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Research report

Appetite, appetite hormone and energy intake responses to two consecutive days of aerobic exercise in healthy young men ★

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ABSTRACT

Single bouts of exercise do not cause compensatory changes in appetite, food intake or appetite regulatory hormones on the day that exercise is performed. It remains possible that such changes occur over an extended period or in response to a higher level of energy expenditure. This study sought to test this possibility by examining appetite, food intake and appetite regulatory hormones (acylated ghrelin, total peptide-YY, leptin and insulin) over two days, with acute bouts of exercise performed on each morning. Within a controlled laboratory setting, 15 healthy males completed two, 2-day long (09:00–16:00) experimental trials (exercise and control) in a randomised order. On the exercise trial participants performed 60 min of continuous moderate-high intensity treadmill running (day one: 70.1 ± 2.5% VO2 peak; day two: 70.0 ± 3.2% VO2 max (mean ± SD)) at the beginning of days one and two. Across each day appetite perceptions were assessed using visual analogue scales and appetite regulatory hormones were measured from venous blood samples. Ad libitum energy and macronutrient intakes were determined from meals provided two and six hours into each day and from a snack bag provided in-between trial days. Exercise elicited a high level of energy expenditure (total = 7566 ± 635 kJ across the two days) but did not produce compensatory changes in appetite or energy intake over two days (control: 29,217 ± 4006 kJ; exercise: 28,532 ± 3899 kJ, P > 0.050). Two-way repeated measures ANOVA did not reveal any main effects for acylated ghrelin or leptin (all P > 0.050). However a significant main effect of trial (P = 0.029) for PYY indicated higher concentrations on the exercise vs. control trial. These findings suggest that across a two day period, high volume exercise does not stimulate compensatory appetite regulatory changes.

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Introduction

The interaction between exercise, appetite control and energy balance has direct relevance for the implementation of exercise as a therapeutic strategy for weight control. Over the last decade, many studies have investigated the impact of acute exercise, and exercise training, on appetite perceptions, food intake and energy balance (Hopkins, King, & Blundell, 2010). Currently, a disparity exists whereby on the one hand evidence suggests that exercise training (4–12 months) does not induce substantial weight loss due to compensatory responses i.e. increases in appetite and food intake (Hopkins et al., 2014; King et al., 2007; Wing, 1999); whilst on the other hand acute laboratory-based studies consistently document that acute exercise has no influence on appetite or ad libitum food intake (King, Burley, & Blundell, 1994; King, Wasse, & Stensel, 2013; Wasse, Sunderland, King, Batterham, & Stensel, 2012). Indeed, a recent meta-analysis concluded that acute exercise has a trivial effect on subsequent energy intake (Schubert, Desbrow, Sabapathy, & Leveritt, 2013). It is possible that this inconsistency between outcomes is related to the rather loose coupling which exists between perturbations to energy balance induced by exercise and subsequent energy intake (Blundell & King, 1998). Compensatory alterations in appetite and food intake in response to single bouts of exercise could possibly occur over a longer duration than that previously examined in acute laboratory studies i.e. over more than 24 h. To date, only two studies have looked at this proposition in detail under strict laboratory conditions. In one study, appetite responses before and after a test meal were examined on the day after a single bout of moderate-intensity exercise (Heden, Liu, Park, Dellsperger, & Kanaley, 2013). The researchers reported that...
exercise on the previous evening reduced perceptions of fullness in obese volunteers, but had no influence in lean individuals. More recently, Beaulieu, Oliver, Abbott, and Lemon (2015) examined appetite and ad libitum energy intake responses over 34 h with an acute bout of sprint interval exercise being performed at the beginning of the trial. The researchers observed a transient suppression of appetite, characteristic of exercise-induced anorexia (King et al., 1994), but then observed a latent increase in hunger and motivation to eat several hours after exercise leading to increased 34-h AUC values compared to control conditions. There was no effect of exercise on energy intake. However, it should be noted that in this study appetite perceptions and ad libitum energy intake may have been compromised by reports of nausea and vomiting during and after exercise (Seimon et al., 2010). Additional work is needed to extend these preliminary findings in order to identify the initial stage of compensation and to better understand the regulatory mechanisms.

