Appetite and Energy Intake Responses to Acute Energy Deficits in Females versus Males

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ABSTRACT

ALAJMI, N., K. DEIGHTON, J. A. KING, A. REISCHAK-OLIVEIRA, L. K. WASSE, J. JONES, R. L. BATTERHAM, and D. J. STENSEL. Appetite and Energy Intake Responses to Acute Energy Deficits in Females versus Males. *Med. Sci. Sports Exerc.*, Vol. 48, No. 3, pp. 412–420, 2016. **Purpose**: To explore whether compensatory responses to acute energy deficits induced by exercise or diet differ by sex. **Methods**: In experiment one, 12 healthy women completed three 9-h trials (control, exercise-induced (Ex-Def) and food restriction–induced energy deficit (Food-Def)) with identical energy deficits being imposed in the Ex-Def (90-min run, ~70% of $\dot{V}O_{2max}$) and Food-Def trials. In experiment two, 10 men and 10 women completed two 7-h trials (control and exercise). Sixty minutes of running (~70% of $\dot{V}O_{2max}$) was performed at the beginning of the exercise trial. The participants rested throughout the remainder of the exercise trial and during the control trial. Appetite ratings, plasma concentrations of gut hormones, and *ad libitum* energy intake were assessed during main trials. **Results**: In experiment one, an energy deficit of approximately 3500 kJ induced via food restriction increased appetite and food intake. These changes corresponded with heightened concentrations of plasma acylated ghrelin and lower peptide YY_{3-36}. None of these compensatory responses were apparent when an equivalent energy deficit was induced by exercise. In experiment two, appetite ratings and plasma acylated ghrelin concentrations were lower in exercise than in control, but energy intake did not differ between trials. The appetite, acylated ghrelin, and energy intake response to exercise did not differ between men and women. **Conclusions**: Women exhibit compensatory appetite, gut hormone, and food intake responses to acute energy restriction but not in response to an acute bout of exercise. Additionally, men and women seem to exhibit similar acylated ghrelin and PYY_{3-36} responses to exercise-induced energy deficits. These findings advance understanding regarding the interaction between exercise and energy homeostasis in women. **Key Words:** SEX-BASED DIFFERENCES, GASTROINTESTINAL HORMONES, COMPENSATION, ENERGY BALANCE, FEMALES

The regulation of appetite control and energy balance is an area of scientific inquiry, which continues to receive widespread attention across disciplines. To date, as in many fields of science, the foundation of our knowledge within appetite regulation has been gleaned from studies conducted predominantly in men. Consequently, less is known, specifically regarding the regulation of appetite control and energy balance in women, and the potential for sex-based differences has not been thoroughly investigated. Preliminary research has hinted that appetite and appetite-regulatory hormones may display divergent responses to nutritional interventions between men and women; however, this proposition continues to be debated (5). Specifically, it has been suggested that women, compared to men, exhibit more potent compensatory responses (appetite, appetite regulatory hormones, food intake) to energy deficits to preserve energy balance and reproductive function (14). This viewpoint is supported by studies demonstrating that men exhibit greater reductions in body fat and body mass than women in response to supervised exercise training (8,19,35). Conversely, other research has suggested that differences in weight loss and adiposity responses to exercise are unrelated to sex (5,6).

Sex-based differences in the short-term regulation of appetite and energy balance were previously investigated in a carefully designed experimental study using consecutive days of exercise to induce an energy deficit in male and female participants (15). The researchers showed that this

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acute exercise-induced energy deficit triggered a compensatory increase in circulating acylated ghrelin (appetite-stimulating hormone) in women but not in men. These changes corresponded with higher appetite ratings in women than men and suggest that sex-based differences may be apparent in the early appetite and gut hormone response to exercise-induced energy deficits.

Over the past decade, our laboratory has conducted many acute experimental trials seeking to enhance understanding concerning the short-term regulation of appetite and energy balance (21,31). In a sample of male participants, we recently demonstrated that the induction of an acute energy deficit by food restriction elicited a rapid and robust compensatory appetite, gut hormone (acylated ghrelin and $PYY_{3–36}$), and energy intake response whereas the same energy deficit imposed by exercise had no effect (20). These findings suggest that the method by which an energy deficit is imposed has a marked impact on the subsequent physiological and behavioral response. It is currently unknown whether women exhibit the same acute responses to exercise and food restriction as men. This information has important implications regarding the use of lifestyle therapies to assist weight control in women.

Within this report, we describe the findings from two acute experimental studies, which sought to provide new information regarding the short-term appetite, food intake, and appetite hormone responses to exercise and food-induced energy deficits in men and women. In experiment 1; we compared the appetite, energy intake, acylated ghrelin, and $PYY_{3–36}$ responses to an equivalent energy deficit induced by exercise or energy restriction in women. In experiment 2, we directly compared appetite, food intake, and circulating acylated ghrelin responses to an exercise-induced energy deficit in men versus women. Our findings identify a high degree of similarity in the acute response to energy deficits in men and women.

