Acute exercise increases feeding latency in healthy normal weight young males but does not alter energy intake

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Abstract

This study investigated the acute influence of exercise on eating behaviour in an ecologically valid setting whereby healthy active males were permitted complete *ad libitum* access to food. Ten healthy males completed two, eight hour trials (exercise and control) in a randomised-crossover design. In the exercise trials participants consumed a breakfast snack and then rested for one hour before undertaking a 60 min run (72% of $\dot{V}O_2$ max) on a treadmill. Participants then rested in the laboratory for six hours during which time they were permitted complete *ad libitum* access to a buffet meal. The timing of meals, energy/macronutrient intake and eating frequency were assessed. Identical procedures were completed in the control trial except no exercise was performed. Exercise increased the length of time (35 min) before participants voluntarily requested to eat afterwards. Despite this, energy intake at the first meal consumed, or at subsequent eating episodes, was not influenced by exercise (total trial energy intake: control 7426 kJ, exercise 7418 kJ). Neither was there any difference in macronutrient intake or meal frequency between trials. These results confirm that food intake remains unaffected by exercise in the immediate hours after but suggest that exercise may invoke a delay before food is desired.

Key words: Exercise, appetite, hunger, energy intake, food intake, feeding latency

Introduction

The influence of exercise on appetite regulation and eating behaviour has important implications regarding its impact on energy balance and weight control (King, Hopkins, Caudwell, Stubbs & Blundell, 2008). Over the last decade, advancements in scientific understanding of the physiological and psychological regulation of appetite and ingestive behaviour have ignited interest around the interaction between exercise, appetite regulation, food intake and weight control. Within this sphere of research, one particular issue that has received significant attention is the short-term impact of acute bouts of exercise on appetite perceptions (e.g. subjective ratings of hunger, fullness, satisfaction and prospective food consumption) and *ad libitum* energy/macronutrient intake.

Evidence has accumulated demonstrating that exercise, regardless of modality (running, cycling, resistance exercise or swimming), transiently suppresses appetite, if performed at a moderate intensity or higher (Broom, Batterham, King & Stensel, 2009; King & Blundell, 1995; King, Miyashita, Wasse & Stensel, 2010; King et al., 2011). This phenomenon has been termed 'exercise induced anorexia' (King, Burley & Blundell, 1994). Despite this potent and consistent effect of exercise, the consensus of the available evidence suggests that this acute appetite perturbation has no subsequent influence on an individual's energy intake or macronutrient preference immediately (Balaguera-Cortes, Wallman, Fairchild & Guelfi, 2011; Hubert, King & Blundell, 1998; King & Blundell, 1995; King, Burley & Blundell, 1994; King, Snell, Smith & Blundell, 1996), or for several hours after exercise (King, Miyashita, Wasse & Stensel, 2010; King et al., 2011; King, Wasse & Stensel, 2011; Wasse, Sunderland, King & Stensel, 2012). Exceptions to this rule have been reported however where energy intake has been

found to be augmented (Martins, Morgan, Bloom & Robertson, 2007) or reduced (Kissileff, Pi-Sunyer, Segal, Meltzer & Foelsch, 1990; Verger, Lanteaumem & Louis-Sylvestre, 1994; Westerterp-Plantenga, Verwegen, Ijedema, Wijckmans & Saris, 1997) after single bouts of exercise.

In most studies that have sought to investigate the short-term influence of exercise on food intake, including some of those conducted within our laboratory, the typical method used to assess energy intake has involved examining energy/macronutrient intake from *ad libitum* meals (buffet style or single item) provided to participants at defined time points during trials (Balaguera-Cortes, Wallman, Fairchild & Guelfi, 2011; George and Morganstein, 2003; Hubert, King & Blundell, 1998; Imbeault, Saint-Pierre, Almeras & Tremblay, 1997; King, Lluch, Stubbs & Blundell, 1997; King, Miyashita, Wasse & Stensel, 2010; King et al., 2011; King, Wasse & Stensel, 2011; Kissileff, Pi-Sunyer, Segal, Meltzer & Foelsch, 1990; Martins, Morgan, Bloom & Robertson, 2007; Pomerleau, Imbeault, Parker & Doucet, 2004; Thompson, Wolfe & Eikelboom, 1988; Tsofliou, Pitsiladis, Malkova, Wallace & Lean, 2003; Verger, Lanteaume & Louis-Sylvestre, 1994; Wasse, Sunderland, King, Batterham & Stensel, 2012; Westerterp-Plantenga et al., 1997).

