Satiety, But Not Total PYY, Is Increased with Continuous and Intermittent Exercise

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Objective: This study determined the hormonal and subjective appetite responses to exercise (1-h continuous versus intermittent exercise throughout the day) in obese individuals.

Design and Methods: Eleven obese subjects (>30 kg/m²) underwent three 12-h study days: control condition [sedentary behavior (SED)], continuous exercise condition [(EX) 1-h exercise], and intermittent exercise condition [(INT) 12 hourly, 5-min bouts]. Blood samples (every 10 min) were measured for serum insulin and total peptide YY (PYY) concentrations, with ratings of appetite (visual analog scale [VAS]: every 20 min). Both total area under the curve (AUC), and subjective appetite ratings were calculated.

Results: No differences were observed in total PYY AUC between conditions, but hunger was reduced with INT (INT < EX; P < 0.05), and satiety was increased with both SED and INT conditions (INT > EX and SED > EX; P < 0.05). A correlation existed between the change in total PYY and insulin levels (r = −0.81; P < 0.05), and total PYY and satiety (r = 0.80; P < 0.05) with the EX condition, not the SED and INT conditions.

Conclusions: The total PYY response to meals is not altered over the course of a 12-h day with either intermittent or continuous exercise; however, intermittent exercise increased satiety and reduced hunger to a greater extent than continuous exercise in obese individuals.

Introduction

Peptide YY (PYY) is among the gut hormones that act to control food intake. Obesity is associated with attenuated PYY concentrations in both the fasting and the postprandial state (1,2). The response to PYY infusion in obese individuals seems well preserved with increased indices of satiety and a reduction in subsequent energy intake (3), resulting in PYY being identified as a potential therapeutic target for weight management. Altering dietary habits toward a positive energy balance for 3 weeks is known to alter appetite-regulating hormone concentrations (4), and is associated with increased energy intake during the subsequent 3-day period.

Exercise, which can impart a negative energy balance, is also known to alter appetite-regulating hormone concentrations and promote tighter appetite control (5-9). Two recent studies demonstrated that 60 min of moderate-intensity exercise in healthy, normal-weight individuals increased plasma PYY concentrations, and transiently reduced subjective scores for hunger (8,10). This increase in PYY has also been demonstrated in obese individuals (11) following moderately intense exercise (60 min of 50 versus 65% VO₂max). Interestingly however, resistance exercise did not result in any increase in PYY levels (10). Research conducted on the acute responses of appetite-related hormones to exercise has only investigated the concentration of these peptides in the immediate postexercise period (5,6,8), without examining the impact throughout the day when additional meals are consumed. Further, since our exercise guidelines now encourage exercise to be done in short intermittent bouts throughout the day, gaining an understanding of the impact of this type of exercise regimen on appetite-related hormones and satiety throughout the day is critically important.

An inverse relationship between insulin and PYY concentrations has been reported. PYY seems to have no effect on baseline insulin, glucose, or glucagon secretion, but decreases glucose-stimulated insulin production (12,13). More specifically, an increased PYY concentration may inhibit insulin production through a neuropeptide-Y mechanism acting at the level of the pancreatic islets (14). A exercise-induced increase in endogenous PYY may contribute to decreased insulin levels and it is possible that exercise intensity or duration may modify this relationship between PYY and insulin levels.
The purpose of this study was (1) to establish the circulating total PYY concentrations and hunger/satiety responses to meal consumption in obese individuals over the course of a 12 h day, (2) to establish how different exercise regimens (continuous versus intermittent exercise) alters total PYY concentration profile and subjective measures of appetite, and (3) determine the relationship between total PYY and insulin/glucose concentrations throughout the 12-h study period. It was hypothesized that a continuous bout of exercise would increase total PYY levels to a greater degree than intermittent bouts of exercise; however, both exercise conditions were expected to increase total PYY concentration to a greater degree than the sedentary condition. Furthermore, it was hypothesized that the increase in circulating total PYY, induced by continuous and intermittent exercise, would correlate with enhanced satiety and reduced hunger, and that these effects would be altered throughout the day. Additionally, it was expected that an inverse correlation between total PYY and insulin concentrations in obese individuals would become stronger following both exercise conditions due to the increase in total PYY and proposed effects on glucose-stimulated insulin production.

