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A single session of treadmill running has no effect on plasma total ghrelin concentrations

Stephen F Burns, David R Broom, Masashi Miyashita, Claire Mundy and David J

Stensel (✉)

School of Sport and Exercise Sciences

Loughborough University

Loughborough

Leicestershire

LE11 3TU, UK

Correspondence and requests for reprints:

Dr David Stensel

School of Sport and Exercise Sciences

Loughborough University

Leicestershire

LE11 3TU, UK

Phone: +44 (0)1509 226344

Fax: +44 (0)1509 226301

E-mail: D.J.Stensel@lboro.ac.uk

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Abbreviated Title: Treadmill running and plasma ghrelin

Key Words: hunger, appetite, exercise, weight control

1 **Abstract**

2 Ghrelin is a hormone stimulating hunger. Intense exercise has been shown to
3 temporarily suppress hunger post-exercise. The present study investigated
4 whether post-exercise hunger suppression is mediated by reduced plasma
5 total ghrelin concentrations.

6

7 Nine men and nine women participated in this study. Age, body mass index
8 and maximal oxygen uptake ($\dot{V}O_2 \text{ max}$) of the participants ($\text{mean} \pm s_{\bar{x}}$)
9 were: 24.8 ± 0.9 yr, 22.9 ± 0.6 kg·m² and 57.7 ± 2.2 mL·kg⁻¹·min⁻¹.
10 Participants completed two, three-hour trials (exercise and control) on
11 separate days in a randomised balanced design after overnight fasts. The
12 exercise trial involved a one-hour treadmill run at 73.5% of
13 $\dot{V}O_2 \text{ max}$ followed by two hours of rest. The control trial involved three
14 hours of rest. Blood samples were collected at 0, 0.5, 1, 1.5, 2 and 3 hours.
15 Total ghrelin concentrations were determined from plasma. Hunger was
16 assessed following blood samples using a 15-point scale. Data were analysed
17 via repeated measures ANOVA.

18

19 Hunger scores were lower in the exercise trial compared with the control trial
20 (Trial $P=0.009$; Time $P<0.001$; Interaction $P<0.001$). Plasma total ghrelin
21 concentrations did not differ between trials.

22

23 These findings indicate that treadmill running suppresses hunger but this
24 effect is not mediated by changes in plasma total ghrelin concentration.

25 **Introduction**

26 Ghrelin is a hormone that is secreted by the stomach and in smaller amounts
27 from the hypothalamus (Kojima et al., 1999). Ghrelin concentrations rise just
28 before meals and decrease rapidly after meals suggesting that ghrelin is
29 involved in the acute regulation of hunger (Ariyasu et al., 2001, Cummings et
30 al., 2001). This is supported by the finding that infusion of ghrelin leads to a
31 short-term increase in hunger in humans (Wren et al., 2001). Plasma total
32 ghrelin concentrations correlate negatively with body mass index (BMI)
33 (Ikezaki et al., 2002, Soriano-Guillen et al., 2004, Tschop et al., 2001) and
34 are responsive to diet and exercise induced changes in body mass (Cummings
35 et al., 2002, Foster-Schubert et al., 2005, Leidy et al., 2004) indicating that
36 ghrelin also has a role in regulating energy balance.

37

38 To our knowledge only four studies have examined the influence of an acute
39 bout of aerobic exercise on total plasma ghrelin (Dall et al., 2002, Kallio et
40 al., 2001, Kraemer et al., 2004a, Schmidt et al., 2004). The findings of these
41 studies are consistent and indicate that a single session of aerobic exercise
42 has no influence on total plasma ghrelin concentration. However, only one of
43 these studies employed a control trial (Kraemer et al., 2004a). Moreover, in
44 three of these studies the duration of exercise was relatively short (<30 min)
45 and none of these studies included an assessment of hunger.