Within this popular methodology participants are typically given discrete pre-scheduled opportunities to eat '*until satisfaction*' from a selection of food items for a set duration of time. Consequently, when examining food intake responses to exercise interventions using this protocol participants' eating behaviour is highly constrained by the predefined feeding schedule that has been determined at the outset by experimenters. Participants therefore do not have the freedom to eat as and when they choose, and

consequently it is possible that this restrictive practice may have impacted food intake outcomes in previous experiments. This procedure also limits our ability to analyse other important aspects of eating behaviour such as feeding latency post-exercise and eating frequency.

The aim of the present study was to examine the acute effects of moderate-high intensity exercise on energy and macronutrient intake when participants are provided with complete unrestricted access to common food items within a controlled laboratory setting. Within this less restrictive protocol, we sought to examine other key components of feeding behaviour such as eating latency post exercise, meal/snack frequency and macronutrient preferences. We anticipated that exercise would delay the voluntary request of a meal compared with responses on a control trial however we were uncertain whether the unrestricted feeding protocol would reveal any other influences of exercise on eating behaviour.

Methods

Participants

After gaining local Ethical Advisory Committee approval 11 healthy males gave their written informed consent to participate. One participant failed to complete all of the research procedures within this study and consequently data are presented for 10 participants. Participants were healthy non-smoking individuals, free of cardio-metabolic disease, not taking any medications and were not obese (BMI $\leq$ 29.9 $kg.m^{-2}$) or hypertensive (blood pressure <140/90 mmHg). All participants were recreationally active (typically games players) and possessed a relatively high level of aerobic fitness. Based on the known occupation of the participants (University students) and habitual physical activity questionnaire responses, it was estimated that participants' physical activity level (PAL) was between 1.70-1.99. This range represents individuals with a predominantly sedentary occupation but who spend a defined amount of time undertaking bouts of moderate to vigorous physical activity (FAO/WHO/UNU Expert Consultation, 2001). By nature, the participants recruited for this study were accustomed to exercise at varied times of the day including the morning. Table 1 displays the characteristics of the study participants.

Insert table 1 near here

Screening, familiarisation and preliminary exercise testing

Prior to main experimental trials participants attended the research laboratory so that they could complete essential screening questionnaires, preliminary exercise tests, and be familiarised with the environment and study protocols. Participants completed questionnaires assessing their health status, food preferences, habitual physical activity

levels and psychological eating tendencies. The examination of food preferences was undertaken to guard against overconsumption of extremely-well liked food items during the main experimental trials. To achieve this, participants were asked to rate a list of food items on a scale of 1-10 (1 representing extremely dislike and 10 extremely like) and those items rated 9 or 10 were not made available to the specific individual during main trials. Eating habits were assessed using the Three-Factor Eating Questionnaire (Stunkard and Messick, 1985). This questionnaire assesses dietary restraint, disinhibition and susceptibility to hunger, and scoring high or in the clinical range for any of these variables may confound appetite and energy intake data collected in research settings. In this investigation none of the recruited participants scored high in any of the three factors and therefore we did not exclude any participants on this basis.

Participants' height, body mass and subcutaneous adipose tissue skinfolds were measured. The equations of Durnin and Wormersley (1974) and Siri (1956) were subsequently used to provide an estimation of body fat percentage.

To determine the individual relationship between treadmill running speed and oxygen consumption, each participant completed an incremental 16 min treadmill running test on a level motorised treadmill (Runrace, Technogym, Italy). This test exercised each participant through a range of submaximal intensities (4 x 4 min stages). Oxygen consumption and carbon dioxide production were determined in the final minute of each stage using Douglas bags and indirect calorimetry (Servomex, Crowborough, UK). After sufficient rest, maximum oxygen uptake was assessed using an incremental (gradient) treadmill run to volitional exhaustion (Taylor, Buskirk & Henschel, 1955).

Main experimental trials

In subsequent weeks each participant completed two, eight hour trials (exercise and control) in a randomised-counterbalanced fashion with at least one-week separating each trial. Participants standardised their diet for 24 h before each trial which was facilitated by the completion of a weighed food record. Participants refrained from undertaking exercise or from consuming alcohol and caffeine during this period. To ensure that participants were adhering to the dietary standardisation procedures the research team contacted participants via telephone on the day before each main trial. Within the laboratory during the conduct of main trials the atmospheric temperature (21 ^{o}C) and relative humidity (30%) were standardised throughout.

Main trials began at 09:00. On the morning of trials participants arrived at the laboratory having fasted overnight. To minimise physical exertion on the morning of trials participants were asked to walk slowly to the laboratory if they lived within 0.5 km. Participants living further away arrived by motorised transport.