Methods and Procedures

Study subjects

All subjects signed an informed consent document approved by the Syracuse University Institutional Review Board before participating in this study. Young (18-35 years old), weight-stable, obese (BMI >30 kg/m²) individuals who were free from gastrointestinal problems and orthopedic limitations to normal walking activity were recruited into this study. Female subjects did not use oral contraceptives, and were consistently tested within the follicular phase (days 1-14) of their menstrual cycles to limit potential hormonal effects on appetite regulation. According to self-report, all subjects met general guidelines for moderate physical activity (3-5 days per week, approximately 150 min total).

Methods

Age, weight, height, and waist and hip circumferences were recorded at baseline. Body mass index (BMI) was calculated as weight (kg) divided by the square of height (m²). All body measurements were recorded in duplicate, and the mean of the two measurements was used.

Experimental design

Subjects completed three 12-h testing days using a randomized crossover design. Participants reported to the Human Performance Laboratory at 0700 h following a 12-h fast from food and caffeine and avoidance of exercise for 24 h. Subjects completed either a sedentary (SED), continuous exercise (EX; 1 h continuous bout from 0705 to 0805 h), or intermittent exercise protocol (INT; 12, 5-min bouts, performed intermittently every hour). The total exercise duration (60 min) and intensity (60-65% VO₂ peak) were matched between the EX and INT study days. Subjects recorded their dietary intake for 3 days prior to the first experimental condition using a food diary and were asked to match intake prior to subsequent testing as closely as possible.

Study protocol

At 0700 h, a registered nurse placed a Teflon catheter into the antecubital vein of each subject for blood sampling. Baseline blood samples (10 ml) were drawn prior to the ingestion of the first meal. Each meal (250 kcal) consisted of a mixed, high-carbohydrate liquid (15% protein (PRO), 65% carbohydrate (CHO), 20% fat (FAT)) beverage (Wegmans Nutritional Beverage, Wegmans, Rochester, NY) which was provided every 2 h, so that a total of 1,500 kcal was consumed during each study period. Exercise sessions started immediately following baseline blood sampling and consumption of the first meal. Subjects remained sedentary outside of prescribed activity during the EX and INT conditions.

Blood samples were drawn from the indwelling catheter at 10-min intervals over the course of each study day. Samples were assayed in duplicate for serum glucose using a commercially available glucose oxidase assay (Sigma-Aldrich Corp., St. Louis, MO). Additionally, samples were centrifuged (3,000g, 5 min, 4°C) and assayed for serum total PYY and insulin concentrations (Millipore, Billerica, MA) using Luminex xMap Technology (Linco Research, St. Charles, MO) on a Luminex 100/200 platform (Luminex Corporation, Austin, TX). All procedures followed manufacturer’s instructions, with quality controls within expected ranges for each assay. Interassay and intraassay coefficients for insulin and total PYY were 4.0 and 9.5%, and 6.0 and 5.3%, respectively. The lowest limits for detection of this assay were 137 and 14 pg/ml, for insulin and total PYY, respectively. All samples for a given subject were analyzed in the same assay series.

Statistical analysis

Area under the curve (AUC) for serum total PYY and VAS scores for hunger and satiety were calculated as the area above baseline using the trapezoidal method within each exercise condition (GraphPad Prism version 3.00 for Windows, GraphPad Software, San Diego, CA). The AUC was calculated for the entire 12-h period and each 2-h increment starting from first blood sample (0705-1905 h). The
change (Δ) in total PYY, insulin, and glucose concentrations; as well as VAS scores for hunger and satiety were calculated for each 2 h meal interval by subtracting 2 h baseline from 2 h peak values. Subsequently, percent change values were calculated from these Δ values by dividing the (peak-baseline)/baseline values) × 100. A one-way ANOVA with repeated measures assessed the differences in the baseline, peak, 2 h and 12 h AUC for total serum PYY concentrations, and VAS scores between meal conditions. Two-tailed Pearson’s correlations between the average magnitude of change, and average percent change between 2 h total PYY concentrations and insulin, glucose, and VAS scores for satiety across study days were calculated. Significance levels in all statistical tests was accepted at α = 0.05. Statistical analyses were performed with SPSS for Windows, version 16.0 (SPSS, Inc., Chicago, IL), and all data are reported as mean ± standard error of the mean.

