopkins M, Long C, Blundell JE, Finlayson G. High Habitual
508 Physical Activity Improves Acute Energy Compensation in Nonobese Adults.
509 *Med Sci Sports Exerc* 2017. doi: 10.1249/mss.0000000000001368.

- 510 14. Van Walleghen E, Orr J, Gentile C, Davy K, Davy B. Habitual physical activity
511 differentially affects acute and short-term energy intake regulation in young
512 and older adults. *International Journal of Obesity* 2007;31(8):1277-85.
- 513 15. Long S, Hart K, Morgan L. The ability of habitual exercise to influence
514 appetite and food intake in response to high-and low-energy preloads in man.
515 *British Journal of Nutrition* 2002;87(05):517-23.
- 516 16. Bray G, Flatt J, Volaufova J, DeLany J, Champagne C. Corrective responses
517 in human food intake identified from an analysis of 7-d food-intake records.
518 *American Journal of Clinical Nutrition* 2008;88(6):1504.
- 519 17. Edholm OG, Fletcher JG, Widdowson EM, McCance RA. The Energy
520 Expenditure and Food Intake of Individual Men. *British Journal of Nutrition*
521 1955;9(03):286-300.
- 522 18. Levitsky DA, Limb JER, Wilkinson L, et al. Lack of negative autocorrelations
523 of daily food intake on successive days challenges the concept of the
524 regulation of body weight in humans. *Appetite* 2017;116:277-83.
- 525 19. Schubert MM, Desbrow B, Sabapathy S, Leveritt M. Acute Exercise and
526 Subsequent Energy Intake: A Meta-Analysis. *Appetite* 2012;63:92-104.
- 527 20. Hagobian TA, Braun B. Physical activity and hormonal regulation of appetite:
528 sex differences and weight control. *Exercise and sport sciences reviews*
529 2010;38(1):25-30.
- 530 21. Godin G, Shephard R. A simple method to assess exercise behavior in the
531 community. *Can J Appl Sport Sci* 1985;10(3):141-6.
- 532 22. Davies S, Burns H, Jewell T, McBride M. Start active, stay active: a report on
533 physical activity from the four home countries. *Chief Medical Officers, 2011:1-*
534 *62.*
- 535 23. Inbar O, Oren A, Scheinowitz M, Rotstein A, Dlin R, Casaburi R. Normal
536 cardiopulmonary responses during incremental exercise in 20-to 70-yr-old
537 men. *Medicine and science in sports and exercise* 1994;26:538-.
- 538 24. Frayn K. Calculation of substrate oxidation rates in vivo from gaseous
539 exchange. *Journal of applied physiology* 1983;55(2):628-34.
- 540 25. Flint A, Raben A, Blundell J, Astrup A. Reproducibility, power and validity of
541 visual analogue scales in assessment of appetite sensations in single test
542 meal studies. *International journal of obesity and related metabolic disorders:*
543 *journal of the International Association for the Study of Obesity* 2000;24(1):38.
- 544 26. Green S, Delargy H, Joanes D, Blundell J. A Satiety Quotient: A Formulation
545 to Assess the Satiating Effect of Food. *Appetite* 1997;29(3):291-304.
- 546 27. Brage S, Ekelund U, Brage N, et al. Hierarchy of individual calibration levels
547 for heart rate and accelerometry to measure physical activity. *Journal of*
548 *Applied Physiology* 2007;103(2):682-92.
- 549 28. Cohen J. *Statistical power analysis for the behavioral sciences* (revised ed.).
550 New York: Academic Press, 1977.
- 551 29. Broom DR, Miyashita M, Wasse LK, et al. Acute effect of exercise intensity
552 and duration on acylated ghrelin and hunger in men. *Journal of Endocrinology*
553 2017;232(3):411-22.
- 554 30. Champagne CM, Han H, Bajpeyi S, et al. Day-to-day variation in food intake
555 and energy expenditure in healthy women: the Dietitian II Study. *Journal of*
556 *the Academy of Nutrition and Dietetics* 2013;113(11):1532-8.
- 557 31. De Castro JM. How can energy balance be achieved by free-living human
558 subjects? *Proceedings of the Nutrition Society* 1997;56(1A):1-14.
- 559 32. Hopkins M, King NA, Blundell JE. Acute and long-term effects of exercise on
560 appetite control: is there any benefit for weight control? *Current Opinion in*
561 *Clinical Nutrition & Metabolic Care* 2010;13(6):635.