The exercise trial commenced when participants were provided with a breakfast snack which was consumed within five min. Participants then rested for the remainder of the first trial hour. In the second trial hour participants ran on a treadmill for 60 min at a speed predicted to elicit 70% of maximum oxygen uptake. During the run samples of expired air were collected at 15 min intervals to monitor the intensity and adjustments were made to the speed of the treadmill if necessary. Ratings of perceived exertion were also assessed at these time points using the Borg scale (Borg, 1973). After completing the run participants rested within the laboratory for a further six hours (sitting reading, working at a computer or watching television). Upon completion of the run participants

were told that a 'buffet style' lunch was available on request and that after lunch food would remain available throughout the remainder of the trial. *Ad libitum* food intake at the freely requested lunch, and subsequent eating episodes during the remainder of the trial, was monitored.

Identical procedures were completed during the control trial except participants rested (sitting reading, working at a computer or watching television) within the laboratory for the entire duration. During the second trial hour samples of expired air were collected in the semi-supine position at 15 min intervals in order to estimate resting oxygen consumption. This permitted the estimation of net energy expenditure during exercise (exercise energy expenditure minus resting energy expenditure). Two hours into the control trial (synonymous with the end of exercise in the exercise trial) participants were told that a 'buffet style' lunch was available on request and that after lunch food would remain available throughout the remainder of the trial.

Appetite assessment and food intake

Before, during, and at the point of voluntary lunch request after exercise, 100 mm visual analogue scales (Flint, Raben, Blundell & Astrup, 2000) were completed to assess perceptions of appetite (hunger, fullness, satisfaction and prospective food consumption).

The breakfast snack provided at the beginning of main trials consisted of a commercial cereal bar (Kellogg's Nutri-grain®). Participants received 1.06 g per kilogram of body weight measured on the first trial visit and the same amount was consumed on each participant's second main trial. For a 70 kg individual this provided 1113 kJ (266 kcal)

of energy, 6 g of fat, 4 g of protein and 48 g of carbohydrate. The breakfast snack was consumed within 5 min on all trials.

During trials the buffet meal was presented in a research kitchen located adjacent to the research laboratory (but was not visible from the laboratory where participants rested) and participants were free to take items from the buffet at any point throughout the trial (after the 2 h point). The research team recorded the time at which participants first chose to eat after exercise. The buffet was set up identically before each trial and was restocked after every individual eating episode. Buffet foods were presented in excess of expected consumption and offered a range of cold familiar food items (milk, cereals, white bread, brown bread, ham, Cheddar cheese, tuna, mayonnaise, butter, margarine, crisps, cereal bars, cookies, chocolate rolls, apples, oranges and bananas). Participants selected and ate food items in isolation within the research kitchen. Food consumption was ascertained by examining the weighted difference in food items remaining compared with that initially presented. The energy and macronutrient content of the items consumed was ascertained using manufacturer values. Participants were not made explicitly aware that their eating behaviours were being monitored during this investigation. Instead, participants were told that the primary outcome of the study was the effects of exercise on metabolic rate and expired air samples were taken periodically after exercise to support this.

Statistical analysis

Data were analysed using the Statistical Package for the Social Sciences (SPSS) software version 16.0 for Windows. Area under the concentration verses time curve calculations were performed using the trapezoidal method. Repeated measures, two-

factor ANOVA was used to assess differences between the exercise and control trials over time for appetite perceptions and energy/macronutrient intake. Relative energy intake was calculated by subtracting relative exercise energy expenditure i.e. that above resting energy expenditure during the 60 min exercise period, from total trial energy intake. Student's *t*-tests were used to assess differences between fasting appetite perceptions between trials. The Pearson product moment correlation coefficient was used to examine relationships between variables. Statistical significance was accepted at the 5% level. Results are presented as mean ± SD except for Figure 1 where for clarity SEM has been used.

Results

Exercise responses

Participants completed the 60 min run at 10.6 ± 0.3 km.h^{-1}. This elicited a mean oxygen consumption equivalent to 71.8 ± 4.8% of $\dot{V}O_2$ max and generated an average heart rate and net (exercise minus resting) energy expenditure of 165 ± 10 beats·min^{-1} and 4117 ± 369 kJ (984 ± 88 kcal), respectively. A gross metabolic respiratory quotient calculated from the pulmonary gas exchange (0.92 ± 0.02) suggested that carbohydrate was the predominant fuel source during exercise (carbohydrate 74 ± 7%, fat 26 ± 7%). A median RPE value of 13 indicated that the participants perceived the intensity of the run to be 'fairly hard.' Resting energy expenditure on the control trial (determined during 1 – 2 h) i.e. equivalent to the exercise period on the exercise trial was 397 ± 47 kJ (95 ± 11 kcal).

