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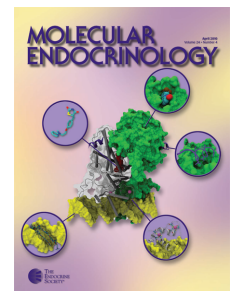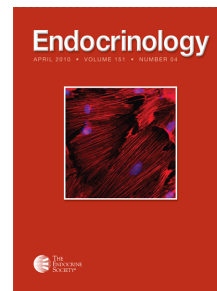
Differential Acylated Ghrelin, Peptide YY$_{3-36}$, Appetite, and Food Intake Responses to Equivalent Energy Deficits Created by Exercise and Food Restriction

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Context: Acute energy deficits imposed by food restriction increase appetite and energy intake; however, these outcomes remain unchanged when energy deficits are imposed by exercise.

Objective: Our objective was to determine the potential role of acylated ghrelin and peptide YY$_{3-36}$ (PYY$_{3-36}$) in mediating appetite and energy intake responses to identical energy deficits imposed by food restriction and exercise.

Design: Twelve healthy males completed three 9-h trials (exercise deficit, food deficit, and control) in a randomized counterbalanced design. Participants ran for 90 min (70% of VO$_2$ max) at the beginning of the exercise deficit trial and then rested for 7.5 h. Participants remained sedentary throughout the food deficit and control trials. Test meals were consumed by participants at 2 and 4.75 h in all trials. The amount provided in the food deficit trial was restricted so that an energy deficit (equivalent to that imposed by exercise) was induced relative to control. Participants were permitted access to a buffet meal at 8 h.

Results: The energy deficits imposed by food restriction (4820 ± 151 kJ) and exercise (4715 ± 113 kJ) were similar. Appetite and *ad libitum* energy intake responded in a compensatory fashion to food restriction yet were not influenced by exercise. Plasma acylated ghrelin concentrations increased, whereas PYY$_{3-36}$ decreased, in response to food restriction (two-way ANOVA, trial × time interaction, $P < 0.001$ for each). Exercise did not induce such compensatory responses.

Conclusions: These findings suggest a mediating role of acylated ghrelin and PYY$_{3-36}$ in determining divergent feeding responses to energy deficits imposed by food restriction and exercise. (*J Clin Endocrinol Metab* 96: 1114–1121, 2011)

A s the prevalence of overweight and obesity continues to rise globally, effective strategies to facilitate successful weight control are needed (1). A more complete understanding of the mechanisms of energy balance regulation is required to enable this. In basic terms, energy balance is determined by the energy consumed as food and drink and that expended during physical activity (2). Thus, in theory, for the purpose of inducing weight loss, individuals can induce an energy deficit by either restricting their dietary intake or by increasing the amount of physical activity performed. Practically, however, at least within the short term, it appears that these two methods of creating an energy deficit have a markedly different influence on appetite and energy intake (3), *i.e.* different responses occur when there is a restriction on energy entering the body compared with when there is an increase in energy leaving the body.

Abbreviations: AUC, Area under the curve; Ex-Def, exercise-induced energy deficit trial; Food-Def, food-induced energy deficit trial; PYY, peptide YY.

It has been shown that restricting energy intake induces a rapid compensatory increase in appetite and food intake (3, 4). Paradoxically, acute bouts of exercise do not produce such compensatory responses, even when the amount of energy expended is large (>5020 kJ) (5–7). At present, the underlying mechanisms determining such divergent responses to a short-term negative energy balance are not entirely clear. It has been suggested that differences in the strength of postingestive satiety signals generated in response to these interventions may be implicative in this (3, 5). Direct evidence supporting this contention is not available, however.