Advances in knowledge about the neuro-humoral regulation of appetite and energy homeostasis have catalysed research investigating the influence of exercise on hormones implicated in appetite control and energy balance (King, Wasse, Stensel, & Nimmo, 2013; Schubert, Sabapathy, Leveritt, & Desbrow, 2013; Stensel, 2010). Findings from this body of work were recently pooled in a meta-analysis investigating the influence of exercise on hormones implicated in appetite and energy homeostasis have catalysed research (Heden et al., 2008; Miyashita, 2007; Seimon et al., 2010; King et al., 1994; Stunkard & Messick, 1985). Participants had no history of cardiovascular or metabolic disease. Participants were recreational games players, not accustomed to performing repeated, prolonged bouts of moderately-high intensity running. This ensured that the aerobic exercise stimulus was unfamiliar to the participants. Table 1 describes the participant characteristics.

### Table 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21.1 ± 1.7</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>23.0 ± 1.9</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>74.8 ± 6.8</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>78.5 ± 5.2</td>
</tr>
<tr>
<td>Treadmill peak oxygen uptake (ml·kg⁻¹·min⁻¹)</td>
<td>57.9 ± 4.2</td>
</tr>
</tbody>
</table>

Before main trials, participants visited the laboratory to undergo preliminary assessments (questionnaires, anthropometry, exercise testing) and to be familiarised with the laboratory environment and study procedures. Specifically, participants completed questionnaires assessing health status, food preferences, habitual physical activity and psychological eating tendencies (Three-Factor Eating Questionnaire (TFEQ)) (Stunkard & Messick, 1985). Participants scoring 11 or more for any factor on the TFEQ were determined to exhibit restrained or disinhibited eating tendencies, and consequently excluded from taking part. Height was measured to the nearest 0.1 cm using a stadiometer (Seca Ltd, Germany) and body weight was measured to the nearest 0.01 kg using a balance beam scale (Avery Industrial Ltd, Leicester, UK). Body mass index (BMI) was subsequently calculated as weight (kg) divided by height (m²). Waist circumference was determined as the narrowest part of the torso between the xiphoid process and the iliac crest (Ross et al., 2008).

To determine the treadmill speed required to elicit 70% of maximum aerobic capacity during main trials, two preliminary running tests were undertaken: 1) a progressive-submaximal test to determine the relationship between treadmill speed and oxygen consumption, 2) a peak oxygen uptake test. Both tests have been described in-depth previously (Broom, Stensel, Bishop, Burns, & Miyashita, 2007). During each test, oxygen consumption and carbon dioxide production were determined from frequent expired air samples collected into Douglas bags (Plysun Protection Systems, Milton Keynes, UK) and analysed using a dry gas metre (Harvard Apparatus, Edenbridge, Kent, UK) and paramagnetic oxygen/infra-red carbon dioxide analyser (Series 1400, Servomex, Crowborough, East Sussex, UK).

### Experimental procedures

Participants completed two, 2-day experimental trials (exercise and control) in a crossover design with each trial being separated by at least one-week (Fig. 1). Each trial required participants to attend the laboratory between 09:00 and 16:00 on day one and day two. Participants remained physically inactive in the time spent away from the laboratory in-between days one and two. Ad libitum food intake was monitored throughout trials including the evening period between days one and two.

### Methods

#### Participants

Following approval from the Institutional Ethics Advisory Committee, 15 healthy physically active males (18–24 years) provided written informed consent to participate in this study. Participants were non-smokers, not taking medication, weight stable for at least three months before the study (body mass deviation of less than ±2 kg) and were not dieting or exhibiting any extreme dietary habits (including disinhibited and restrained eating tendencies) (Stunkard & Messick, 1985). Participants had no history of cardiovascular or metabolic disease. Participants were recreational games players, not accustomed to performing repeated, prolonged bouts of moderately-high intensity running. This ensured that the aerobic exercise stimulus was unfamiliar to the participants. Table 1 describes the participant characteristics.