46

47 There is evidence that intense exercise ($> 60\%$ of $\dot{V}O_2$ max) causes a
48 temporary post-exercise suppression of hunger (King et al., 1994, King and

49 Blundell, 1995.). This is possibly due to a decline in splanchnic blood flow
50 during exercise (Rowell, 1974) although other mechanisms may be
51 responsible. If it could be shown that exercise suppresses plasma total ghrelin
52 concentration and hunger simultaneously this would: a) support previous
53 research findings indicating that intense exercise suppresses hunger, b)
54 indicate a mechanism by which exercise and hunger are related. Exercise
55 may then be recommended as an alternative to pharmacological methods
56 (currently being developed) for lowering plasma total ghrelin concentration,
57 reducing hunger and controlling weight.

58

59 Therefore, in view of the limitations of current research we decided to re-
60 examine the relationship between exercise and plasma total ghrelin
61 concentration using a greater exercise stimulus (i.e. greater exercise intensity
62 and duration and therefore greater energy deficit) than has been examined
63 previously. We also sought to link changes in plasma total ghrelin
64 concentration with changes in feelings of hunger – this has not been
65 monitored in previous studies. Our primary hypothesis was that prolonged,
66 intense exercise (1 hour at 73.5% of $\dot{V}O_2$ max) would lead to a short-term
67 suppression of hunger which would be linked to suppressed plasma total
68 ghrelin concentration. A secondary hypothesis was that two hours after
69 exercise, hunger ratings and plasma total ghrelin concentrations would be
70 higher on the exercise compared with the control trial due to the energy
71 deficit created by the exercise.

95 **Preliminary tests**

96 **Anthropometry:** Height was assessed using a Holtain fixed wall stadiometer
97 (Seca, Germany). Measurements were taken to the nearest 0.1 cm. Body
98 mass was measured using a beam balance (Avery, Birmingham, U.K.).
99 Measurements were taken to the nearest 0.01 kg. Skinfold thickness was
100 measured at four sites (triceps, biceps, subscapular and suprailiac) on the
101 right hand side of the body using calipers (John Bull, U.K.). Body density
102 was calculated using a four site formula and body fat percentage then
103 estimated using the Siri equation (Durnin and Womersley, 1974).

104

105 **Submaximal treadmill test:** A 16 minute, four-stage, submaximal treadmill
106 test was used to determine the relationship between running speed and
107 oxygen consumption. Initial running speed was set between 8 and 9 km·h⁻¹
108 depending upon participants' running ability. The treadmill was level
109 throughout the test. Speed was increased by between 1 and 1.6 km·h⁻¹ every 4
110 minutes depending on participants' fitness. Expired air samples, heart rate
111 and ratings of perceived exertion (Borg, 1973) were collected during the final
112 minute of each stage. A linear regression equation was used to calculate the
113 relationship between running speed and oxygen consumption.

114

115 **Maximum oxygen uptake test:** $\dot{V}O_2$ max was determined using an
116 incremental protocol in three-minute stages (Taylor et al., 1955). Treadmill
117 speed remained constant throughout the test. The initial incline of the
118 treadmill was 3.5%. Treadmill gradient was increased by 2.5% every 3

minutes. Expired air samples, heart rate and ratings of perceived exertion were collected from 1:45 to 2:45 minutes of each stage and throughout the final minute of the test. Participants determined the end point of the test by indicating to the experimenters when they felt they could run for only one further minute. The final expired air collection was started at that point. Strong verbal encouragement was given to participants throughout the test. Criteria for $\dot{V}O_2$ max included two or more of the following: 1) heart rate within $\pm 10 \text{ b}\cdot\text{min}^{-1}$ of age-predicted maximum heart rate, 2) a respiratory exchange ratio value ≥ 1.15 , 3) a plateau in oxygen consumption.

Main trials

Two main trials (exercise or control) were performed in a counterbalanced, randomised design. The interval between the two trials was at least one week. For each trial the participants reported to the laboratory at 08.00 hours after a 10-hour overnight fast. A cannula was inserted into a forearm or antecubital vein and the participants rested quietly for ten minutes. During this period participants were asked to rate their hunger (see below). In the control trial participants continued resting (reading, working quietly, watching television) for the next three hours. In the exercise trial participants performed a one-hour treadmill run (see below) and then rested for two hours.