**Hormone concentrations**
Baseline total PYY values did not differ across conditions following the overnight 12 h fast. The pattern of hormone release was similar across conditions (Figure 1; P > 0.05). Similarly, there were no significant differences in the change in total PYY between conditions (Table 2; P > 0.05). Integrated AUC analysis for total PYY over the course of the day were comparable among the SED, EX, and INT conditions, and examination of the 2 h total PYY responses to each meal revealed no significant differences between conditions during any of these meal blocks (P > 0.05).

**VAS scores**
Baseline hunger VAS values following the 12-h fast were not different between conditions (Figure 2a; SED: 49.2 ± 22.9, EX: 42.8 ± 24.9, INT: 51.7 ± 17.3 mm). When the 12-h AUC for the VAS scores for hunger were compared, no significant differences were noted across conditions (AUC: SED: 1705.4 ± 315.8, EX: 1744.9 ± 584.2, INT: 1490.617.8 mm min for 12 h).

Examination of VAS scores during each 2-h meal period revealed a significant effect of condition in the hunger response between 1300 and 1500 h (Figure 2b; SED: 256.2 ± 20.5, EX: 290.7 ± 36.0, INT: 211.4 ± 37.4 mm min for 2 h; P < 0.05), where intermittent exercise resulted in reduced hunger AUC than in the EX condition. Between 1500 and 1700 h, the hunger AUC was lower in response to the INT compared to the SED and EX conditions (Figure 2b; SED: 286.1 ± 24.2, EX: 294.3 ± 33.9, INT: 221.7 ± 39.2 mm min for 2 h; P < 0.05). A similar trend of a lower 2-h hunger AUC in the INT condition approached significance (P = 0.068) in the hunger response between 1700 and 1900 h.

No significant differences were noted between conditions for the baseline satiety VAS at the beginning of each testing day (Figure 3a; SED: 39.1 ± 24.1, EX: 28.8 ± 17.7, INT: 29.0 ± 19.0 mm). Similar to the hunger VAS scores, there were no significant differences between conditions when satiety AUC was compared.

### TABLE 1 Subject characteristics

|                | Female (n = 3) | Male (n = 8) | Total (n = 11) |
|----------------|---------------|-------------|---------------|
| Age (years)    | 25 ± 3.1      | 25.3 ± 1.5  | 25.2 ± 1.3    |
| Height (cm)    | 170 ± 0.5     | 176.0 ± 2.7 | 174.4 ± 2.1   |
| Weight (kg)    | 103.6 ± 10.2  | 104.5 ± 4.7 | 104.3 ± 4.1   |
| BMI (kg/m²)    | 35.8 ± 3.3    | 33.8 ± 1.4  | 34.3 ± 1.3    |
| Body fat %     | 42.0 ± 3.3    | 28.9 ± 2.7* | 32.5 ± 2.8    |
| Physical inactivity (self-report hours per day) | 19.7 ± 1.6 | 16.9 ± 0.9 | 17.6 ± 0.8 |
| Fasting blood glucose (mg/dl) | 91.3 ± 4.7 | 84.8 ± 2.2 | 86.5 ± 2.1 |
| Two-hour OGTT glucose (mg/dl) | 112.7 ± 8.1 | 103.6 ± 5.9 | 106.1 ± 4.8 |
| Resting systolic BP (mmHg) | 125.3 ± 7.7 | 120.8 ± 3.1 | 122.0 ± 2.9 |
| Resting diastolic BP (mmHg) | 68.3 ± 3.8 | 65.9 ± 1.8 | 66.5 ± 1.6 |
| Total cholesterol (mg/dl) | 181 ± 2.4 | 127.3 ± 2.6* | 145.2 ± 8.6 |
| LDL cholesterol (mg/dl) | 91.5 ± 10.2 | 51.3 ± 5.7* | 64.7 ± 7.7 |
| HDL cholesterol (mg/dl) | 57.5 ± 8.6 | 38.8 ± 4.3 | 45 ± 4.5 |
| Cholesterol ratio (TC/HDL) | 3.3 ± 0.4 | 3.5 ± 0.6 | 3.41 ± 0.4 |

Mean ± SEM.