- 562 33. King N, Caudwell P, Hopkins M, Stubbs J, Naslund E, Blundell J. Dual-
563 process action of exercise on appetite control: increase in orexigenic drive but
564 improvement in meal-induced satiety. *American Journal of Clinical Nutrition*
565 2009;90(4):921-7.
- 566 34. Martins C, Kulseng B, King N, Holst J, Blundell J. The effects of exercise-
567 induced weight loss on appetite-related peptides and motivation to eat.
568 *Journal of Clinical Endocrinology & Metabolism* 2010;95(4):1609-16.
- 569 35. Blundell JE, Caudwell P, Gibbons C, et al. Role of resting metabolic rate and
570 energy expenditure in hunger and appetite control: a new formulation.
571 *Disease Models & Mechanisms* 2012;5(5):608-13.
- 572 36. Blundell J, Stubbs R, Hughes D, Whybrow S, King N. Cross talk between
573 physical activity and appetite control: does physical activity stimulate
574 appetite? *Proceedings of the Nutrition Society* 2007;62(03):651-61.
- 575 37. Deslandes A, Moraes H, Ferreira C, et al. Exercise and mental health: many
576 reasons to move. *Neuropsychobiology* 2009;59(4):191-8.
- 577 38. Fox KR. The influence of physical activity on mental well-being. *Public health*
578 *nutrition* 1999;2(3a):411-8.
- 579 39. Johnson, W. G., Carr-Nangle, R. E., & Bergeron, K. C. (1995). Macronutrient
580 intake, eating habits, and exercise as moderators of menstrual distress in
581 healthy women. *Psychosomatic Medicine*, 57(4), 324-330.
- 582 40. Hagobian, T. A., Yamashiro, M., Hinkel-Lipsker, J., Streder, K., Evero, N., &
583 Hackney, T. (2012). Effects of acute exercise on appetite hormones and ad
584 libitum energy intake in men and women. *Applied Physiology, Nutrition, and*
585 *Metabolism*, 38, 66–72.
- 586 41. Larson-Meyer, D. E., Palm, S., Bansal, A., Austin, K. J., Hart, A. M., &
587 Alexander, B. M. (2012). Influence of running and walking on hormonal
588 regulators of appetite in women. *Journal of Obesity*, 2012.
- 589 42. Tsofliou, F., Pitsiladis, Y., Malkova, D., Wallace, A., & Lean, M. (2003).
590 Moderate physical activity permits acute coupling between serum leptin and
591 appetite–satiety measures in obese women. *International Journal of Obesity*,
592 27, 1332–1339.
- 593
- 594

595 Tables

596 **Table 1.** Participants' baseline characteristics

	Active	Inactive
Age (years)	21.9 ± 4.0	24.5 ± 3.5
Stature (m)	1.68 ± 0.07	1.65 ± 0.07
Body mass (kg)	62.1 ± 5.8	62.7 ± 9.9
BMI (kg.m ⁻²)	22.2 ± 2.0	23.0 ± 3.1

Body fat (%) *	23.6 ± 5.7	32.8 ± 4.2
$\dot{V}O_{2max}$ (ml·kg⁻¹·min⁻¹) **	38.8 ± 4.2	26.1 ± 2.3
Cognitive restraint scale (TFEQ)	11.6 ± 3.0	11.0 ± 3.4
Severity of premenstrual symptoms (SPAF)	18.1 ± 5.8	17.6 ± 5.9

597 N=8 per group; values presented as mean ± SD.

598 BMI = body mass index; $\dot{V}O_{2max}$ = maximal oxygen consumption; TFEQ = three-
599 factor eating questionnaire; SPAF = shortened premenstrual assessment form.

600 * Means significantly different ($P < 0.01$).

601 ** Means significantly different ($P < 0.001$).

602

603

604 **Table 2.** *Ad libitum* lunch meal energy intake

	Active	Inactive
Absolute EI during EX (kJ)	2965 ± 583	2458 ± 1296
Absolute EI during CON (kJ)	2843 ± 1099	2033 ± 619
Relative EI during EX (kJ)*	1503 ± 452	1331 ± 1319
Relative EI during CON (kJ)	2518 ± 1108	1723 ± 601

605 N=8 per group; values presented as mean ± SD; EI = energy intake. EX = exercise
606 condition; CON = control condition. Relative energy intake (REI) is the difference
607 between lunch energy intake and the net exercise-induced energy expenditure
608 (exercise condition) or the resting energy expenditure (control condition).

609 * Condition effect ($F(1,14) = 11.735$; $P = 0.004$, $\eta_p^2 = 0.46$).

610

611

ACCEPTED MANUSCRIPT

613 **Figures captions**

614

615 **Figure 1.** Schematic representation of the laboratory period of the experimental days.

616

617 **Figure 2.** Subjective feelings of hunger (n = 8 per group; means \pm SEM). Hatched
618 rectangles are consumption of meals; dark rectangle is equivalent to the 60 minutes
619 cycling period.

620

621 **Figure 3.** Satiety quotient (n = 8 per group; means \pm SEM) Hatched rectangles
622 represent consumption of breakfast and *ad libitum* lunch.

623

624 **Figure 4.** Daily energy intake (n = 8 for active and n = 7 for inactive; means \pm SEM).

625

626 **Supplementary file.** Combined 3-way mixed model ANOVA of total 4-day EI data
627 from the present study (n = 8 for active non-OC, n = 7 for inactive non-OC; means \pm
628 SEM) and from Rocha, J., Paxman, J., Dalton, C., Winter, E., & Broom, D. Effects of
629 an acute bout of aerobic exercise on immediate and subsequent three-day food intake
630 and energy expenditure in active and inactive pre-menopausal women taking oral
631 contraceptives. *Appetite*, 89, 183-191, Elsevier, 2015 study (n = 10 for active OC, n =
632 9 for inactive OC; means \pm SEM). * denotes $P < 0.05$ Inactive OC vs Non-OC.

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