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Before each trial participants standardised their dietary intake for 48 h using a weighed food record (24-h average reported energy intake: 11,226 ± 2956 kJ). Alcohol, caffeine and structured physical activity were not permitted during this time. On day one of the exercise trial participants arrived at the laboratory following an overnight fast of at least 10 h. After the collection of a fasting blood sample, participants commenced a 60 min continuous treadmill run (Technogym Excite Med, Cesena, Italy) at a speed predicted to elicit 70% of VO₂ peak. Expired air samples were collected at 15, 30, 45 and 60 min during exercise to monitor the intensity with subtle adjustments being made to the treadmill speed if necessary. Heart rate and ratings of perceived exertion (RPE, Borg, 1973) were assessed periodically during the run. Energy expenditure during the exercise session was calculated from oxygen uptake and carbon dioxide production (Frayn, 1983). These measurements were also used to calculate non-protein respiratory exchange ratio (RER) (carbon dioxide production divided by oxygen consumption).

Following the run participants rested in the laboratory for 6 h (sitting, reading, working at a desk or watching films). At the end of this time a blood sample was collected, after which participants left the laboratory. Participants returned the next day to determine actual consumption. Water was available for 30 min throughout trials. The procedures in the control trial were identical to the exercise trial except that no exercise was performed. The sole exception to this was that resting expired air samples were collected during the first hour of each control trial day to assess resting metabolic rate. These data subsequently permitted the calculation of net exercise energy expenditure i.e. gross exercise energy expenditure minus resting energy expenditure.

**Appetite and food intake**

During the laboratory phase of the main trials appetite perceptions (hunger, satisfaction, fullness and prospective food consumption (PFC)) were assessed at baseline and every 30 min thereafter using 100 mm visual analogue scales (Flint, Raben, Blundell, & Astrup, 2000). Energy and macronutrient intake were assessed from two ad libitum meals provided on both days of the exercise and control trials. Specifically, at 2 h a cold buffet meal was provided with participants being given access for 30 min. The items available were: semi-skimmed milk, three varieties of cereal, white bread, brown bread, margarine, mayonnaise, ham, tuna, crisps, chocolate rolls, Mars bars, cereal bars, cookies, muffins, apples, oranges and bananas. The buffet foods were presented identically on each occasion and were in excess of expected consumption. Participants were instructed to eat until ‘comfortably full’ and informed that additional food was available if desired. At 6 h a hot ad libitum meal was provided. This was a homogenous pasta meal, composed of white fusilli that was cooked in a microwave for 10 min in unsalted water and mixed with a tomato sauce, Cheddar cheese and olive oil. The macronutrient composition of the meal was balanced (52% carbohydrate, 14% protein and 34% fat), and designed to meet current UK dietary guidelines (Food Standards Agency, 2007). Participants were provided with a small bowl of the meal which was replaced with a full bowl at regular intervals in an attempt to blind the participants from the amount of food eaten. Participants consumed meals in isolation so that social influence did not affect food selection or quantity eaten. Leftovers were weighed and food consumption was determined as the weighed difference of items before and after each meal. The energy and macronutrient content of the items consumed were determined from manufacturers’ values.

For the time spent away from the laboratory in-between the visits on day one and day two participants were free to select, and consume, a selection of items presented at the cold buffet meal. Participants were permitted to consume these items after leaving the laboratory on day one and until 22:30. The food items available for selection included; crisps, chocolate rolls, Mars bars, cereal bars, cookies, muffins, apples, oranges and bananas. Leftovers were returned the next day to determine actual consumption. Water was available ad libitum throughout trials.

**Blood sampling**

Venous blood samples were collected at 0 and 7 h on day one of each trial, and at 0, 2, 3, 6 and 7 h during day two of trials. Both samples on day one, and the baseline sample on day two, were collected by venepuncture of an antecubital vein. The remaining blood samples on day two were collected using a cannula (Venflon, Becton Dickinson, Helsingborg, Sweden) inserted into an antecubital vein. Blood samples were taken into pre-chilled EDTA monovettes (Sarstedt, Leicester, UK) for the measurement of plasma total PYY, acylated ghrelin, leptin, glucose and insulin. As per manufacturer instructions, samples collected for acylated ghrelin were taken into monovettes containing protease inhibitors and were spun in a refrigerated centrifuge (Heraeus Labofuge 400R, Thermo Electron, Osterode, Germany) at 1287 × g for 10 min at 4 °C. The plasma supernatant was immediately removed and acidified before sample storage. All other samples were spun at 1681 × g for 10 min at 4 °C.
with plasma supernatant being collected and stored for future analysis.