Energy homeostasis is regulated by a complex neuroendocrine system, spanning both central and peripheral tissues (8). Within this system, peptides secreted from the gastrointestinal tract in response to nutrient ingestion have an important role in regulating both acute and chronic energy homeostasis (9). Herein, ghrelin remains unique as the only known circulating peptide that stimulates appetite and food consumption, and this property has made ghrelin an intriguing research target (10, 11). Conversely, several gastrointestinal peptides exist that function as negative feedback signals, suppressing appetite and food intake once nutrients are ingested. In this regard, peptide YY (PYY) has received explicit attention owing to its prominent role in mediating within meal satiation and intermeal satiety (12).

Circulating levels of ghrelin and PYY are sensitive to nutrient intake (13–17). Compensatory adjustments in circulating levels of ghrelin and PYY occur as mechanisms aiding the acute regulation of energy balance. This responsiveness of ghrelin and PYY to acute nutrient intake may be linked to the apparent sensitivity of appetite and energy intake to acute food restriction. In contrast to this, research suggests that ghrelin and PYY remain unresponsive to acute deficits in energy induced by exercise (7, 18–20). Although moderate- to high-intensity bouts of exercise transiently alter circulating levels of these gut hormones in directions consistent with an inhibition of appetite (18, 20, 21), it does not appear that compensatory responses occur in the hours after exercise to correct for the energy imbalance. This unresponsiveness of ghrelin and PYY may be related to the apparent insensitivity of appetite and energy intake to the expenditure of energy through exercise.

The aim of the present study was to compare acylated ghrelin and PYY_{3-36} (the form of PYY chiefly responsible for appetite regulation) responses to equivalent energy deficits induced by diet (food restriction) and exercise. Within this, we sought to explore whether divergent acylated ghrelin and PYY_{3-36} responses were associated with dissimilar appetite and energy intake responses to these interventions. We predicted that circulating levels of acy-

lated ghrelin and PYY_{3-36} would respond in a compensatory fashion (higher acylated ghrelin and lower PYY_{3-36}) to acute energy deficits induced by restricting food intake but would be unresponsive to energy deficits induced by exercise.

Subjects and Methods

Participants

Loughborough University's ethical advisory committee approved the study. Twelve healthy physically active males of white European decent (20–30 yr) gave their written informed consent to participate. Participants were nonsmokers, not taking any medication, and weight stable for 3 months before the study and had no food allergies or eating disorders. The physical characteristics of the participants were as follows: age, 23.4 ± 1.0 yr; body mass index, 22.8 ± 0.4 kg/m²; waist circumference, 75.3 ± 1.3 cm; and maximal oxygen uptake, 57.3 ± 1.2 ml/kg · min (mean ± SEM).

Preliminary sessions

Before the main trials, across two laboratory visits, participants were familiarized with the experimental setting, and the necessary anthropometric and preliminary exercise test data were collected. A submaximal treadmill running test and a maximal oxygen uptake test were each undertaken on a motorized treadmill as described previously (18). These data were used to determine the running speed required to elicit 70% of maximal oxygen uptake for each individual. A 90-min familiarization run was also completed to permit an accurate estimation of energy expenditure that was necessary to determine energy provision at test meals during the main trials.

Main trials

In subsequent weeks, participants completed three main trials (control, exercise-induced energy deficit, and diet-induced energy deficit) in a randomized-counterbalanced fashion, separated by at least 1 wk. Diet was standardized within the 24 h before each main trial, and alcohol, caffeine, and structured physical activity were not permitted during this period. Each main trial began at 0800 h and lasted 9 h. Participants arrived at the laboratory in the fasted state.