Blood samples were obtained at baseline and at 0.5, 1, 1.5, 2 and 3 hours after baseline. The cannula was kept patent by flushing with nonheparinised saline ($9 \text{ g}\cdot\text{L}^{-1}$, B.Braun Medical Ltd, Buckinghamshire, UK). The first 2 mL

143 of blood withdrawn was always discarded to avoid dilution of the sample.
144 Participants were always lying in a supine position for at least five minutes
145 before blood samples were taken except for the 0.5 and 1 hour samples taken
146 during the exercise trial. For these samples participants straddled the
147 treadmill while blood was being drawn. This process took approximately one
148 minute. Water was available ad libitum during both trials and the volume
149 ingested was recorded. Hunger was reassessed at each blood sampling point.

150

151 **One-hour treadmill run**

152 Participants were instructed that the exercise was designed to be a 'hard run'
153 for one hour. Participants were initially set running at a speed calculated to
154 elicit 75% of their $\dot{V}O_2$ max . If the run was too difficult for participants the
155 speed of the treadmill was lowered. However, the speed was still maintained
156 to produce a high intensity. Expired air samples were collected into 200 L
157 Douglas bags (Plysu Protection Systems, Milton Keynes, U.K.) at 14-15, 29-
158 30, 44-45 and 59-60 minutes during the run. Heart rate was measured using
159 short-range telemetry (Polar Electro, OV), and ratings of perceived exertion
160 were recorded during collections of expired air. Oxygen consumption and
161 carbon dioxide production were determined from expired air samples using a
162 paramagnetic oxygen analyser and an infrared carbon dioxide analyser
163 (Servomex Analyser Series 1400; Servomex, Crowborough, East Sussex,
164 U.K.). Expired air volumes were measured using a dry gas meter (Harvard
165 Apparatus, Edenbridge, Kent, U.K.) and corrected to standard temperature
166 and pressure (dry). Energy expenditure during exercise, substrate utilisation,

167 carbohydrate oxidation rate ($\text{g}\cdot\text{min}^{-1}$) and fat oxidation rate ($\text{g}\cdot\text{min}^{-1}$), were
168 calculated using equations for energy expenditure assuming no protein
169 oxidation (Frayn, 1983).

170

171 **Hunger scale**

172 A 15-point visual scale was used to assess hunger. Participants indicated their
173 perceived level of hunger by pointing to a number which best represented
174 how hungry they felt. The following phrases were included on the scale: not
175 hungry, fairly hungry, hungry and very hungry. The visual scale was
176 validated against the visual analogue scales developed by King and
177 colleagues (King et al., 1996, King et al., 1994). The responses were
178 identical.

179

180 **Control for diet and exercise**

181 For two days preceding the main trials participants were asked to replicate
182 their physical activity. Participants weighed and recorded all food and drink
183 consumed during the 48 hours immediately preceding their first trial and they
184 replicated this intake during the 48 hours prior to their second trial.
185 Participants were asked to refrain from alcohol consumption during these
186 periods. There was no control for menstrual cycle phase amongst female
187 participants in this study.

188

189 **Analytical methods**

190 At each sampling point, blood samples were collected into pre-cooled 9mL

191 potassium-EDTA monovettes (Sarstedt Monovette Potassium EDTA 1.6mg
192 EDTA/mL blood, Sarstedt, Germany) that were kept on ice until
193 centrifugation (Koolspin Refrigerated Centrifuge, Burkard Scientific,
194 Uxbridge, Middlesex, U.K.). Plasma was separated within 15 min of
195 collection, divided into aliquots, and stored at -80°C.

196

197 Plasma samples were analysed for total ghrelin concentration by enzyme
198 immunoassay (Phoenix Pharmaceuticals) using a plate reader (Opsys
199 Microplate Reader, Dynex Technologies Inc., Franklin MA, U.S.). Glucose
200 (Randox Laboratories Ltd. U.K.) and NEFA (Wako Chemicals GmbH,
201 Germany) were analysed from plasma samples by enzymatic, colorimetric
202 methods using an automated centrifugal analyser (Cobas Mira Plus; Roche,
203 Basel, Switzerland). Plasma insulin concentration was determined using a
204 solid-phase ¹²⁵I radioimmunoassay available in a commercial kit (MP
205 Biomedicals, Orangeburg, NY, U.S.). Radioactivity was measured using an
206 automated gamma counting system (Cobra II, Packard Instrument, Downers
207 Grove, IL, U.S.). Haemoglobin concentration and haematocrit were
208 determined from blood samples collected at baseline and three hours so that
209 changes in plasma volume could be estimated (Dill and Costill, 1974). The
210 within batch coefficients of variation for the assays were as follows: ghrelin
211 9.6%, glucose, 1.3%, NEFA 0.8%, insulin 5.7%. To eliminate inter-assay
212 variation, samples from both trials for each participant were analysed in the
213 same batch.