METHODS

Experimental protocol. This investigation contained two experiments that were conducted according to the guidelines laid down in the Declaration of Helsinki. All procedures were approved by the Institutional Ethics Advisory Committee, and written informed consent was obtained from all participants. Study participants were nonsmokers, not taking medication, weight stable for at least 6 months before participation, and were not dieting. Participants had no known history of cardiovascular/metabolic disease, and the female participants were of reproductive age but were not pregnant. In each study, participants were recreationally active, i.e., were familiar with exercise but were not formally trained in endurance activities such as running or cycling.

The participants completed a weighed food diary in the 24 h before the first main trial of each experiment and replicated this before each subsequent trial. Alcohol, caffeine, and strenuous physical activity were not permitted during this period. All trials commenced between 8:00 a.m. and 9:00 a.m. after an overnight fast of at least 10 h, and the participants exerted themselves minimally when traveling to the laboratory, using motorized transport when possible. Verbal confirmation of dietary and exercise standardization was obtained at the beginning of each experimental trial. The female participants completed all main trials within the follicular phase of the menstrual cycle (4).

Preliminary trials. To determine the running speed required to elicit 70% of maximum oxygen uptake ($\dot{V}O_{2max}$) for each individual, the participants completed a preliminary trial before the main trials for each experiment. This consisted of a submaximal running test and a $\dot{V}O_{2max}$ test on a motorized treadmill (34). Anthropometric measurements and study questionnaires, e.g., Three Factor Eating Questionnaire (TFEQ) (33), were also taken/completed at this time. At this visit, the participants also verbally confirmed acceptability of the test meals and *ad libitum* meals subsequently to be provided during main experimental trials.

In experiment one, a second preliminary trial was completed to determine the net energy cost of exercise, which was needed to calculate food provision in the main trials and to enable trial randomization in advance. During this session, the participants ran for 90 min at 70% of $\dot{V}O_{2max}$, with expired air samples being collected into Douglas bags at 15-min intervals to calculate energy expenditure using the equations provided by Frayn (12).

Experiment one. Twelve female participants performed three 9-h experimental trials (control (Con)), exercise-induced energy deficit (Ex-Def) and diet-induced energy deficit (Food-Def)) separated by 1 wk in a randomized counterbalanced design. To ensure standardization of menstrual phase, the participants' first main trial was undertaken at the beginning of their follicular phase, with their second trial occurring 1 wk later. The participants' third main trial was subsequently undertaken at the beginning of their next cycle approximately 4 wk later. The participants rested within the laboratory throughout all trials, with participants being permitted to read, work at a computer, or watch DVDs, which had been screened to ensure that there was no overt emphasis on food and drink. The exception to this occurred at 0–1.5 h during Ex-Def, where participants performed 90 min of treadmill running at approximately 70% of $\dot{V}O_{2max}$ (identical to that performed during the preliminary trial). Resting expired air samples were collected from 0 to 1.5 h during the Con and Food-Def trials to calculate the net energy expenditure of exercise (gross energy expenditure of exercise minus energy expenditure at rest) (12).

Identical test meals were provided at 2 h (breakfast) and 4.75 h (lunch) and were each consumed within 15 min. The meals consisted of a tuna and mayonnaise sandwich, salted crisps, chocolate muffin, and green apple. The macronutrient composition of the meal was 47% carbohydrate, 18% protein, and 35% fat. The energy content of the test meals was identical in Con and Ex-Def (2778 (109) kJ), with each meal providing 35% of the participants' estimated daily energy needs for a sedentary day. This calculation was based on an estimation of each participant's daily energy needs, which was determined using a validated equation for resting metabolic rate (28) that was multiplied by an activity factor (1.4) deemed appropriate for a sedentary day (10). In Food-Def, the energy content of the test meals was reduced (1025 (159) kJ) by deducting the net energy expenditure of exercise from the energy provided at the test meals during Con and Ex-Def. This energy deficit was individually prescribed based on the exercise energy expenditure data derived from the preliminary trials, and the total amount of energy deducted was divided equally between breakfast and lunch. Therefore, equivalent energy deficits were induced in Ex-Def and Food-Def relative to Con. The macronutrient percentage of the test meals was identical across main trials, i.e., only the meal energy content was altered in the Food-Def trial.

Experiment two. Ten female and 10 male participants performed two 7-h experimental trials (exercise and control) separated by 1 wk in a randomized counterbalanced design. The female participants completed both main trials during the follicular phase (days 1–11) of their menstrual cycle. The participants rested within the laboratory throughout each trial, except from zero to 1 h during the exercise trial, where the participants performed 60 min of treadmill running at approximately 70% of $\dot{V}O_{2max}$. Expired air samples were collected as described earlier to calculate the net energy expenditure of exercise. A test meal was provided at 2 h, consisting of a ham sandwich, banana, salted crisps, and chocolate bar. The macronutrient composition of the meals was 63% carbohydrate, 9% protein, and 28% fat. The energy content was 42 $kJ \cdot kg^{-1}$ body mass (men, 3167 (395) kJ; women, 2599 (305) kJ).