Appetite responses

There were no significant differences in baseline ratings of hunger (t (9) = 1.393, P = 0.197), fullness (t (9) = 1.862, P = 0.096), satisfaction (t (9) = -0.259, P = 0.802) and prospective food consumption (t (9) = 0.242, P = 0.814) between the exercise and control trials.

Figure 1 shows subjective appetite responses to exercise. Two-factor ANOVA revealed significant trial (F (1,9) = 13.173, P = 0.005), time (F (5,45) = 8.576, P = 0.034) and interaction main effects (trial x time, F (5,45) = 7.019, P < 0.001) for subjective ratings of hunger. Post-hoc analysis identified between trial differences at 1.5 h (t (9) = 3.308, P = 0.009) and 2 h (t (9) = 3.745, P = 0.005) however after correction for multiple

comparisons using the Bonferroni method only the 2 h values remained significantly different ($P < 0.0083$).

For prospective food consumption two-factor ANOVA revealed a significant main effect of time (F (5,45) = 5.310, P = 0.001) and a significant interaction effect (trial x time, F (1.7,15.29) = 9.485, P = 0.003) however there was no significant main effect of trial (F (1,9) = 6.051, P = 0.36). Post hoc analysis identified significant differences between trials at 1.5 h (t (9) = 3.045, P = 0.014 and 2 h (t (9) = 3.224, P = 0.010) however after correcting for multiple comparisons these differences did not remain significant.

For subjective ratings of fullness there was a significant main effect of trial (F (1,9) = 7.514, P = 0.023), time (F (2.70, 24.33) = 3.510, P = 0.034) and a significant interaction effect (F (5,45) = 3.177, P = 0.015). Post hoc analysis identified a significant difference between trials at 1.5 h (t (9) = -3.096, P = 0.013) however following correction for multiple comparisons this difference did not remain significant.

For satisfaction there was a significant main effect of time (F (5,45) = 4.365, P = 0.003) and a significant interaction effect (trial x time, F (5,45) = 2.804, P = 0.027) however there was no significant main effect of trial (F (1,9) = 1.224, P = 0.297).

Insert figure 1 near here

Feeding latency, energy and macronutrient intake

There was a significant difference in the timing of the first meal (lunch) between the control and exercise trials (t (9) = -3.344, P = 0.009) with nine out of ten participants having a greater delay in the exercise trial than in the control trial. In the exercise trial participants requested to eat 81 ± 45 min after exercise completion. This was a 35 ± 33 min delay in the spontaneous request of lunch compared with control. Consequently, the lunch request in the exercise trial was at 3.35 h (3 h 21 min) and in the control trial at 2.77 h (2 h 46 min). Figure 2 displays the individual participant values for the time delay until participants voluntarily requested to eat after having exercised or rested whilst Figure 3 displays individual energy intake responses at the first voluntary requested meal after exercise.

Insert figures 2 & 3 near here

There was no significant difference in the frequency of eating episodes between the exercise and control trials (t (9) = 0.000, P = 0.999) as the number of eating episodes between trials was identical for eight out of ten participants. Specifically, six participants had two eating episodes on both trials and two participants had one on each trial. The remaining two participants had one or two eating episodes on each trial. As all participants had either one or two meals during trials energy intake was subsequently analysed by separating that consumed at the first and second eating occasions. Table 2 shows absolute and relative energy intake values from the main trials. Two-factor ANOVA revealed a significant main effect of time (F (1,9) = 23.849, P < 0.001), indicating that energy intake was significantly higher at the freely requested lunch (first

meal) than that consumed over the remainder of trials. No significant trial (F (1,9) = 0.000, P = 0.993) or interaction (trial x time, F (1,9) = 2.647, P = 0.138) main effects were found, confirming there were no differences in energy intake between the exercise and control trials. After accounting for the energy expended during exercise, relative energy intake was significantly lower on the exercise trial (3667 ± 2977 kJ) compared with control (7426 ± 3181 kJ) (t (9) = 5.310, P = 0.001).

Insert table 2 near here

Table 3 shows the macronutrient intake in the exercise and control trials. For the percentage intake of carbohydrate and fat, two-factor ANOVA revealed no significant main effects of time (meal) or trial (all $P > 0.05$). For protein, there was a significant main effect of time (F (1,9) = 25.152, P = 0.001) however no trial (F (1,9) = 1.529, P = 0.248) or interaction (F (1,9) = 0.506, P = 0.495) effects were found.