On the control trial, participants rested throughout. At two points (2 and 4.75 h) participants consumed test meals that were of sufficient energy content for their individually estimated energy requirements. At 8 h, a buffet meal was provided from which participants were free to consume food *ad libitum*. The exercise-induced energy deficit trial (Ex-Def) commenced when participants began a 90-min run on a level treadmill. The speed of the treadmill was identical to that completed during preliminary testing and was set to elicit 70% of maximal oxygen uptake. After the run, participants rested within the laboratory for 7.5 h. At 2 and 4.75 h, participants consumed test meals that were identical to those provided in the control trial. At 8 h, a buffet meal was offered to participants. On the food-induced energy deficit trial (Food-Def), participants remained sedentary throughout. Test meals were provided at 2 and 4.75 h; however, the amount of energy provided at these meals was restricted so that an energy deficit was induced relative to control. The energy

deficit was identical to that elicited by exercise in the Ex-Def trial. This permitted a comparison of responses to identical energy deficits induced through diet as compared with exercise. At 8 h, the same a buffet meal was offered to participants as in the control and Ex-Def trials.

Appetite and test meals

During the main trials, 100-mm visual analog scales were completed at 30-min intervals to assess perceptions of appetite (hunger, fullness, satisfaction, and prospective food consumption) (22). During the main trials, test meals were provided to participants at 2 and 4.75 h. Each meal was consumed within 15 min. The test meals consisted of a tuna and mayonnaise sandwich, salted crisps, chocolate muffin, and green apple. The macronutrient content of the meal was balanced (fat 34%, protein 18%, carbohydrate 48%) and remained consistent across meals. The energy content of the test meals were identical in the control and Ex-Def trials and was calculated to be sufficient to meet each participants' individual energy requirements. To calculate this, resting daily energy requirements were estimated for each individual (23). This amount was then multiplied by a physical activity level of 1.4 to yield an amount of energy sufficient for a resting day. Participants received 70% of this amount divided equally across two identical test meals. In the Food-Def trial, participants received a restricted amount of energy at the test meals. The amount provided was calculated by deducting the net estimated energy expenditure of exercise from the energy provided at the test meals in the control and Ex-Def trials. The total amount deducted was divided equally across the two test meals.

Ad libitum buffet meals

At 8 h, participants were given access to a buffet meal for 30 min 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 semiskimmed milk, three varieties of cereal, cereal bars, white bread, brown bread, ham, Cheddar cheese, tuna, mayonnaise, butter, margarine, cookies, chocolate rolls, apples, oranges, and bananas. Participants were told to eat until satisfied and that additional food was available if desired. Meals were consumed in isolation so that social influence did not affect food selection. 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.

Blood sampling and analysis

During the main trials, venous blood samples were collected via a cannula (Venflon; Becton Dickinson, Helsingborg, Sweden) inserted into an antecubital vein. Blood samples were collected at baseline and 2, 3, 4.75, 6, 7, 8, and 9 h to measure circulating concentrations of acylated ghrelin and PYY_{3-36}. Details on acylated ghrelin and PYY_{3-36} sample collection and processing have been described previously (18, 24). All blood samples were collected in the semisupine position. Measurements of hemoglobin and hematocrit were taken to estimate changes in plasma volume using the method of Dill and Costill (25).

An 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 RIA (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 acylated ghrelin and PYY_{3-36} assays were 7.8 and 6.8%, respectively.

Statistical analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) software version 16.0 for Windows. All area under the curve (AUC) calculations were performed using the trapezoidal method. One-way repeated-measures ANOVA was used to assess differences between trials in fasting parameters, AUC values and energy/macronutrient intake. Repeated measures, two-factor ANOVA was used to examine differences between trials over time for appetite perceptions, acylated ghrelin and PYY_{3-36}. Where significant main effects were found *post hoc* analysis was performed using the Bonferroni correction for multiple comparisons. The Pearson product moment correlation coefficient was used to examine relationships between variables. Correction of values for changes in plasma volume did not alter the statistical significance of findings therefore for simplicity the unadjusted values are presented. Statistical significance was accepted at the 5% level. Results are presented as mean ± SEM.

Results

Exercise responses

Participants completed the 90-min run at 9.6 ± 0.2 km/h. This elicited a mean oxygen consumption equivalent to 69.8 ± 0.9% of maximal oxygen uptake (40.0 ± 0.9 ml/kg · min, 2.87 ± 0.1 liters/min) and generated a mean heart rate and net energy expenditure of 173 ± 3 beats/min and 4715 ± 113 kJ, respectively. A mean nonprotein respiratory quotient of 0.92 ± 0.01 reflected the proportional oxidation of carbohydrate and fat (72 ± 3 and 28 ± 3%).