214

215 **Data analysis**

216 Results were analysed using statistical software (SPSS 11.0, SPSS Inc.,
217 Chicago, IL, U.S.). Fasting and area under the curve values were compared
218 between trials using *t*-tests for correlated data. Where gender comparisons
219 were required independent *t*-tests were used. Repeated measures two-way
220 ANOVA was used to determine differences between trials and over time for
221 measurements of hunger and plasma concentrations of total ghrelin. Where
222 appropriate post-hoc pair wise comparisons were made using the Bonferroni
223 method. Relationships between variables were evaluated using Pearson's
224 product-moment correlation coefficient. A 5% level of significance was
225 adopted throughout, and data are expressed as mean $\pm$ $s_{\bar{x}}$.

226 **Results**

227 **Responses to treadmill running**

228 Average heart rate during exercise was 173 ± 2 b·min⁻¹. This represented 91
229 $\pm 1\%$ of maximum heart rate. The mean % $\dot{V}O_2$ max elicited during exercise
230 was $73.5 \pm 0.8\%$ and the mean respiratory exchange ratio was 0.89 ± 0.01 .
231 Gross energy expenditure during exercise was 3747 ± 207 kJ with $35 \pm 3\%$ of
232 energy provided from fat and $64 \pm 3\%$ of energy provided from carbohydrate.
233 The median rating of perceived exertion during exercise was 15 i.e. 'hard'
234 (range 13-16).

235

236 **Fluid consumption and body mass**

237 Participants consumed more water ($P<0.001$) during the exercise trial ($978 \pm$
238 115 mL) compared to the control trial (443 ± 76 mL). Body mass did not
239 differ between trials at baseline. Body mass was lower ($P=0.006$) at the end
240 of the exercise trial (i.e. at 3 hours) compared with the end of the control trial
241 (67.9 ± 2.6 kg *versus* 68.5 ± 2.6 kg for exercise and control respectively).

242

243 **Hunger**

244 Hunger scores (Figure 1) were suppressed during and after exercise: main
245 effect of trial ($P=0.009$), main effect of time ($P<0.001$), trial $\times$ time
246 interaction ($P<0.001$). Post-hoc tests revealed that hunger scores were lower
247 during the exercise *versus* control trial at 0.5, 1, 1.5 and 2 hours (all $P<0.05$).
248 There was a main effect of time and a trial $\times$ time interaction for both sexes

249 for hunger. However a main effect of trial was not found for either sex in
250 isolation. Males: trial $P=0.059$, time $P<0.001$, trial $\times$ time interaction
251 $P=0.022$; females: trial $P=0.100$, time $P<0.001$, trial $\times$ time interaction
252 $P=0.004$.

253

254 **FIGURE 1 NEAR HERE**

255

256 **Hormone and substrate concentrations at baseline**

257 Baseline plasma concentrations are shown in Tables 2 and 3. There were no
258 differences between the control and exercise trials for any of the
259 hormones/metabolites at baseline. Although baseline plasma total ghrelin
260 concentrations tended to be higher for the males than the females on both the
261 control and exercise trials these differences were not significant ($P=0.52$ and
262 $P=0.54$ for the control and exercise trials respectively).

263

264 **Hormone and substrate responses to exercise**

265 Changes in plasma volume over the period of observation were small and did
266 not differ ($P=0.865$) between control ($-0.6 \pm 1.7\%$) and exercise ($0.0 \pm 3.3\%$)
267 trials. Therefore, no adjustments were made to measured concentrations of
268 plasma constituents.