*a* P < 0.05 versus female subjects.

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**Results**

**Subject characteristics**

Twenty-three subjects met the requirements for this study, completed the initial screening visit, and came to the lab for the first experimental session. Of these individuals, 11 did not return subsequent scheduling requests, and 11 were unable to complete all three trials due to difficulties in maintaining the antecubital catheter for the full 12-h sessions. Eleven subjects (three women, eight men) completed all trials (Table 1). Female subjects had a higher percent body fat and total and LDL cholesterol levels than their male peers (Table 1, *P* < 0.05). All of the subjects (n = 11) had impaired fasting glucose concentrations (>110 mg/dl). None of the study subjects had more than a ±2% change in weight between testing days. Subjects reported an average of 4.7 ± 0.4 meals per day, and participation in 3.3 ± 0.6 bouts of moderate-intensity physical activity per week. The male subjects had a lower VO2 peak (25.5 ± 1.8 ml/kg/min) than the male subjects (32.6 ± 2.5 ml/kg/min). During the study days, treadmill speeds ranged from 3 to 3.5 mph (3.2 ± 0.1 mph), with ranges in grade between 0 and 8% (2.9 ± 1.0%).
However, the 2-h meal intervals for satiety demonstrated improvements later in the day in the SED and INT, compared to the EX condition. Between 1300-1500 h and 1500-1700 h, the 2-h AUC for satiety was higher ($P < 0.05$) in the SED and INT conditions than the EX condition (Figure 3b; 1300: SED: 167.9 ± 30.3, EX: 123.3 ± 27.6, INT: 154.2 ± 31; 1500: SED: 173.1 ± 32.7, EX: 117.9 ± 26.1, INT: 150.2 ± 31.3 mm min for 2 h; $P < 0.05$).

**Relationship between total PYY and insulin, glucose, and satiety.** A significant inverse relationship was reported between the in Δ total PYY and insulin concentrations within each 2-h meal interval in the EX ($r = −0.81; P = 0.05$), but not the SED ($r = 0.70; P > 0.05$) and INT conditions ($r = 0.72; P > 0.05$). This finding was supported by the fact that the percentage change values

| Time of day (h)   | 0700-0900 | 0900-1100 | 1100-1300 | 1300-1500 | 1500-1700 | 1700-1900 |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| PYY (pg/ml)-SED   | 17.7      | 11.4      | 0.3       | 6.2       | 5.4       | 11.7      |
| EX                | 22.4      | −2.7      | 5.5       | 7.3       | 5.0       | 10.2      |
| INT               | 16.4      | 13.0      | 5.3       | 10.4      | 14.8      | −6.7      |
| Insulin (pg/ml)-SED | 804.5    | 581.3     | 624.8     | 593.6     | 561.1     | 740.9     |
| EX*               | 207.3     | 584.3     | 477.3     | 418.6     | 484.4     | 600.7     |
| INT*              | 513.8     | 539.0     | 430.8     | 494.8     | 479.0     | 441.1     |
| VAS satiety (mm)-SED | 9.2       | 3.2       | 10.0      | 10.2      | 11.3      | 15.3      |
| EX                | 1.0       | −8.7      | −10.6     | −8.3      | −5.1      | −7.7      |
| INT               | 9.0       | 5.8       | 5.4       | 3.1       | 12.1      | 8.4       |

*Mean ± SEM.

*aCalculated as 2-h baseline value for each meal condition. EX, exercise; INT, intermittent exercise.

*P < 0.05 versus SED condition.*
for total PYY and insulin during each 2-h interval were also significantly correlated in only the EX condition ($P = -0.88; P < 0.05$).