Appetite perceptions and *ad libitum* buffet meals. Appetite perceptions (hunger, satisfaction, fullness, and prospective food consumption) were assessed at baseline and every 30 min during both experiments using 100-mm visual analog scales (11). An overall appetite rating was calculated for each time point as the mean value of the four appetite perceptions after inverting the values for satisfaction and fullness (32). At 8 h during experiment one and 5 h during experiment two, the participants were given 30-min access to a buffet meal from which they were free to select and consume food *ad libitum*. The buffet was set up identically before each meal, with food being presented in excess of expected consumption. The items available were milk, three varieties of cereal, cereal bars, white bread, brown bread, ham, cheese, tuna, mayonnaise, butter, margarine, cookies, chocolate rolls, apples, oranges, and bananas. The participants were told to eat until satisfied and that additional food was available if desired. The participants were not overtly aware that their food intake was being monitored with actual intake being deduced by experimenters covertly reweighing leftover foods after *ad libitum* meals. Energy and macronutrient intake was determined using values provided by the food manufacturers. All meals were consumed in isolation so that social influence did not affect food selection. Water was available *ad libitum* throughout each trial.

Blood sampling and analysis. During the experimental trials, venous blood samples were collected via a cannula (Venflon, Becton Dickinson, Helsinborg, Sweden) inserted into an antecubital vein. Blood samples were collected at baseline, 2, 3, 4.75, 6, 7, 8, and 9 h in experiment one and baseline, 0.5, 1, 2, 2.5, 3, 4, 4.5, 5, 5.5, 6, and 7 h in experiment two. Plasma acylated ghrelin concentrations were measured from blood samples in both experiments, and PYY_{3-36} was additionally measured in experiment one. Details on acylated ghrelin and PYY_{3-36} sample collection and processing have been described in-depth previously (7).

A commercially available enzyme immunoassay was used to determine plasma concentrations of acylated ghrelin (SPI BIO, Montigny le Bretonneux, France). Plasma concentrations of PYY_{3-36} were determined using a commercially available radioimmunoassay (Millipore, Watford, UK). To eliminate interassay variation, samples from each participant were analyzed in the same run. The within-batch coefficients of variation for the assays were 6.9% and 6.8% for acylated ghrelin and PYY_{3-36}, respectively.

Statistical analysis. Data were analyzed using IBM SPSS statistics version 19 for Windows. Time-averaged area under the curve (AUC) values were calculated using the trapezoidal method. For experiment one, one-way repeated-measures ANOVA was used to assess trial-based differences in energy intake at the *ad libitum* meal as well as AUC values for appetite, acylated ghrelin, and PYY_{3-36}. For experiment two, independent samples *t*-tests were used to assess baseline differences between male and female participants. Mixed measures, two-way ANOVA (sex × trial) was used to assess differences in energy intake and AUC values for appetite and acylated ghrelin. Where significant main effects were found, *post hoc* analysis was performed using Holm-Bonferroni correction for multiple comparisons. Statistical significance for this study was accepted as $P \leq 0.05$. Results in text and tables are presented as mean (SD). Graphical representations of results are presented as mean (SEM) to avoid distortion of the graphs.

Sample size calculations. The sample sizes used within this study were deemed sufficient to detect a significant difference in energy intake between trials in experiment one and a significant difference in relative energy intake between sexes in experiment two. These variables were selected as the primary outcome measure for each experiment. The anticipated effect size for a difference in energy intake between trials for experiment one was based on previous findings from our laboratory using an identical experimental protocol in men (20). The anticipated effect size for a difference in relative energy intake between the sexes for experiment two was based on the findings from previous research that used methods similar to those of the present experiment (16). Based on these effect sizes and an alpha value of 5%, a sample size of 12 participants in experiment one would have more than 95% power to detect a difference

TABLE 1. Participant characteristics in experiments one and two.

	Experiment 1	Experiment 2	
	(Females)	(Females)	(Males)
Participant number, N	12[a]	10[b]	10[b]
Age, yr	22.4 (2.1)	22.3 (2.5)	22.6 (3.8)
Height, cm	165.6 (5.4)	166.6 (5.4)	180.5 (6.2)*
Body mass, kg	60.4 (4.2)	61.9 (7.3)	75.4 (9.4)*
BMI, kg·m^{-2}	22.0 (1.1)	22.3 (2.32)	23.1 (2.1)
Body Fat, %	24.1 (2.8)	22.4 (5.5)	10.1 (4.2)*
Lean mass (kg)	45.9 (3.7)	47.4 (1.4)	67.5 (3.3)*
$\dot{V}O_{2max}$, mL·kg^{-1}·min^{-1}	50.4 (4.3)	48.8 (6.1)	66.1 (9.2)*

*Significantly different between males and females ($P < 0.005$).

[a] Acylated ghrelin and $PYY_{3–36}$ data available for 11 participants.

[b] Acylated ghrelin data available for 8 participants.

in energy intake, and 20 participants (10 men and 10 women) in experiment two would have more than 87% power to detect a difference in relative energy intake between the sexes. All calculations were performed using G*power (9).