Insert table 3 near here

Discussion

There are two key findings arising from this investigation. Firstly, an acute bout of moderate-high intensity treadmill running increased the length of time before participants voluntarily chose to eat after completing exercise. Secondly, despite this resistance to begin eating, total unrestricted food intake from a buffet style meal remained unchanged for up to 6 h after exercise. Collectively these findings indicate that the acute appetite suppressive effects of exercise manifest as a resistance to commence eating rather than affecting energy or macronutrient intake *per se*.

In recent years there has been a wealth of research investigating the acute influence of various forms of exercise on appetite and food intake. When reviewing these studies it came to our attention that one potentially significant limitation of many of these interventions, including some of those previously conducted within our laboratory, was that food intake responses to exercise had been assessed from meals that were provided to study participants on predetermined schedules (Balaguera-Cortes, Wallman, Fairchild & Guelfi, 2011; George and Morganstein, 2003; Hubert, King & Blundell, 1998; Imbeault, Saint-Pierre, Almeras & Tremblay, 1997; King, Lluch, Stubbs & Blundell, 1997; King, Miyashita, Wasse & Stensel, 2010; King et al., 2011; King, Wasse & Stensel, 2011; Kissileff, Pi-Sunyer, Segal, Meltzer & Foelsch, 1990; Martins, Morgan, Bloom & Robertson, 2007; Pomerleau, Imbeault, Parker & Doucet, 2004; Thompson, Wolfe & Eikelboom, 1988; Tsofliou, Pitsiladis, Malkova, Wallace & Lean, 2003; Verger, Lanteaume & Louis-Sylvestre, 1994; Wasse, Sunderland, King, Batterham & Stensel, 2012; Westerterp-Plantenga et al., 1997). In several of these investigations this feeding protocol has been unavoidable as researchers have concomitantly sought to assess hormonal responses to exercise interventions which require the timing of meals

to be standardised across trials. Nonetheless, for the purpose of optimally investigating feeding responses to exercise, such a constraining procedure lacks ecological validity and may have influenced study outcomes in previous investigations.

The present investigation sought to circumvent this limitation by examining food intake responses to moderate-high intensity exercise when participants are given complete free access to food over the period of observation. In this situation participants are able to consume food whenever desired, without a time limit on each eating episode or a restriction on the number of eating episodes across trials. In effect, this procedure provides a more realistic assessment of food intake responses to exercise and enables us to measure additional aspects of eating behaviour such as feeding latency after exercise and meal frequency.

Despite employing this less restrictive feeding protocol, the results from the present investigation support those of previous studies which have shown no change in energy or macronutrient intake in response to an acute bout of moderate-high intensity exercise (Blundell & King, 2000; Martins, Morgan & Truby, 2008; Stensel, 2010). Specifically, in the present study there was no difference in energy intake at the first (voluntary initiated) meal after exercise or in the subsequent intake in the period of observation thereafter. Strikingly, although there was large variation between individual participants (three participants consumed more energy on the control trial than the exercise trial whilst seven participants displayed the reverse), the total energy intake for all meals consumed within the exercise and control trials were within 8 kJ of each other. Furthermore, no differences were observed in the number of eating episodes undertaken on each trial as eight out of ten participants exhibited the same number of eating

episodes on both trials. Taken together, these findings suggest that acute moderate-high intensity exercise does not alter energy intake or the size of meals in the immediate hours after exercise when participants' access to food is completely unrestrained.

The findings in the present study confirm others which have demonstrated that relative energy intake is significantly reduced after the completion of single bouts of aerobic exercise (Laan, Leidy, Lim & Campbell, 2010; Martins, Morgan, Bloom & Robertson, 2007). Specifically, relative energy intake was 3759 kJ (898 kcal) lower on the exercise trial than on the control trial resulting from the significant amount of energy that was expended during exercise (4117 kJ (984 kcal)). These findings support previous work which has shown that exercise is able to induce large short-term energy deficits without provoking an immediate compensatory energy intake response (Hubert et al, 1998; King et al., 2011). The present results therefore suggest that if exercise is completed regularly a significant negative energy balance can be achieved and body fat would theoretically decrease accordingly. Unfortunately, in reality we know that this vision is too simplistic as exercise training (and the initial associated weight loss) stimulates a host of metabolic and behavioural compensatory responses which collectively attenuate the impact of exercise on energy homeostasis (King et al., 2007). A partial increase in energy intake is a central component of this response (King, Hopkins, Caudwell, Stubbs & Blundell, 2008; Whybrow et al, 2008). Consequently, if exercise is to be used as a method to improve body composition or reduce body fat attention must be given to minimise the extent to which individuals compensate by increasing their energy intake.