Appetite responses

Fasting appetite ratings (hunger, fullness, satisfaction, and prospective food consumption) did not differ significantly between trials. For each appetite marker, two-factor ANOVA revealed significant trial, time, and interaction (trial × time) main effects (all $P < 0.001$), indicating that appetite responses differed over time between the main trials (Fig. 1). For each appetite marker, *post hoc* analysis revealed significant trial differences between the Food-Def and control trial (all $P < 0.001$) and the Food-Def and Ex-Def trial (all $P < 0.001$), demonstrating higher ratings of hunger and prospective food consumption and reduced ratings of satisfaction and fullness in the Food-Def trial. At individual time points, *post hoc* analysis identified differences between the Food-Def and control trial (all $P < 0.004$) and the Food-Def and Ex-Def trial (all $P < 0.006$) at 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, and 8 h.
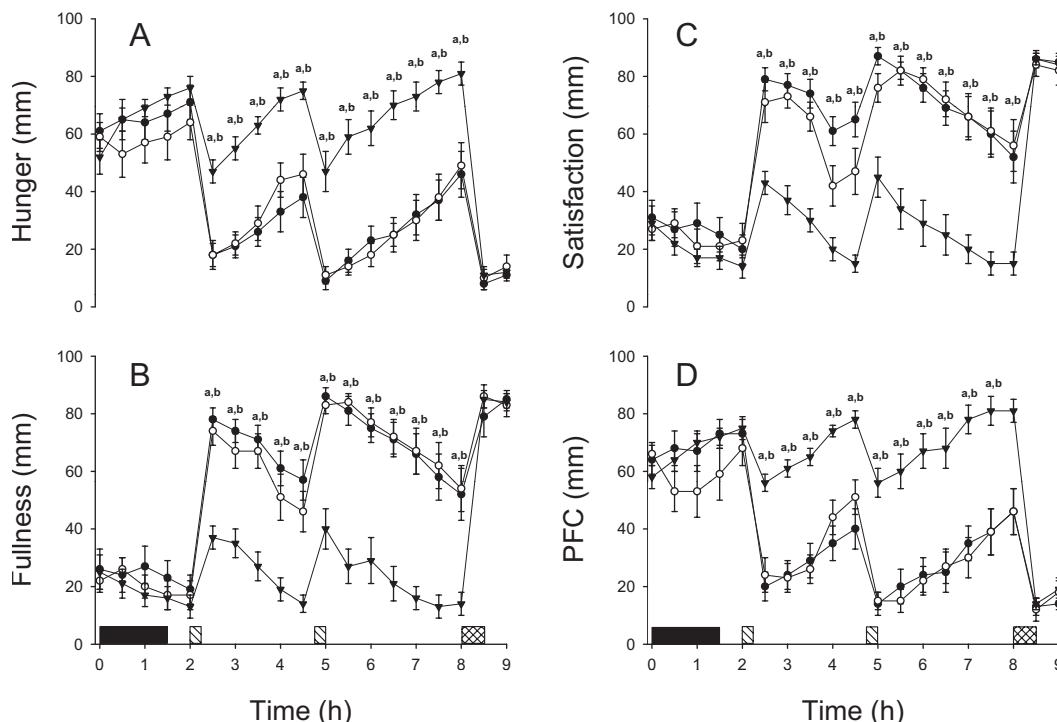
FIG. 1. Ratings of hunger (A), fullness (B), satisfaction (C), and prospective food consumption (D) in the control (●), Ex-Def (○), and Food-Def (▼) trials. Values are mean ± SEM (n = 12). *Black rectangle* indicates exercise, *diagonal rectangles* indicate test meals, and *hatched rectangle* represents the buffet meal. a, Food-Def different from control at $P < 0.05$; b, Food-Def different from Ex-Def at $P < 0.05$.