RESULTS

Experiment One

Participant characteristics and exercise responses. The physical characteristics of the participants are described in Table 1. The participants rated "low" for each trait within the TFEQ (cognitive restraint, 7.8 (3.3); disinhibition, 7.9 (3.2); and hunger, 6.9 (3.1). The participants completed the 90-min run at 8.6 (1.0) km·h^{-1}. This elicited an oxygen consumption equivalent to 70.2% (1.5%) of $\dot{V}O_{2max}$ and a net energy expenditure of 3560 (382) kJ. The nonprotein respiratory exchange ratio was 0.86 (0.04), which reflected a proportional contribution to energy provision of 54% (13%) carbohydrate and 46% (13%) fat. Heart rate and RPE were 175 (3) bpm and 13 (1), respectively.

Appetite and energy intake. Overall appetite ratings did not differ between trials at baseline (Ex-Def, 71 (23); Food-Def, 77 (12); Con, 75 (16); $P = 0.536$). One-way ANOVA revealed higher appetite AUC in Food-Def than in Ex-Def and Con across the 9-h trial ($P < 0.0005$; Figs. 1 and 2). At the *ad libitum* buffet meal, total energy intake was significantly higher in Food-Def than in Ex-Def and Control (Ex-Def, 2774 (1682); Food-Def, 3965 (1409); Control, 2560 (1112) kJ; $P < 0.0005$). Similarly, energy intake from fat, protein, and carbohydrate was significantly higher in Food-Def than in Ex-Def and Control (all $P < 0.004$; data not presented).

Plasma acylated ghrelin and $PYY_{3–36}$ concentrations. Owing to problems with venous cannulation acylated ghrelin and $PYY_{3–36}$, data are only available for 11 participants. Fasting plasma acylated ghrelin concentrations did not differ significantly between trials at baseline (Con, 148 (100); Ex-Def, 140 (86); Food-Def, 148 (96) pg·mL^{-1}; $P = 0.422$). Acylated ghrelin concentrations were significantly higher in Food-Def and significantly lowest in Ex-Def across the 9-h trial ($P < 0.0005$; Figs. 1 and 2). Fasting $PYY_{3–36}$ concentrations did not differ significantly between the trials at baseline (Con, 77 (39); Ex-Def, 76 (34); Food-Def, 77 (36) pg·mL^{-1}; $P = 0.989$). Time-averaged AUC for $PYY_{3–36}$ was significantly highest in Ex-Def and significantly lowest in Food-Def across the 9-h trial ($P < 0.0005$; Figs. 1 and 2).

Experiment Two

Participant characteristics and exercise responses. The physical characteristics of the participants are described and contrasted (men vs women) in Table 1. There were no differences between men and women in their TFEQ scores for cognitive restraint (men, 6 (1); women, 8 (2)), disinhibition (men, 4 (1); women, 6 (1)) or hunger (men, 6 (1); women,

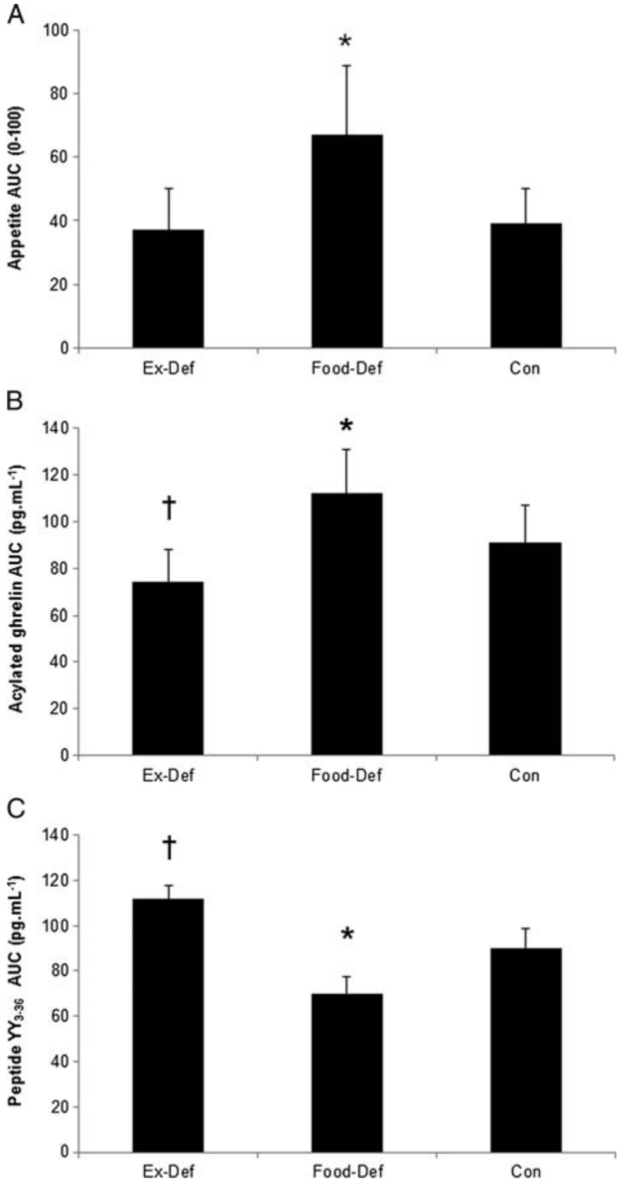

FIGURE 1—Time-averaged appetite (A), circulating acylated ghrelin (B), and peptide $YY_{3–36}$ (C) AUC for each 9-h trial. *Food-Def significantly different from Ex-Def and control; †Ex-Def significantly different from Food-Def and control (experiment one: female participants only). Values are mean (SEM), $n = 12$ for appetite and $n = 11$ for acylated ghrelin and peptide $YY_{3–36}$.