The present investigation has shown that an acute bout of moderate-high intensity exercise acutely suppresses appetite and induces a significant time delay before individuals choose to eat after exertion. This outcome is consistent with previous findings which have shown that appetite is suppressed in response to high intensity exercise (generally > 70% of maximum oxygen uptake). Low intensity exercise does not have any influence on appetite perceptions (King, Burley & Blundell, 1994; King, Wasse, Broom & Stensel, 2010) therefore it is likely that low intensity exercise would not have any impact on feeding latency after exercise. In the present study, participants ran for 60 min at ~72% of their maximum oxygen uptake. In future studies it would be interesting to see whether exercise of higher intensity or longer duration prolongs the feeding delay reported in the present study.

A brief resistance to voluntarily commence eating after exercise has previously been hinted following running and cycling (King and Blundell, 1995; King, Burley & Blundell, 1994). In these previous studies participants exercised in a fasted state and energy intake/eating behaviour was directly assessed only at one eating opportunity after exercise. In the present study, to get a better assessment of eating behaviour we were keen to replicate the most typical circumstances under which individuals perform exercise and to monitor responses directly within a controlled laboratory setting for an extended period after exercise. Consequently, in the present study, participants exercised having consumed breakfast 1 h earlier. This difference in feeding status may explain the greater resistance to commence feeding reported in the present study (~35 min), as recent work in our laboratory has shown a greater appetite suppressive effect of exercise when performed postprandially compared with when exercise is performed in the fasted state (Deighton, Zahra & Stensel, 2012).

The mechanism(s) by which an acute bout of moderate-high intensity exercise causes a reduced motivation to commence eating afterwards was not investigated in the present study but it may be pertinent to speculate. It is thought that a high body temperature suppresses appetite (Brobeck, 1948) and it is possible this may have contributed to the resistance to commence eating after exercise in the present study. Further work is needed to test this idea. The role of gut hormones in the acute and chronic regulation of appetite and energy intake has received significant interest in recent years. Episodic changes in the circulating levels of acylated ghrelin (appetite stimulating) and peptide-YY_{3-36} (PYY_{3-36}), glucagon-like-peptide-1 (GLP-1), and pancreatic polypeptide (PP) (all appetite inhibiting) have important roles in regulating energy intake on a meal-to-meal basis (Neary & Batterham, 2009). Moderate-high intensity exercise acutely suppresses circulating concentrations of acylated ghrelin and increases levels of PYY_{3-36}, GLP-1 and PP (Broom, Batterham, King & Stensel, 2009; King, Miyashita, Wasse & Stensel, 2010; King et al., 2011; Martins, Morgan, Bloom & Robertson, 2007; Wasse, Sunderland, King, Batterham & Stensel, 2012) and it is possible that exercise-induced changes in the circulating concentrations of these hormones may have influenced feeding latency in this study. Future research is needed to test this hypothesis. Fluid consumption and/or hydration status are additional factors which may have contributed to the reduced motivation to eat after exercise in the present study. During main trials water was available to participants *ad libitum* and across the entire trial days water intake was significantly greater in the exercise trial than the control trial (1677 ± 603 vs. 1005 ± 605 mL, $P = 0.042$). Unfortunately in the present study we did not record the specific times when water was consumed during main trials, however it is possible that if a large amount of water was consumed during, or soon after exercise, this may have reduced appetite (and subsequently the desire to consume food) through liquid bolus

related activation of gastric mechanosensor satiety mechanisms (Janssen et al., 2011). Moreover, it has been suggested that humans place a greater priority on restoring fluid balance over energy balance, and in theory it is possible that the reduced motivation to eat observed after exercise may be related to participants' prioritising the restoration of fluid balance over energy balance following sweating induced body water loss. Although gut blood flow was not measured in the present study, it has been suggested that reduced flow to the gut during strenuous exercise might be involved in exercise induced anorexia. Recent research demonstrates acute exercise of a similar duration and intensity to the present study causes up to an 80% reduction in gut blood flow which recovers within 60 minutes after exercise (Rehrer, Smets, Reynaert, Goes & De Meirleir,2001; van Wijck et al., 2011). It is possible that the delay to spontaneous lunch request after exercise is related to a reduction of gut blood flow during exercise and in the immediate post-exercise period. Other non-homeostatic factors may also have contributed to the delayed request to eat in the present study as a recent investigation has shown that neural responses to food cues in brain regions associated with motivation to eat, the pleasure of food and the anticipation/consumption of food are reduced after 60 min of moderate intensity cycling (Evero, Hackett, Clark, Phelan & Hagobian, 2012).