At each sampling point duplicate 20 μL blood samples were collected into micropipettes for the determination of haemoglobin, and triplicate 20 μL blood samples were collected into heparinised micro haematocrit tubes for the determination of blood haematocrit concentration. These data were used to estimate plasma volume and to assess changes over time (Tudor-Locke & Bassett, 2004).

**Biochemical analysis**

Enzyme immunoassays were used to determine concentrations of plasma acylated ghrelin (SPI BIO, Montigny le Bretonneux, France), total PYY (Millipore, Billerica, USA), leptin (R&D Systems, Minneapolis, USA) and insulin (Mercodia, Uppsala, Sweden). Plasma glucose concentrations were determined by enzymatic, colorimetric methods using a bench top analyser (Pentra 400; HORIBA ABX Diagnostics, Montpellier, France). To eliminate inter-assay variation, samples from each participant were analysed on the same run. The within-batch coefficients of variation for the assays were as follows: acylated ghrelin 10.9%, total PYY 7.7%, leptin 5.9%, insulin 7.9%, and glucose 0.6%.

**Statistical analysis**

Data were analysed using IBM SPSS statistics, version 21.0 for Windows. Appetite perceptions and appetite hormone area under the curve (AUC) calculations were performed using the trapezoidal method. Comparison between trials for exercise responses, energy and macronutrient intake, and day two AUC appetite hormone data were compared using Student’s paired t-tests. Two-way repeated measures ANOVA was used to examine differences between trials and interaction effects. Post-hoc analyses were performed using Bonferroni correction for multiple comparisons (Atkinson, 2002). The Pearson product moment correlation coefficient was used to examine relationships between variables. Corrections of plasma analyte values for changes in plasma volume did not alter the statistical significance of the results; therefore, for simplicity, the unadjusted values are presented. Statistical significance was accepted at 5%. Results are shown as mean ± SD in text and tables, and mean ± SEM in figures (for clarity).

**Results**

**Exercise responses**

The exercise responses for day one and day two are summarised in Table 2. There was no significant difference in oxygen consumption, exercise intensity, running speed, RPE, net energy expenditure or respiratory exchange ratio (RER) between the two days of exercise. There was no difference between trials in pedometer-assessed physical activity (control 4337 ± 1683; exercise 4524 ± 2112 counts \( P = 0.991, r = 0.84 \)) demonstrating that participants remained equally inactive outside of formal exercise periods during main trials (<5000 steps; Tudor-Locke & Bassett, 2004).

**Appetite responses**

Fasting appetite perceptions (hunger, satisfaction, fullness and PFC) did not differ between trials at baseline on either day of each trial (all \( P > 0.061 \)). Two-way ANOVA revealed a significant main effect of time (all \( P < 0.001 \)) and interaction effects (all \( P < 0.001 \)) for each appetite perception (Fig. 2). Significant trial effects were also reported for hunger (\( P = 0.046 \)) and PFC (\( P = 0.045 \)), indicating suppressed levels in the exercise trial across days one and two. Compared with control, post-hoc analysis revealed suppressed hunger ratings at 1.5 h on day one (\( P = 0.029 \)) and at 0.5 (\( P = 0.029 \)) and 1 h (\( P < 0.001 \)) on day two of the exercise trial. Fullness ratings were significantly elevated at 1 h on day one of the exercise trial (\( P = 0.030 \)), whilst PFC was lower at 0.5 (\( P = 0.029 \)) and 1 h (\( P < 0.001 \)) on day two of the exercise trial.

Analysis of the appetite AUC (calculated separately for days one and two) using two-way ANOVA (day vs. trial) confirmed significant trial effects for hunger (\( P = 0.042 \)), fullness (\( P = 0.050 \)), and PFC (\( P = 0.036 \)) but did not show any differences in appetite between trial days one and two (data not shown).