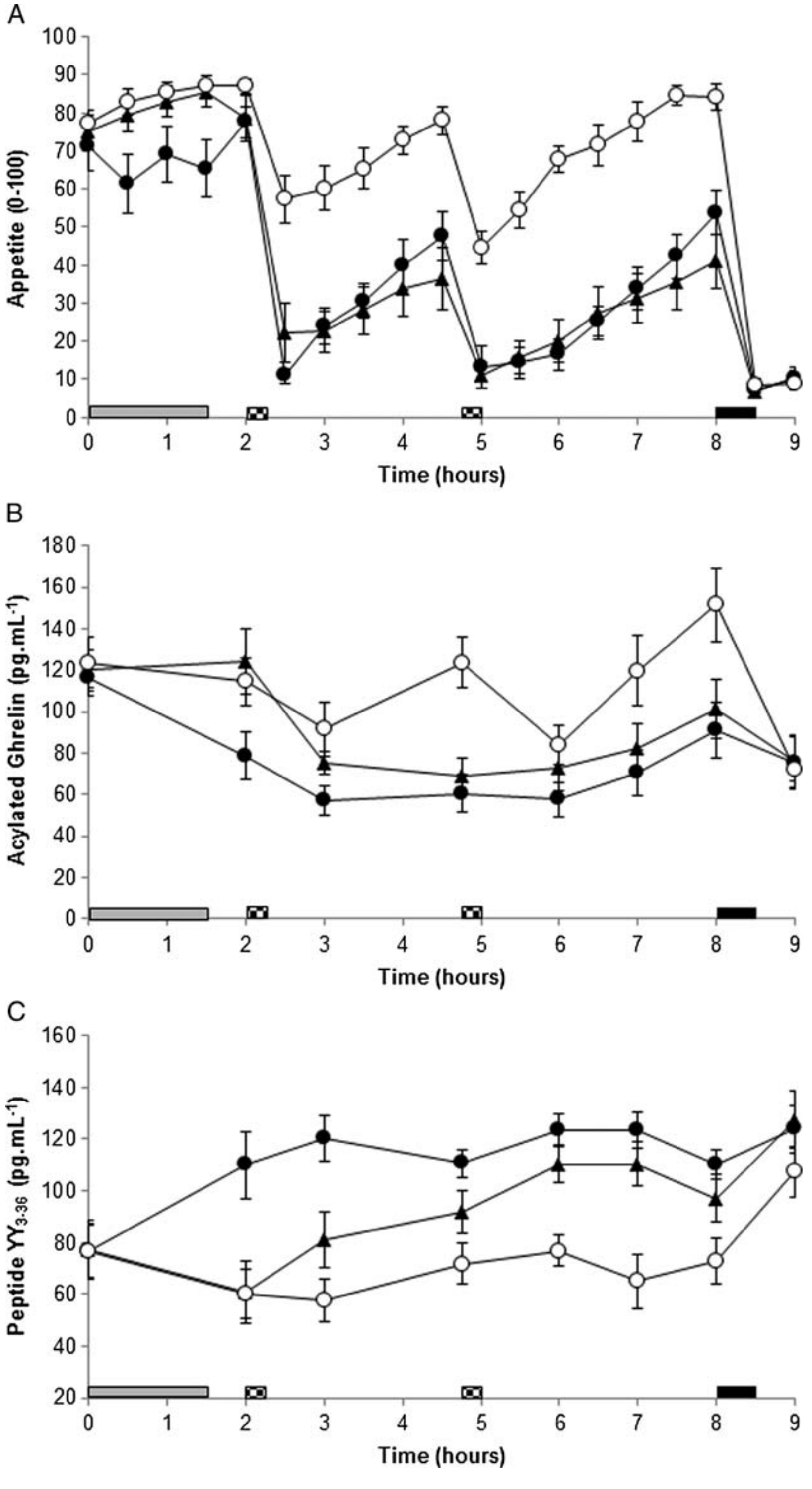

FIGURE 2—Appetite (A), circulating acylated ghrelin (B), and peptide YY$_{3–36}$ (C) concentrations across the Con (▼), Ex-Def (●), and Food-Def (○) trials (experiment one: female participants only). *Hatched shaded rectangles* indicate standardized test meals, *lightly shaded rectangle* indicates exercise, *black rectangle* indicates *ad libitum* meal. Values are mean (SEM), *n* = 12 for appetite and *n* = 11 for acylated ghrelin and peptide YY$_{3–36}$.