Table 1 shows AUC values calculated for each appetite visual analog scale.

Energy and macronutrient intake

At the test meals (first and second meal combined), participants consumed 7021 ± 92 kJ in the control and Ex-Def trials and 2200 ± 142 kJ in the Food-Def trial. Consequently, the energy deficit induced by food restric-

tion was 4820 ± 151 kJ. This was comparable with the energy deficit induced through exercise (4715 ± 113 kJ). Table 2 displays the energy and macronutrient intake data at the *ad libitum* buffet meal. One-factor ANOVA revealed a significant main effect of trial for energy intake ($P < 0.002$). *Post hoc* analysis revealed a higher intake of energy on the Food-Def trial than the control trial ($P < 0.001$), whereas energy intake tended to be higher on the

TABLE 1. Effect of control, Ex-Def, and Food-Def trials on appetite assessed using visual analog scales

	Preprandial (0-2 h), units 2 h	Intertest meal (2.5-4.5 h), units 2 h	Posttest meals (4.5-9 h), units 4.5 h	Total trial (0-9 h), units 9 h
Hunger				
Control	131 ± 12	76 ± 12	110 ± 20	317 ± 40
Ex-Def	115 ± 12	84 ± 12	112 ± 18	312 ± 33
Food-Def	135 ± 6	156 ± 7^{a,b}	262 ± 17^{a,b}	553 ± 25^{a,b}
Satisfaction				
Control	53 ± 12	167 ± 11	326 ± 22	546 ± 39
Ex-Def	48 ± 8	143 ± 11	321 ± 21	512 ± 31
Food-Def	39 ± 7	72 ± 9^{a,b}	158 ± 19^{a,b}	269 ± 32^{a,b}
Fullness				
Control	48 ± 12	162 ± 12	319 ± 24	529 ± 43
Ex-Def	41 ± 7	145 ± 10	324 ± 19	509 ± 26
Food-Def	36 ± 8	66 ± 10^{a,b}	146 ± 18^{a,b}	248 ± 34^{a,b}
PFC				
Control	138 ± 10	82 ± 13	121 ± 22	342 ± 40
Ex-Def	116 ± 12	88 ± 12	120 ± 20	324 ± 31
Food-Def	136 ± 6	166 ± 5^{a,b}	276 ± 16^{a,b}	579 ± 22^{a,b}

Values are mean ± SEM (n = 12).

[a] Different from control ($P < 0.001$).

[b] Different from Ex-Def ($P < 0.001$).

TABLE 2. *Ad libitum* energy and macronutrient intake in the control, Ex-Def, and Food-Def trials

	Control	Ex-Def	Food-Def
Energy (kJ)	4004 ± 427	4343 ± 653	6167 ± 318^a
Fat (g)	34 ± 5	38 ± 5	$63 \pm 5^{a,b}$
Fat (%)	30.7 ± 3.3	33.4 ± 2.0	$38.3 \pm 1.7^{a,b}$
Protein (g)	40 ± 10	47 ± 15	67 ± 9^a
Protein (%)	14.7 ± 2.1	15.0 ± 2.5	17.9 ± 1.8
Carbohydrate (g)	124 ± 12	129 ± 17	159 ± 10^a
Carbohydrate (%)	54.6 ± 4.4	51.6 ± 3.1	$43.8 \pm 2.5^{a,b}$

Values are mean $\pm$ SEM (n = 12).

^{a} Different from control (P < 0.05).

^{b} Food-Def different from Ex-Def (P < 0.05).