Tables 3 and 4 show the energy and macronutrient intake data from the exercise and control trials. No significant main effects were apparent for energy intake (all \( P > 0.137 \)). For macronutrient intake, no significant main effects were found for carbohydrate or fat intake (all \( P > 0.261 \)), however a main effect of time was observed for protein intake (\( P < 0.001 \)) which was reduced during the evening period between days 1 and 2 on both the control and exercise trials. Relative energy intake (REI) was calculated for days one and two as energy intake minus the net energy expenditure elicited by exercise (exercise day one: 3179 ± 586 kJ; exercise day two: 1934 ± 321 kJ; control day one: 4127 ± 663 kJ; control day two: 2856 ± 196 kJ). Significant trial (\( P < 0.001 \)) and time (\( P < 0.001 \)) effects were found, indicating lower REI across days one and two on the exercise trial and also reflecting the fewer number of meals consumed on day two compared with day one (three vs. two) on both trials.

Two-way ANOVA revealed a significant main effect of trial for ad libitum water intake (\( P < 0.001 \)) (exercise day one: 1825 ± 825 ml; exercise day two: 1687 ± 692 ml; control day one: 1319 ± 842 ml; control day two: 1301 ± 591 ml).

**Blood analyses**

Due to problems with blood sampling data for plasma acylated ghrelin, total PYY and leptin are presented for 14 (rather than 15) participants whilst data for plasma insulin are presented for 13 (rather than 15) participants. Figure 3 shows the circulating appetite hormone responses on days one and two of the control and exercise trials.

Fasting acylated ghrelin concentrations did not differ between the exercise and control trials at baseline on day one or day two (control day one: 128 ± 113; exercise day one: 144 ± 169; control day two: 127 ± 121; exercise day two: 117 ± 143 pg/mL (P for trial, time and interaction all >0.05)) (Fig. 3A). Across the whole trial, two-way repeated measures ANOVA did not show any significant main effects for plasma acylated ghrelin (all \( P > 0.05 \)).

Fasting plasma total PYY concentrations did not differ between trials at baseline on day one or day two of main trials (control day one: 84 ± 40; exercise day one: 95 ± 63; control day two: 87 ± 37; exercise day two: 104 ± 50 pg/mL (P for trial, time and interaction all >0.05)) (Fig. 3B). Across the whole trial, two-way repeated measures ANOVA revealed a significant main effect of trial (\( P = 0.029 \))
indicating higher total PYY concentrations on the exercise trial. There was also a significant main effect of time ($P < 0.001$) for total PYY.

Fasting plasma leptin concentrations did not differ between trials at baseline on day one or day two of the exercise and control trials (control day one: $1543 \pm 1042$; exercise day one: $1738 \pm 1716$; control day two: $1860 \pm 2044$; exercise day two: $1710 \pm 1733$ pg/mL, $P > 0.333$) (Fig. 3C). Across trial days, two-way repeated measures ANOVA revealed a significant main effect of time ($P < 0.001$) but no trial or interaction effects ($P > 0.05$).

Fasting plasma insulin concentrations were found to differ across time ($P = 0.0015$); however, there were no trial or interaction effects (both $P > 0.05$) (control day one: $21 \pm 5$; exercise day one: $25 \pm 10$; control day two: $30 \pm 10$; exercise day two: $29 \pm 13$ pmol/mL) (Fig. 3D). Across trial days, two-way repeated measures ANOVA
revealed a significant trial ($P = 0.025$), time ($P < 0.001$) and interaction effect ($P = 0.019$) for plasma insulin concentrations. Post-hoc analysis showed insulin levels to be significantly lower for the exercise condition in comparison to the control condition at 2 h on day two ($P < 0.001$).

Area under the curve calculations for day two of each trial revealed no significant differences for acylated ghrelin (control: 833 ± 1090; exercise: 909 ± 1337 pg/mL/h) and leptin (control: 10,376 ± 10,652; exercise: 9783 ± 9244 pg/mL/h) (both $P > 0.050$). For insulin, values were significantly lower during the exercise trial (control: 1446 ± 785; exercise: 852 ± 316 pmol/mL/h, $P = 0.050$), whilst total PYY values were significantly higher (control: 720 ± 253; exercise: 883 ± 374 pg/mL/h, $P = 0.010$).

### Correlations

Correlation analyses were performed for all major outcomes (AUC hormone data and appetite ratings, energy intake and subject characteristics); however, no statistically significant outcomes were found (data not shown).

### Table 4

Macronutrient intake in the control and exercise trials.