7 (1)). The 60-min run was completed at a significantly higher speed in men than in women (men, 10.7 (0.7) km·h^{-1}; women, 8.4 (0.3) km·h^{-1}; $P = 0.006$). The run also generated a greater net energy expenditure in men than in women (men, 3971 (200) kJ; women, 2536 (126) kJ; $P < 0.0005$). However, there was no difference in relative exercise intensity (70.9% (1.4%) and 73.3% (0.6%) of $\dot{V}O_{2max}$ in men and women, respectively; $P = 0.130$). There was a tendency for a lower heart rate in men than in women (men, 163 (4) bpm; women, 174 (4) bpm; $P = 0.068$). Ratings of perceived exertion did not differ between the sexes (13 (1) and 12 (0) in men and women, respectively; $P = 0.797$).

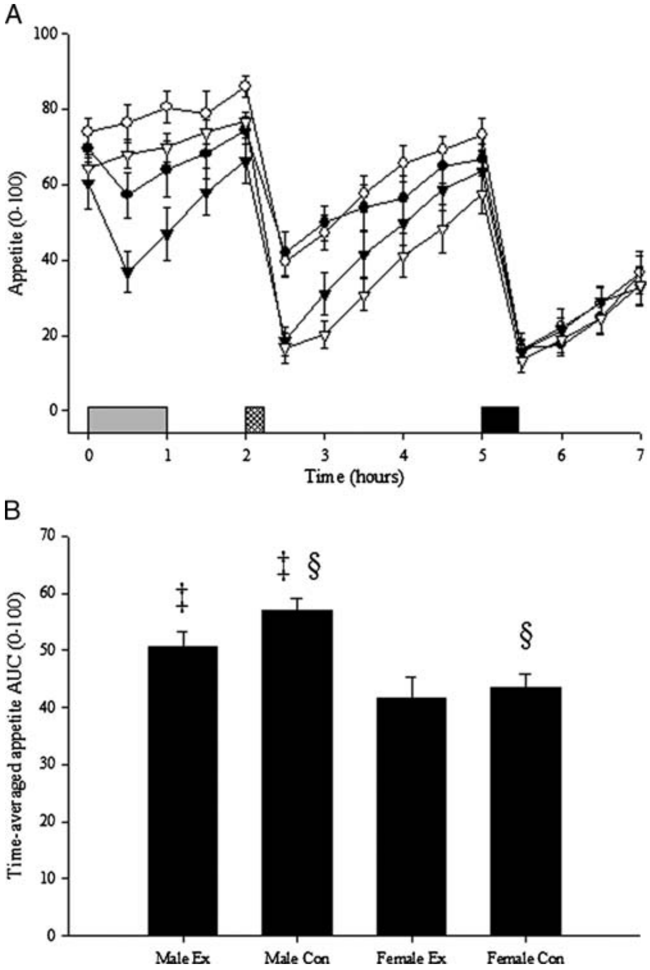

FIGURE 3—A, Appetite ratings in Male Con (○), Male Ex (●), Female Con (∇), and Female Ex (▼) (experiment two: male and female participants). ***Hatched shaded rectangles*** **indicate standardized test meal,** ***lightly shaded rectangle*** **indicates exercise,** ***black rectangle*** **indicates** ***ad libitum*** **meal. B, Time-averaged appetite AUC for each 7-h trial. ‡Males significant different than females. §Control significantly different than exercise. Values are mean (SEM). Females, *n* = 10; males, *n* = 10.**

Appetite and energy intake. Appetite did not differ by trial (exercise vs Con) or sex at baseline (Female Ex, 61 (22); Female Con, 65 (11); Male Ex, 70 (12); Male Con, 74 (11); all $P > 0.05$). Two-way ANOVA revealed main effects of trial ($P = 0.05$) and sex ($P = 0.01$) for AUC appetite ratings across the 7-h trial, with higher appetite ratings in men than in women and in control compared with exercise (Fig. 3).

Two-factor ANOVA revealed a main effect of sex for energy intake ($P = 0.023$) and carbohydrate intake ($P = 0.013$) during the *ad libitum* buffet meal, indicating greater consumption by men than women. Differences between sexes no longer remained after intakes were adjusted for lean body mass (both, $P \geq 0.289$). There was no effect of trial for energy or macronutrient intake and no differences between sexes for fat and protein intake (both $P > 0.05$; Table 2).

Two-factor ANOVA revealed a main effect of trial for relative energy intake (energy intake minus net energy expenditure of exercise) indicating lower relative energy intake in the exercise trial compared with control (Female Ex, 442 (1711); Female Con, 2916 (1510); Male Ex, 1414 (2510); Male Con, 4971 (2648) kJ; $P < 0.0005$). This resulted in a similar energy deficit for men and women in the exercise trial relative to control (men, 3557 (598); women, 2474 (406) kJ; $P = 0.152$).

Acylated ghrelin. Owing to problems with venous cannulation, acylated ghrelin data are only available for 8 men and 8 women. Baseline values were not different between the control and exercise trials ($P > 0.05$) but were significantly higher in women than men (Female Ex, 155 (101); Female Con, 178 (61); Male Ex, 71 (31); Male Con, 100 (56); $P = 0.018$). Two-way ANOVA revealed main effects of trial ($P = 0.004$) and sex ($P = 0.034$) for AUC acylated ghrelin concentrations across the 7-h trial, with higher concentrations in women than in men and in control compared with exercise (Fig. 4).