Food-Def trial than the Ex-Def trial ($P = 0.058$). Both the absolute amount (grams) and percentage of energy derived from the macronutrients was compared across the main trials. The absolute intake of fat was significantly higher on the Food-Def trial than both the control and Ex-Def trials ($P < 0.001$). The absolute intake of protein and carbohydrate was significantly higher on the Food-Def trial than the control trial ($P < 0.05$ for each). The percentage of energy derived from fat was significantly higher in the Food-Def trial than the control ($P = 0.044$) and Ex-Def ($P = 0.044$) trials, whereas the percentage intake of carbohydrate was significantly reduced ($P < 0.006$ for both).

Plasma acylated ghrelin and PYY$_{3-36}$

Fasting plasma acylated ghrelin concentrations did not differ significantly between trials (Fig. 2a). Two-factor ANOVA revealed significant trial, time, and interaction (trial $\times$ time) main effects (all $P < 0.001$). Across trials, *post hoc* analysis identified significantly higher circulating acylated ghrelin concentrations in the Food-Def trial compared with the control ($P = 0.002$) and Ex-Def ($P < 0.001$) trials. At individual time points, *post hoc* analysis identified significant differences between trials at 2, 3, 4.75, 6, 7, and 8 h (all $P < 0.05$).

Fasting plasma PYY$_{3-36}$ concentrations did not differ significantly between trials (Fig. 2B). Two-factor ANOVA revealed significant trial, time, and interaction (trial $\times$ time) main effects (all $P \leq 0.001$). Across trials, *post hoc* analysis identified significantly lower circulating PYY$_{3-36}$ concentrations in the Food-Def trial as compared with the control trial ($P = 0.004$) and Ex-Def ($P < 0.001$) trials. At individual time points, *post hoc* analysis identified significant differences between trials at 2, 3, 4.75, 6, 7, and 8 h (all $P < 0.05$). Table 3 shows acylated ghrelin and PYY$_{3-36}$ AUC values calculated for the pre- and postprandial periods.
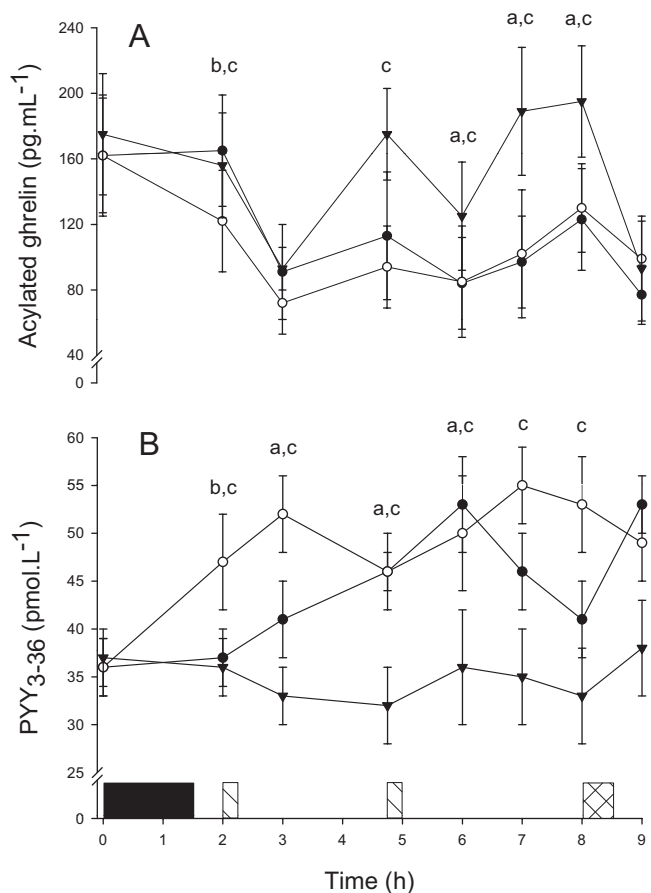

FIG. 2. Plasma concentrations of acylated ghrelin (A) and PYY$_{3-36}$ (B) in the control ($\bullet$), Ex-Def ($\circ$), and Food-Def ($\blacktriangledown$) trials. Values are mean $\pm$ SEM (n = 12). *Black rectangle* indicates exercise, *diagonal rectangles* indicate test meals, and *hatched rectangle* represents the buffet meal. a, Food-Def different from control at $P < 0.05$; b, Ex-Def different from control at $P < 0.05$; c, Food-Def different from Ex-Def at $P < 0.05$.