Although this study provides novel information about the interaction between moderate-high intensity exercise and appetite regulation/eating behaviour this study does have limitations that warrant recognition. Firstly, the participants in this study were a homogenous group of young, healthy males and this prevents the generalisation of these findings to wider groups such as females, those who are overweight/obese and those with disturbed psychological eating tendencies. Secondly, it must be recognised that

assessment of energy intake is extremely challenging and although some data suggests that energy intake assessments from buffet meals show good reproducibility at rest (Arvaniti, Richard & Tremblay, 2000), and after exercise (Laan, Leidy, Lim & Campbell, 2010), this is not a universal finding (Brown, Lean & Hankey, 2012). The present results should be interpreted with this in mind. Thirdly, it should also be noted that participants consumed a breakfast snack before exercise in the present study which was of significantly lower energy content than participants' typical breakfast. Pre-exercise feeding status may have an important influence in determining feeding latency after exercise therefore future studies are needed to examine the interaction between these parameters. Finally, in the present study the assessment of energy intake was conducted for 6 h after exercise however it is possible that exercise-related changes in energy intake may occur over a longer time-frame i.e. on the following day. Additional studies will be needed to test this hypothesis.

In conclusion, this study has shown that a single bout of moderate-high intensity exercise suppresses appetite and induces an increase in duration before individuals voluntarily choose to eat afterwards. Despite this resistance, total energy and macronutrient intake remain unchanged for several hours after exercise. These findings indicate that the acute appetite suppressive effects of moderate-high intensity exercise manifest as a resistance to commence eating rather than affecting energy or macronutrient intake *per se*.

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Table 1: Characteristics of the study participants

Characteristic			
Age (y)	21.3	±	2.1
BMI ($kg \cdot m^{-2}$)	23.9	±	2.3
Body Mass (kg)	78.7	±	8.7
Body Fat* (%)	14.9	±	3.2
Maximum oxygen uptake ($mL \cdot kg^{-1} \cdot min^{-1}$)	61.5	±	4.8

Values are mean ± SD (*n* = 10). *Body fat estimated via subcutaneous skinfold measurements.

Table 2: Absolute and relative energy intake in the exercise and control trials

	Control	Exercise
Voluntarily requested lunch	4778 ± 1469	5385 ± 1697
	(1142 ± 351)	(1287 ± 406)
Subsequent intake	2648 ± 2403	2033 ± 1706
	(633 ± 574)	(486 ± 408)
Total trial	7426 ± 3181	7418 ± 2862
	(1775 ± 760)	(1773 ± 648)
Relative energy intake (total trial)	7426 ± 3181	3667 ± 2977
	(1775 ± 760)	(876 ± 712)

Values are mean ± SD (*n* = 10). Data presented as kJ and (kcal).

Table 3: Macronutrient percentage intake in the exercise and control trials

Control Trial	**Fat**	**Carbohydrate**	**Protein**
Voluntarily requested lunch	39. 8 ± 6.3	43.7 ± 10.2	16.5 ± 4.4
Subsequent intake	39.9 ± 6.9	49.9 ± 10.8	10.2 ± 4.6
Total trial	40.0 ± 5.2	45.7 ± 9.1	14.3 ± 3.9
Exercise Trial	**Fat**	**Carbohydrate**	**Protein**
Voluntarily requested lunch	41.9 ± 6.1	41.6 ± 9.4	16.5 ± 3.9
Subsequent intake	37.0 ± 7.0	49.2 ± 13.1	13.8 ± 6.9
Total trial	40.4 ± 5.5	43.6 ± 9.8	16.0 ± 4.5

Values are mean ± SD (*n* = 10).

Figure Legends

Figure 1: Ratings of hunger (a), satisfaction (b), fullness (c) and prospective food consumption (PFC) (d) in the exercise (○) and control (●) trials. Values are mean ± SEM *(n* = 10). Black rectangle indicates a breakfast snack, diagonally shaded rectangle indicates exercise, black arrow indicates VLR (control trial: 2.77 ± 0.27 h), white arrow indicates VLR (exercise trial: 3.35 ± 0.22 h). *Exercise values significantly different from control ($P<0.05$), # Exercise values significantly different from control after correction for multiple comparisons ($P < 0.0083$).

Figure 2: Time until voluntary feeding request in the exercise and control trials. Values represent the individual scores of each participant (n = 10). NB: on the control trial participants 2, 6 and 10 requested to eat as soon as they were permitted i.e. at 2 h.