DISCUSSION

In recent years, there has been an explosion of research examining the interaction between exercise and energy homeostasis. One area that has received widespread attention is the influence of exercise and associated changes in energy balance on gut hormones, which have been identified as key regulators of appetite, energy intake, and adiposity (21,30,31). To date, most research within these areas has been conducted using male participants, meaning that much less is known regarding the interaction between acute exercise and food intake regulation in women. The findings of the present

TABLE 2. Energy and macronutrient intakes of men and women during the buffet meal in the control and exercise trials.

	Control		Exercise	
	Men	Women	Men	Women
Fat, kJ	355 (274)	175 (142)	348 (245)	168 (142)
Fat, kJ·kg^{-1} lean mass	5 (5)	4 (3)	5 (3)	4 (3)
Carbohydrate,* kJ	680 (318)	434 (174)	788 (322)	446 (201)
Carbohydrate, kJ·kg^{-1} lean mass	10 (6)	9 (4)	12 (6)	10 (5)
Protein, kJ	148 (111)	87 (75)	149 (100)	95 (68)
Protein, kJ·kg^{-1} lean mass	2 (1)	2 (1)	2 (1)	2 (1)
Energy intake,* kJ	4971 (2644)	2916 (1506)	5385 (2423)	2979 (1586)
Energy intake, kJ·kg^{-1} lean mass	75 (38)	63 (25)	84 (38)	63 (38)

Values are presented as mean (SD).
Females, *n* = 10; males, *n* = 10.
*Significantly higher in men than in women ($P < 0.05$).

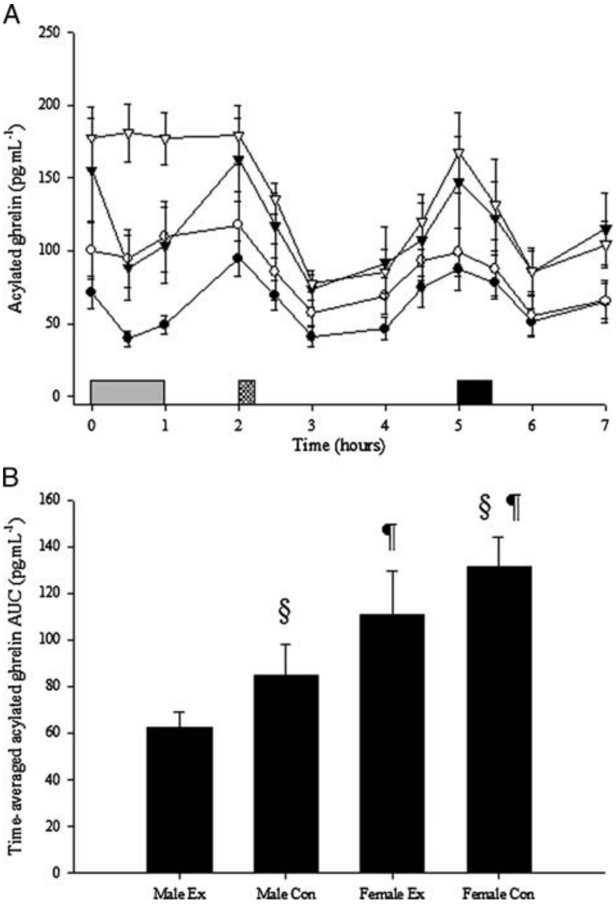

FIGURE 4—A, Plasma acylated ghrelin concentrations in Male Con (○), Male Ex (●), Female Con (▽), and Female Ex (▼) (experiment two: male and female participants). *Hatched shaded rectangles* indicate standardized test meal, *lightly shaded rectangle* indicates exercise, black rectangle indicates *ad libitum* meal. B, Time-averaged acylated ghrelin AUC for each 7-h trial. ¶Females significantly different than males. §Control significantly different than exercise. Values are mean (SEM). Females, *n* = 8; males, *n* = 8.

experiments demonstrate that women respond similarly to men with regard to short-term responses to energy deficits induced by exercise and food restriction. Specifically, in accordance with our previous results in male participants (20), in experiment one, our female sample demonstrated rapid and robust compensatory appetite, energy intake, and appetite hormone responses (acylated ghrelin and PYY_{3-36}) to energy deficits induced by food restriction but not exercise. Additionally, in experiment two, both male and female participants exhibited suppressed appetite and circulating acylated ghrelin in response to exercise without any change in *ad libitum* energy intake being apparent. These data provide new information regarding short-term physiological and behavioral responses to energy deficits in women.