269

270 There was no significant difference in plasma total ghrelin concentrations
271 between trials or over time in either the group as a whole (Figure 2) or the
272 males or females separately. Area under the curve values for plasma total

273 ghrelin concentration did not differ significantly between the exercise and
274 control trials for the males, the females or the group as a whole (Table 2).
275 Although the area under the curve values tended to be higher for males than
276 females on both the control and the exercise trials these gender differences
277 were not significant ($P=0.457$ for the control trial and $P=0.302$ for the
278 exercise trial, t -tests for correlated data).

279

280 TABLE 2 NEAR HERE

281 FIGURE 2 NEAR HERE

282

283 Area under the curve values for insulin, glucose and NEFA are shown in
284 Table 3. Area under the curve values for NEFA and glucose were higher on
285 the exercise than the control trial for the group as a whole ($P=0.007$ for
286 NEFA, $P=0.004$ for glucose).

287

288 TABLE 3 NEAR HERE

289

290 Mean fasting plasma total ghrelin concentrations (i.e. control trial
291 concentration plus exercise trial concentration divided by two) were not
292 significantly correlated with BMI, body mass, body fat percentage, waist
293 circumference, insulin, glucose or $\dot{V}O_2$ max for the group as a whole. For the
294 males a negative correlation between fasting plasma total ghrelin
295 concentration and BMI was observed ($r=-0.726$, $P=0.027$) and both body fat
296 percentage ($r=-0.626$, $P=0.071$) and waist circumference ($r=-0.606$, $P=0.084$)

297 showed a trend toward significant negative correlations with plasma total
298 ghrelin concentration. No significant correlations were observed between
299 fasting plasma total ghrelin concentration and any of the above variables for
300 the females.

301 **Discussion**

302 The main finding in the present study is that hunger was suppressed during
303 and after treadmill running whereas plasma total ghrelin concentration was
304 unaffected. The lack of change in plasma total ghrelin concentration during
305 aerobic exercise is consistent with the findings of previous studies (Dall et
306 al., 2002, Kallio et al., 2001, Kraemer et al., 2004a, Schmidt et al., 2004).
307 However, the present study extends the findings of these studies by showing
308 that plasma total ghrelin concentrations are unrelated to feelings of hunger
309 during and following exercise, which has not been examined previously.

310

311 The volume of exercise performed in the present study would have induced a
312 greater energy deficit compared to that in previous studies (Dall et al., 2002,
313 Kallio et al., 2001, Kraemer et al., 2004a, Kraemer et al., 2004b, Schmidt et
314 al., 2004). We employed a high volume and intensity of exercise for two
315 reasons. Firstly, we attempted to provoke a temporary suppression of hunger
316 which we thought might be linked to suppressed concentrations of plasma
317 total ghrelin. Secondly, we hypothesised that the large energy deficit (3747
318 kJ = approximately 900 kcal) would result in an elevated plasma total ghrelin
319 concentration two hours post exercise when feelings of hunger had returned
320 and possibly increased. Support for this notion comes from the finding that
321 plasma total ghrelin concentration is elevated in women who are in a state of
322 chronic energy deficit as evidenced by amenorrhoea or anorexia (De Souza et
323 al. 2004, Otto et al. 2001). In the present study, the elevated NEFA
324 concentrations on the exercise trial suggest that participants were in an acute

325 state of negative energy balance compared with the control trial. However,
326 there was no evidence that plasma total ghrelin concentrations were increased
327 at any point in the exercise trial.

328

329 The suppressed hunger ratings observed in the present study lasted for at least
330 one hour post-exercise. There was no difference in hunger at the start or end
331 of the trials in the present study, thus the suppression in hunger seen here
332 suggests a temporary exercise-induced anorexia (King et al., 1994, King and
333 Blundell, 1995). It is known that during exercise there is redistribution of
334 blood flow away from the splanchnic circulation towards the working
335 muscles (Rowell, 1974). Since ghrelin is produced in the stomach (Kojima et
336 al., 1999) and blood flow to this region is reduced during exercise we
337 speculated that ghrelin concentrations would also be reduced. Another reason
338 for expecting exercise induced suppression of ghrelin is that exercise
339 increases growth hormone secretion (Schmidt et al 2004) and this is thought
340 to down regulate ghrelin secretion (Korbonits et al 2004). However, ghrelin
341 may stimulate changes in hunger via afferent activity of the vagus nerve
342 (Hosoda et al. 2002). Therefore, it is possible that exercise could influence
343 hunger by altering ghrelin signalling through the vagus nerve without
344 changing circulating ghrelin concentrations.