Discussion

This study compared acylated ghrelin, PYY$_{3-36}$, appetite, and energy intake responses to equivalent energy deficits induced through acute dietary restriction and exercise. This study has shown that prandial acylated ghrelin and PYY$_{3-36}$ responses are sensitive to acute energy manipulation, acting in a compensatory fashion to an energy deficit imposed by dietary restriction. In contrast, such compensatory adjustments do not occur when an equivalent energy deficit is imposed through exercise. These divergent responses of acylated ghrelin and PYY$_{3-36}$ are consistent with the respective appetite and energy intake responses to these interventions.

The present findings show that two methods of inducing an acute energy deficit have markedly different influences on appetite and energy intake; *i.e.* appetite and energy intake increase in response to food restriction but remain unchanged by exercise, despite the similarity of the energy deficit. These findings are consistent with previous results (3, 6, 7, 26) and from a practical perspective may

TABLE 3. Acylated ghrelin and PYY_{3-36} AUC in the control, Ex-Def, and Food-Def trials

	Preprandial (0-2 h), units 2 h	Postprandial (2-9 h), units 7 h	Total trial (0-9 h), units 9 h
Acylated ghrelin (pg/ml)			
Control	327 ± 70	729 ± 209	1055 ± 276
Ex-Def	284 ± 65^a	677 ± 190	961 ± 254^a
Food-Def	331 ± 69^b	$1040 \pm 195^{a,b}$	1371 ± 262^b
PYY_{3-36} (pmol/liter)			
Control	73 ± 6	318 ± 17	391 ± 22
Ex-Def	84 ± 7^a	354 ± 25	438 ± 31^a
Food-Def	73 ± 6^b	$237 \pm 28^{a,b}$	$310 \pm 34^{a,b}$

Values are mean $\pm$ SEM (n = 12).

[a] Different from control at $P < 0.05$.

[b] Different from Ex-Def at $P < 0.05$.

indicate why dieting is often perceived as being so difficult and is typically unsuccessful. Equally, this work underscores the potential for exercise to facilitate weight management (27).

Hubert *et al.* (3) reported that the intake of a reduced energy breakfast elicited a rapid compensatory increase in hunger and subsequently led to an increase in energy intake at an *ad libitum* lunch (~20%). These compensatory adjustments did not occur when participants expended over 1320 kJ during 40 min of cycling (70% of $\dot{V}O_2$ max). The researchers proposed that the rapid increase in appetite observed in response to the reduced energy breakfast may be related to weakened postingestive satiety signals. The findings from the present study support this hypothesis and suggest a mediating role of acylated ghrelin and PYY_{3-36}.

Several studies have shown that circulating concentrations of ghrelin and PYY are sensitive to meal-related energy/nutrient intake. Circulating concentrations of PYY increase postprandially in proportion to ingested energy (13, 16). Moreover, both the preprandial rise and postprandial decline in circulating ghrelin are sensitive to the energy content of recent meals (15, 17). The present findings support the notion that acylated ghrelin and PYY_{3-36} are responsive to acute energy/nutrient intake. After the first test meal in the Food-Def trial, the acylated ghrelin AUC was 42% higher than the control trial and 54% higher than the Ex-Def trial. Thus, the reduced energy contents of the test meals in the Food-Def trial were detected, and this led to a briefer postprandial suppression of acylated ghrelin. Similarly, levels of PYY_{3-36} were lower during the Food-Def trial than the control and Ex-Def trials, indicating a weakened postprandial satiety response. These changes in acylated ghrelin and PYY_{3-36} were concordant with augmented appetite ratings and an

approximately 50% higher *ad libitum* energy intake in the Food-Def trial compared with responses on the control and Ex-Def trials.