<table>
<thead>
<tr>
<th>Day</th>
<th>Control Trial</th>
<th>Exercise Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fat (g)</td>
<td>Carbohydrate (g)</td>
</tr>
<tr>
<td></td>
<td>[%]</td>
<td>[%]</td>
</tr>
<tr>
<td>1</td>
<td>Cold buffet (2 h)</td>
<td>51 ± 35</td>
</tr>
<tr>
<td></td>
<td>[29 ± 10]</td>
<td>[58 ± 11]</td>
</tr>
<tr>
<td></td>
<td>Hot meal (6 h)</td>
<td>54 ± 8</td>
</tr>
<tr>
<td></td>
<td>[34 ± 0]</td>
<td>[52 ± 0]</td>
</tr>
<tr>
<td></td>
<td>Overnight food</td>
<td>47 ± 14</td>
</tr>
<tr>
<td></td>
<td>[34 ± 5]</td>
<td>[61 ± 6]</td>
</tr>
<tr>
<td>2</td>
<td>Cold buffet (2 h)</td>
<td>47 ± 24</td>
</tr>
<tr>
<td></td>
<td>[29 ± 11]</td>
<td>[59 ± 12]</td>
</tr>
<tr>
<td></td>
<td>Hot meal (6 h)</td>
<td>54 ± 7</td>
</tr>
<tr>
<td></td>
<td>[34 ± 0]</td>
<td>[52 ± 0]</td>
</tr>
<tr>
<td></td>
<td>Overnight food</td>
<td>47 ± 12</td>
</tr>
<tr>
<td></td>
<td>[35 ± 5]</td>
<td>[60 ± 5]</td>
</tr>
<tr>
<td></td>
<td>Total trial</td>
<td>252 ± 59</td>
</tr>
<tr>
<td></td>
<td>[32 ± 4]</td>
<td>[56 ± 4]</td>
</tr>
</tbody>
</table>

Mean ± SD ($N = 15$). Food consumption outside of the lab on day 1 (overnight) was between 16:30 and 22:30.

### Discussion

The consensus from the research literature suggests that exercise does not stimulate appetite on the day it is performed, even when responses have been examined for several hours post-exercise. Conversely, daily exercise undertaken over four to five consecutive days has been shown to increase hunger, motivation to eat or reduce satiation (Hagobian et al., 2009; Mackelvie et al., 2007). The present study sought to explore whether initial alterations in appetite could be detected after two bouts of exercise performed on consecutive days across a period of 30 h after the first bout of exercise. Besides witnessing a transient exercise-induced suppression of appetite on each day, we observed no subsequent changes in any of the subjective appetite measurements assessed. Thus, repeated bouts of exercise on two days did not impact hunger, satiation or satiety. These findings indicate that over this duration, exercise and its associated energy expenditure, are not perceived.

Previously, King, Lluch, Stubbs, and Blundell (1997) examined appetite responses across two days with two bouts of exercise being performed on the first day of the exercise trial [combined energy expenditure 4983 ± 1004 kJ]. Similar to the current investigation, these researchers observed no alterations in appetite. It should however be noted that in this particular study appetite assessments were made in participants' free living environment; meaning that various extraneous factors may have confounded the results. More recently, Heden et al. (2013) also observed no changes in fasting or postprandial ratings of hunger and fullness in response to a test meal consumed on the morning after moderate-intensity exercise completed on the previous evening. In contrast to these findings, Beaulieu et al. (2015) recently published data showing a greater motivation to eat on the day after a single bout of sprint interval training (supra-maximal exercise) in a small group of trained men ($N = 8$). Taken collectively, the available data suggest that acute exercise, even when repeated on two days, does not automatically stimulate appetite. Very high intensity exercise may be an exception; however additional studies with a larger group of more diverse participants are needed to state this with any certainty.