345

346 Plasma ghrelin concentrations have been shown to change in response to
347 individual meals (Ariyasu et al., 2001, Cummings et al., 2001), although this
348 is not a universal finding (English et al., 2002) and at least one study has

349 demonstrated a preservation of meal related ghrelin responses in subjects
350 who fasted for 24 hours (Natalucci et al. 2005). The acute change in ghrelin
351 following food intake was one factor that led us to hypothesize that plasma
352 total ghrelin concentration might respond acutely to exercise. However, food
353 intake could influence ghrelin concentrations via mechanisms that are less
354 applicable to exercise.

355

356 The presence of nutrients in the gut (Caixas et al., 2002) and increases in
357 insulin (Flanagan et al., 2003) and glucose (Nakagawa et al., 2002)
358 concentrations in the blood have all been associated with reductions in
359 plasma total ghrelin concentration. Such changes do not necessarily occur
360 during or following an acute bout of exercise. Plasma insulin concentrations,
361 for example, were unaffected by exercise in the present study although
362 plasma glucose concentrations were elevated. Moreover, short-term (4-day)
363 energy restriction (-3360 kJ/d) has been found to have no effect on fasting
364 and postprandial plasma total ghrelin concentrations (Doucet et al., 2004).
365 Therefore, perhaps plasma total ghrelin concentrations are more sensitive to
366 acute changes in nutrient intake than to acute physiological changes
367 (redistribution of blood flow, short-term energy deficit) induced by exercise.

368

369 Some studies have reported that plasma total ghrelin concentrations are
370 negatively correlated with BMI, body fat percentage and waist circumference
371 (Ikezaki et al., 2002, Tschop et al., 2001). In the present study BMI was
372 negatively correlated with plasma total ghrelin concentration in the male

373 group. Moreover, body fat percentage and waist circumference showed a
374 trend towards a significant negative correlation with plasma total ghrelin
375 concentration in the males. Possibly the range of values was too narrow in
376 the present study to produce statistically significant correlations. However,
377 the trends in the present study for males support previous evidence that
378 plasma total ghrelin concentration is related to body composition.

379

380 The present study did not control for menstrual cycle phase between trials for
381 female participants. No study has systematically investigated plasma total
382 ghrelin concentration changes over the course of the menstrual cycle.
383 However, Barkan and colleagues (2003) reported that plasma total ghrelin
384 concentration (measured in the late follicular stage of the menstrual cycle)
385 was higher in five young women compared to six young men. Conversely,
386 Tschop and colleagues found no sex differences for plasma total ghrelin
387 concentration in either Caucasians or Pima Indians (Tschop et al., 2001).
388 Similarly, Purnell and co-workers reported that fasting plasma total ghrelin
389 concentrations did not differ in 21 male and 39 female healthy subjects
390 (Purnell et al., 2003). Our findings are consistent with these studies in
391 indicating that plasma total ghrelin concentrations do not differ significantly
392 between men and women.

393

394 Although the findings of the present study concur with the evidence currently
395 available regarding exercise and plasma total ghrelin concentration, caution is
396 required when interpreting the results. Ghrelin is also released in small

397 amounts within the central nervous system and acts directly on the
398 hypothalamus (Kojima et al., 1999). This was not measured in the present
399 study and it is possible that ghrelin release within the central nervous system
400 differed between the control and exercise trials. Furthermore, ghrelin
401 circulates in both active and inactive forms in the plasma (Kojima et al.,
402 1999). The present study measured total plasma ghrelin concentrations (i.e.
403 active and inactive combined) and not active ghrelin. Active ghrelin is more
404 sensitive to changes in energy intake than total ghrelin (Hosoda et al., 2004)
405 and it is possible that active ghrelin may respond to exercise. Nevertheless,
406 previous studies have demonstrated changes in plasma total ghrelin
407 concentration in response to meals (Ariyasu et al., 2001, Cummings et al.,
408 2001) suggesting that changes in total ghrelin do reflect changes in active
409 ghrelin in some situations.