A handful of studies have examined the influence of exercise on acylated ghrelin and PYY. These studies have shown that moderate- to high-intensity aerobic exercise transiently suppresses circulating levels of acylated ghrelin, an effect that occurs concomitantly with a suppression of appetite (7, 18, 20, 28). This effect appears to be brief, however, with levels of acylated ghrelin returning quickly to control values and remaining no different for several hours after exercise. It is possible that this lack of change in acylated ghrelin after exercise may be one reason why acute bouts of exercise do not induce compensatory appetite and energy intake responses.

Circulating levels of PYY appear to increase transiently in response to exercise (21, 29, 30) and may even remain elevated for several hours after (20). It is important to note that these initial investigations measured circulating concentrations of total PYY and not PYY_{3-36}, the PYY variant responsible for the appetite-inhibitory action of PYY (31). Only one study has investigated PYY_{3-36} responses to exercise (32). The results from this investigation showed that 60 min of moderate-intensity cycling did not alter circulating levels of PYY_{3-36} *per se* yet may potentiate PYY_{3-36} responses to feeding. In the present investigation, circulating PYY_{3-36} concentrations were 27% higher than control 30 min after the end of exercise. Thus, exercise stimulated circulating levels of PYY_{3-36}, and this finding contradicts that reported by Cheng *et al.* (32). The intensity and duration of exercise was greater in the present investigation; therefore, it is possible that only intense and/or prolonged exercise stimulates an increase in circulating PYY_{3-36}.

In the present study, PYY_{3-36} responses to feeding were also examined. Interestingly, although the differences were not quite statistically significant, levels of PYY_{3-36} were notably higher after the test meals on the Ex-Def trial compared with the control trial. Thus, exercise appeared to potentiate increases in PYY_{3-36} after eating, and these findings support those previously described (20, 32). These outcomes suggest a beneficial effect of exercise on appetite regulation, *i.e.* enhanced satiation and/or satiety after meals. It is possible that an accentuated PYY_{3-36} response to exercise is implicated in the lack of change in appetite and energy intake observed afterward.

This study has some notable limitations. First, excess postexercise oxygen consumption, *i.e.* the sustained elevation in oxygen consumption that occurs after exercise, was not measured; therefore, it is likely that the energy deficit imposed by exercise may have been marginally underestimated ($\leq$314 kJ) (33). Second, the participants in

the present study were male, young, lean, and fit; therefore, the findings may not generalize to females or those who are overweight or sedentary. Third, this study examined vigorous intensity exercise, and the findings may not apply to moderate- and light-intensity exercise, although the findings of one recent study are consistent in demonstrating that there is no compensatory increase in appetite, energy intake, and acylated ghrelin in response to brisk walking (19). Finally, it must be noted that the present investigation examined acute responses to a single bout of exercise, and this work does not provide information about the chronic effects of exercise over several days or longer on the reported outcomes.

In summary, this study has shown that equivalent energy deficits induced by food restriction and exercise have markedly different effects on appetite and energy intake. Food restriction elicits a rapid increase in appetite and energy intake, and these responses appear to be related to an attenuated postprandial PYY_{3-36} response and to a more transient postprandial suppression of circulating acylated ghrelin. In contrast to this, acute energy deficits induced by exercise do not alter appetite or energy intake, and the results of this study suggest that this may be related to the failure of exercise to induce compensatory acylated ghrelin and PYY_{3-36} responses. Further research is needed to examine other appetite-regulating peptides such as cholecystokinin and glucagon-like peptide-1 to see whether their reactions to the present interventions are consistent with those of acylated ghrelin and PYY_{3-36}. Future investigations may also seek to characterize responses in other populations, particularly the overweight/obese because it is with these individuals where the findings may hold most clinical relevance.

Acknowledgments

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