An additional aim of the present investigation was to characterise the extended impact of exercise on energy and macronutrient intake. Consistent with the lack of alteration in appetite, we also observed no significant changes in energy or macronutrient intake assessed from several ad libitum meals consumed across days one and two. Previous studies have shown that over an extended period (one to two weeks) individuals may begin to partially increase the amount of food consumed in an attempt to counter the heightened energy expended during exercise (Stubbs, Sepp, Hughes, Johnstone, Horgan et al., 2002; Stubbs, Sepp, Hughes, Johnstone, King et al., 2002; Whybrow et al., 2008). The precise point at which this response is initiated is not known; however it is clear that such compensation does not occur immediately on the actual day that exercise is performed (Schubert, Desbrow et al., 2013). When considering responses on the day after exercise, King et al. (1997) previously reported a lack of change in energy intake. Unfortunately in this study the implementation of diaries to assess energy intake, and the aforementioned lack of study control, limits the strength of these findings. The present study sought to provide a more rigorous analysis by utilising laboratory based assessments of energy and macronutrient intake. The present results are consistent with recent findings reported by Beaulieu et al. (2015) who observed no changes in energy intake within the 36 h after sprint interval training. Together, these data indicate that the initial stages of energy intake compensation are not seen on the day after exercise, even when a successive bout is performed on the second day. It is likely that compensatory responses will begin to appear after...
additional days of exercise with a higher level of energy expenditure and/or negative energy balance.

Appetite and food intake are subject to regulation by a complex network of neural-hormonal mediators which act acutely (meal to meal) and chronically (over days/weeks) to facilitate energy homeostasis (Neary & Batterham, 2009; Perry & Wang, 2012). Notable within the short-term regulation of appetite and energy intake are acylated ghrelin and PYY which work antagonistically to coordinate meal initiation and termination (De Vriese, Perret, & Delporte, 2010; Manning & Batterham, 2014). Specifically, acylated ghrelin remains unique as the only known hormonal stimulant of appetite, with circulating levels increasing prior to meal initiation and subsequently decreasing postprandially (Cummings, Frayo, Marmonier, Aubert, & Chapelot, 2004). Conversely, PYY is a key mediator of satiation and satiety, with circulating levels increasing in response to nutrient intake and remaining elevated between meals (Le Roux et al., 2005). Acylated ghrelin and PYY are also implicated in the chronic regulation of energy homeostasis with each being sensitive to deviations in energy balance/stores. Specifically, negative energy balance and weight loss increased circulating levels of acylated ghrelin (King et al., 2011; Leidy, Dougherty, Frye, Duke, & Williams, 2007) and reduced those of PYY (Hill, De Souza, & Williams, 2011; King et al., 2011). These responses serve to promote the restoration of energy balance and limit perturbations in body weight. The present study sought to characterise the latent impact of exercise on acylated ghrelin and PYY. Specifically, we wanted to determine how exercise, and the associated high level of energy expenditure, would impact circulating levels of these hormones over an extended duration. It was anticipated that fasting and/or postprandial levels of acylated ghrelin on day two would be elevated, whilst those of PYY would be reduced as mechanisms to preserve energy homeostasis. In contrast, we saw no changes in acylated ghrelin whilst PYY was transiently elevated on day two after exercise. The present findings therefore contrast recent data reported by Heden et al. (2013) who observed attenuated fasting and postprandial suppression of acylated ghrelin at a test meal consumed on the morning after exercise completed on the previous evening. The discrepancy in findings is likely related to key differences between protocols such as the time between exercise and blood sampling and the additional bout of exercise performed in the present study. This inconsistency in outcome identifies a need to further scrutinise the protracted impact of exercise on acylated ghrelin.

In the present investigation we saw no change in fasting levels of PYY on day two; however a transient increase in circulating PYY levels was apparent after the second bout of exercise i.e. on day two. This investigation is the first to assess the impact of exercise on the fasting level of PYY on the day after exercise and therefore the lack of change despite a high level of energy expenditure is a novel observation. The short-term increase in PYY after exercise on day two is consistent with previous research which has described a transient increase in PYY in response to moderate-high intensity exercise (Broom, Batterham, King, & Stensel, 2009; Martins, Morgan, Bloom, & Robertson, 2007; Ueda et al., 2009). It is beyond the scope of the present manuscript to speculate on the mechanisms mediating this response; it is clear however that this acute effect is maintained with repeated bouts of exercise on consecutive days. Nonetheless, we did not observe any compensatory down-regulation of PYY in response to exercise-related energy expenditure across the timeframe examined. Furthermore, as shown in previous studies, this exercise-induced change in PYY does not appear to have any influence on appetite or energy intake. PYY has many physiological functions in the body e.g. gastrointestinal transit, substrate metabolism, thermogenesis; and it is possible that the change we are witnessing with exercise is unrelated to appetite control and food intake. Conversely, it is also possible that the response is relevant but is insufficient to overcome ingrained habits and behaviour relating to food intake so that visible effects on these outcomes may only be seen over a greater period of time or with a larger stimulus.