410

411 In conclusion our findings indicate that a one-hour bout of high intensity
412 treadmill running leads to a temporary suppression of hunger. However, this
413 effect does not appear to be mediated through a decrease in plasma total
414 ghrelin concentration. This suggests that plasma total ghrelin concentration is
415 not responsive to acute exercise induced alterations in metabolism.

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584 **Figure Captions**

585

586 **Figure 1.** Subjective feelings of hunger in the fasted state over 3 hours
587 during exercise and control trials. Values are mean $\pm s_{\bar{x}}$, $n=18$. Main effect
588 of trial ($P=0.009$), main effect of time ($P<0.001$), trial $\times$ time interaction
589 ($P<0.001$). *Significantly different ($P<0.05$) between trials using a
590 Bonferroni post hoc test.

591

592 **Figure 2.** Plasma total ghrelin concentrations in the fasted state over 3 hours
593 during exercise and control trials. No significant main effects. No significant
594 interaction. Values are mean $\pm s_{\bar{x}}$, $n=18$.

Table 1. Physical characteristics of the subjects.

	Males ($n=9$)	Females ($n=9$)	P
Age (yrs)	24.5 ± 1.3	25.1 ± 1.2	0.737
Height (m)	1.78 ± 0.02	1.68 ± 0.02	0.007
Body mass (kg)	74.03 ± 4.20	63.57 ± 2.55	0.049
BMI ($\text{kg}\cdot\text{m}^2$)	23.4 ± 1.0	22.5 ± 0.8	0.501
Waist circumference (cm)	79 ± 3	76 ± 1	0.324
Body fat (%)	16.9 ± 1.7	28.3 ± 1.2	0.001
$\dot{V}\text{O}_2$ max ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	63.2 ± 2.5	52.1 ± 2.4	0.006

Values are mean $\pm$ $s_{\bar{x}}$. Means were compared using independent t -tests.

Table 2. Baseline and three-hour areas under the plasma total ghrelin concentration *versus* time curve (AUC) during the control and exercise trials.

	Control	Exercise	<i>P</i>
Baseline Ghrelin			
Whole Group (pmol·L ⁻¹)	412.2 ± 75.6	410.2 ± 66.8	0.910
Males (pmol·L ⁻¹)	463.1 ± 144.0	453.1 ± 130.6	0.664
Females (pmol·L ⁻¹)	361.4 ± 54.1	367.3 ± 38.1	0.840
Ghrelin 3-hour AUC			
Whole Group (pmol·L ⁻¹ ·3 h)	1374.9 ± 231.7	1240.7 ± 179.8	0.189
Males (pmol·L ⁻¹ ·3 h)	1556.1 ± 440.6	1431.9 ± 326.5	0.383
Females (pmol·L ⁻¹ ·3 h)	1193.7 ± 160.5	1049.5 ± 147.2	0.366

Values are mean ± $s_{\bar{x}}$. Whole Group $n=18$; Males $n=9$; Females $n=9$. Means

were compared using *t*-tests for correlated data.

Table 3. Baseline and three-hour areas under the plasma concentration *versus* time curve (AUC) for insulin, NEFA and glucose during the control and exercise trials.

	Control	Exercise	<i>P</i>
Baseline			
Insulin (pmol·L ⁻¹)	158.8 ± 12.0	168.9 ± 12.5	0.455
NEFA (mmol·L ⁻¹)	0.51 ± 0.05	0.53 ± 0.06	0.799
Glucose (mmol·L ⁻¹)	5.27 ± 0.16	5.49 ± 0.18	0.273
3-hour AUC			
Insulin (pmol·L ⁻¹ ·3 h)	494.0 ± 33.7	492.6 ± 35.0	0.962
NEFA (mmol·L ⁻¹ ·3 h)	1.67 ± 0.17	2.29 ± 0.22	0.007
Glucose (mmol·L ⁻¹ ·3 h)	15.66 ± 0.25	16.67 ± 0.35	0.004

Values are mean ± $s_{\bar{x}}$, $n=18$. Means were compared using *t*-tests for correlated data. NEFA: non-esterified fatty acids.