Experiment one showed that in women, an acute energy deficit of approximately 3500 kJ robustly stimulated appetite and energy intake when induced via energy restriction, but such compensatory responses did not occur when an equivalent deficit was induced by exercise. These outcomes are consistent with the findings from an identical previous study in men (20) and highlight the importance of orogastric mechanisms, e.g., stomach distention and/or passage of nutrients through the gastrointestinal tract, for short-term appetite control in men and women (2,36). Such regulatory mechanisms are complemented by a network of appetite regulatory hormones, and the identification of higher circulating concentrations of acylated ghrelin, and lower PYY_{3-36} in response to energy restriction is consistent with the known acute regulatory actions of these hormones (24,25). In contrast, within experiment one, exercise elicited reductions in circulating acylated ghrelin and elevations in PYY_{3-36} across the 9-h trial in our female sample. These responses are consistent with previous studies in men, which have identified a potent capacity of exercise to perturb the circulating concentrations of these hormones in directions associated with a reduction in appetite (30). The mechanisms promoting such changes are unclear and were not investigated in the present experiments. It has been suggested that exercise-induced changes in sympathetic nervous system activity (3,38) and splanchnic blood flow (29,37) may be important; however, additional work is needed to investigate this issue. As per our previous findings in males (20), the results from experiment one demonstrate the usefulness of exercise for weight management in women to minimize compensatory responses associated with energy deficits produced solely by dietary restriction. Additional research is now needed to determine the more prolonged impact of exercise and diet-related energy deficits on appetite and energy intake in men and women, research that will provide more tangible information for individuals concerned with weight management.

The second experiment of this article demonstrated that an acute bout of exercise, performed at the same relative exercise intensity, decreased appetite ratings in men and women. Furthermore, this response was consistent with lower acylated ghrelin concentrations in both sexes and the absence of any compensatory increase in *ad libitum* energy intake. These findings are consistent with the suggestion that men and women do not differ in their physiological and behavioral responses to exercise (5), and this notion is supported by previous data albeit with a very brief period of observation after exercise (16). Our findings therefore add to the literature by demonstrating that acute responses to exercise do not differ between men and women over a prolonged duration within the laboratory.

In contrast to the present results, previous research has shown that appetite is not suppressed in women during exercise (18,22,23). Furthermore, Larson-Meyer et al. (23) observed an increase in circulating acylated ghrelin in response to acute exercise, contrasting the suppression reported in the present article. The discrepant findings with regard to appetite may be related to exercise intensity, with the intensity in the present studies being much greater (70% of $\dot{V}O_{2max}$) than that used by Hopkins et al. (18) (~50% of $\dot{V}O_{2max}$). Training status and familiarity with exercise also moderate exercise-related appetite responses (26,27), and the lack of influence of exercise on appetite in the studies of King et al.

(22) and Larson-Meyer et al. (23) may be because their participants were regularly active and particularly familiar with the mode of exercise used. An increase in circulating acylated ghrelin in response to exercise (23) contrasts the present findings and the bulk of the literature that have studied men (30). Regression to the mean may have been a confounding factor in the study of Larson-Meyer et al. (23), however. Furthermore, differences in the analytical techniques used between studies may also be influential. Nonetheless, despite these noted discrepancies, *ad libitum* energy intake remained unchanged in each of the aforementioned studies. Thus, as seen in men, single sessions of exercise do not seem to influence energy intake in women.

Although we found no differences between the sexes in compensatory responses to exercise, female participants exhibited significantly higher plasma acylated ghrelin concentrations across the main trials compared with men, a finding that has been reported previously (13). Despite this disparity, appetite ratings were paradoxically higher in men than women across the main trials. This difference may highlight the importance of relative changes in gut hormone concentrations, rather than absolute circulating levels, which may markedly differ between individuals. The similar acylated ghrelin response to exercise in both sexes may therefore underpin the comparable appetite and energy intake responses observed. Given that acylated ghrelin and PYY_{3-36} function within a network of other key appetite regulatory peptides (17), additional research is needed to characterize the impact of the present interventions on glucagon-like-peptide-1, oxyntomodulin, pancreatic polypeptide, and leptin in men compared with women.

The higher appetite ratings and food intake seen in men in experiment two supports the concept that lean body mass is the primary determinant of tonic appetite ratings and energy intake (1). This theory is further supported by our finding that energy intake during *ad libitum* feeding did not differ between the sexes when expressed per kilogram of lean body mass. Although acylated ghrelin may in part mediate the episodic changes in appetite observed in the present study, the lower tonic concentrations observed in men suggests that lean body mass may influence appetite and energy intake through an alternative mechanism. Recent evidence suggests that resting metabolic rate may be important in this regard (1).

Our findings provide a comparative insight into the short-term appetite, energy intake, and gut hormone responses to acute energy deficits in women compared with men. In accordance with the recent findings of Caudwell et al. (5), these new data support the perspective that men and women do not exhibit different physiological or behavioral compensatory responses to energy deficits (induced by exercise or food restriction), at least during the actual day when an energy deficit is imposed. Our findings therefore support the importance of exercise for weight management in women; however, these data must be considered in light of certain limitations. First, experiment one and experiment two were powered to detect changes in food intake, and it is possible that subtle effects of the present interventions on appetite and gut hormones may not have been detected. Second, the implementation of prolonged and strenuous exercise protocols, completed by recreationally active individuals, may limit the generalizability of the findings, i.e., to those who are less active or less fit. The arduous exercise undertaken in the present studies may therefore not be achievable by many seeking to commence a weight loss program, and additional work is needed with overweight and/or obese participants.

In conclusion, the experiments presented in this article have provided evidence that appetite, energy intake, and gut hormone responses to acute energy deficits do not differ between men and women. These data support the importance of exercise for weight management in women to reduce the compensatory responses to energy deficits achieved solely via food restriction.

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