Episodic signals regulating appetite and energy intake function synergistically with additional chronic hormonal mediators which
are primarily sensitive to perturbations in energy balance and bodily energy stores. Within this system leptin and insulin are well defined; being positively associated with energy availability and responding dynamically to perturbations in energy balance (Gautron & Elmqquist, 2011; Woods, Lutz, Geary, & Langhans, 2006). Previous research has shown that leptin is sensitive to negative energy balance induced by exercise (≥ 3340 kJ) with compensatory decreases in circulating levels being detectable after a latency period of 12–24 h (Essig, Alderson, Ferguson, Bartoli, & Durstine, 2000; Olive & Miller, 2001). In the present investigation, despite a net energy expenditure of ~3765 kJ on day one, we did not detect any change in fasting leptin on the following morning; nor did we see any changes after the second bout of exercise on day two. It is possible that the second bout of exercise on day two may have masked any latent changes which may have otherwise occurred. Furthermore, despite exercise on day one inducing a relative energy deficit of 4234 kJ, the somewhat high amount of energy intake across each trial on day one (control 17268 ± 2775; exercise 10812 ± 2899 kJ) may have been sufficient to block any exercise-related decrease in leptin.

In addition to its central role in regulating glycemia, insulin is also a tonic signal regulating energy balance either by acting directly within the hypothalamus, or by modulating the brain’s sensitivity to episodic appetite signals (McMinn, Sindelar, Havel, & Schwartz, 2000; Woods et al., 2006). Chronically, circulating levels of insulin are positively related to adiposity and insulin resistance within key metabolic tissues. An increase in insulin sensitivity is a well characterised effect of acute exercise that endures for up to 72 h after each individual bout (Hawley & Lessard, 2008). In the present study our participants were young and healthy, with low basal insulin levels. It is therefore perhaps unsurprising that fasting concentrations on day two were not lowered further by prior exercise. On day two we did however observe reduced levels of insulin in response to the morning meal; a response which is consistent with an enhancement of insulin sensitivity induced by exercise. Although important for glycemic control, this transient response is unlikely to have any influence on energy balance.

This study has some notable limitations. By estimating participants’ energy requirements (Mifflin et al., 1990) it appears that participants overate during main trials. This was likely due to the wide selection of foods available at ad libitum meals and an associated ‘banquet effect.’ Consequently, the sensitivity to detect changes in energy intake after consecutive days of exercise may have been reduced. Furthermore, such overconsumption may have also dampened the ability to detect changes in appetite hormones in response to exercise. Another limitation of this study is that performance of a second bout of exercise may have masked any changes in study outcomes on day 2; however this is unlikely given other recent findings of ours (King et al., 2015). Finally, this study focused solely on homeostatic factors contributing to the regulation of appetite and food intake. Recent investigations have highlighted the importance of hedonic factors contributing to these outcomes (Crabtree, Chambers, Hardwick, & Blannin, 2014; Everno, Hackett, Clark, Phelan, & Hagobian, 2012).

In summary, this investigation sought to characterise the impact of two bouts of moderate to high intensity exercise, performed on consecutive mornings, on appetite perceptions, food intake and circulating levels of key appetite regulatory hormones. This study found that besides inducing a transient inhibition of appetite, exercise did not exert any other influence on subjective appetite perceptions and did not alter ad libitum energy or macronutrient intake on day one or two. Furthermore, exercise had no impact on circulating levels of leptin or acylated ghrelin, but did augment levels of total PYY and reduced those of insulin, on day two. These findings support previous data in lean individuals, indicating that acute exercise does not induce compensatory appetite or food intake responses within the short-term (King et al., 1994; King, Wasse, & Stensel, 2013; Wasse et al., 2012). This study has demonstrated that this lack of response persists on the day after exercise.

References