Figure 3: Individual energy intake responses at the voluntary requested lunch in the exercise and control trials (n =10).

Figure 1

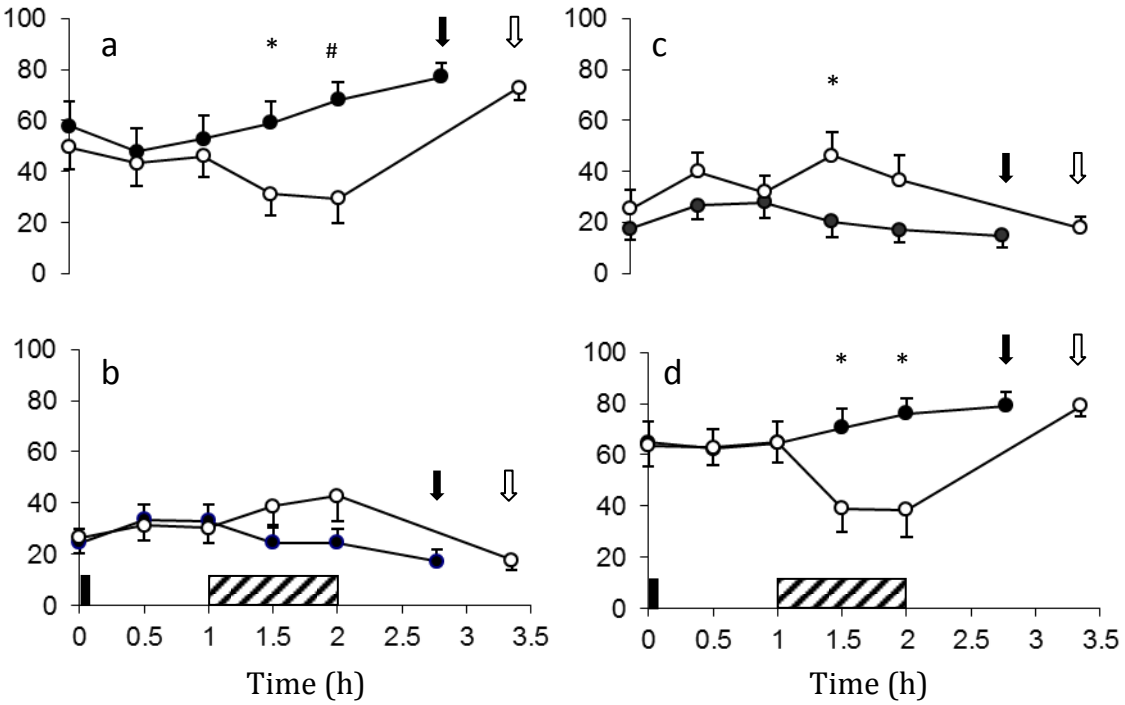

Figure 2

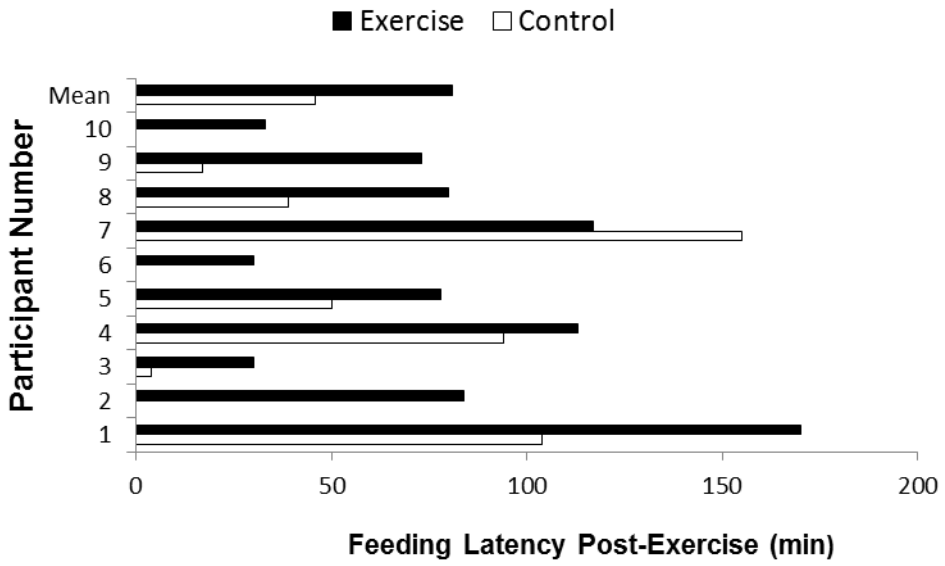

Figure 3