There were no significant correlations reported between the $\Delta$ total PYY or percentage change in total PYY and glucose levels across the 2-h meal intervals in any of the experimental conditions. However, the $\Delta$ total PYY was strongly correlated with the $\Delta$ VAS scores for satiety across 2-h meal intervals ($r = 0.80, P < 0.05$) in the EX condition. There were no significant correlations noted between total PYY and satiety; or insulin and satiety in the SED and INT conditions.

**Discussion**

Exercise has been shown to alter appetite-regulating hormone concentrations, and in particular total PYY concentration, as well as promoting tighter appetite control (5-9). This research however, has typically focused on continuous exercise, and monitored appetite and appetite-regulating hormones during the period immediately (1-3 h) postexercise (5,6,8). This study extends these findings by examining the effects of exercise on appetite-related hormones and satiety beyond the first few hours of the postexercise period and extending these observations out over 12 h. This study reports for the first time that the addition of a 1-h morning exercise (EX) or intermittent 5-min exercise bouts every hour throughout the day (INT) does not alter total PYY concentrations over the course of a 12-h day in obese individuals with impaired fasting glucose. However, the intermittent exercise resulted in lower perceived hunger and increased satiety in the midafternoon hours, which did not occur in the sedentary or exercise condition.

Despite no change in the hormonal responses, intermittent exercise was more effective in reducing the perception of hunger as the day progressed with a robust attenuation of hunger perception (32.3%) demonstrated between the INT and EX conditions between 1300 and 1500 h, and a 24.6 and 26.9% reduction in hunger between 1500 and 1700 h when compared to the SED and EX conditions, respectively. Intermittent activity also improved the perception of satiety, with increased indices of meal-induced satiety reported in the INT compared to the EX and SED conditions. Between 1300 and 1500 h, intermittent exercise resulted in a 25.7% increase in satiety when compared to EX. Similarly, in the 2-h period between 1500 and 1700 h when compared to the SED and EX conditions, respectively. The current findings demonstrate little to no effect of continuous exercise (EX) on appetite over the course of a 12-h day, in agreement with a previous review (18). However, there is evidence of an accumulating effect of intermittent exercise (INT) on appetite, independent of changes in total PYY, which may result in
sustained appetite modulation over the course of the day. Intermit-
tent exercise, therefore, presents a promising alternative for weight
maintenance and weight loss.

Previous studies have demonstrated that prolonged, moderate-inten-
sity exercise increases PYY concentrations (9,11,19), though this
has not been demonstrated exclusively (20), and these changes are
often elevated transiently (11). While total PYY was elevated imme-
diately following the morning exercise bout (EX) as compared to
the SED (11.9%) and INT conditions (19.3%), this effect had disap-
peared by 2 h (Figure 1). The 12- and 2-h AUC for total PYY con-
centrations were not different between conditions, which is consist-
ent with previous findings (11).

While Martins et al. (7) did not report differences between VAS
measures of hunger and satiety in response to a 1-h bout of moder-
ate exercise (65% of max heart rate), their measurements were
restricted to a 3-h period after the exercise bout. Likewise, we did
not observe any changes in hunger or satiety in the immediate 3-h
period following the acute, continuous exercise bout. While 1 h of
moderate-intensity exercise at the beginning of the day did not result
in changes in the hunger and satiety perception in our obese subjects
with impaired fasting glucose, intermittent exercise participation resulted in a decreased hunger perception (Figure 2) and increased
satiety later in the day (Figure 3). This finding is surprising, as pre-
vious work has demonstrated that intermittent aerobic exercise
results in a higher excess postexercise oxygen consumption and
energy expenditure than an intensity- and duration-matched single
bout of aerobic exercise (21,22). The potential for an exercise inter-
vention that increases overall daily energy expenditure, while
decreasing hunger and increasing satiety, is promising.

An inverse relationship was confirmed between insulin and total
PYY concentrations over the course of the day during the EX condi-
tion; where an increase in total PYY concentration was associated
with an attenuated increase in insulin concentrations. This was not
demonstrated in the SED and INT conditions. This inverse relation-
ship during the EX condition occurred despite no differences in the
indices of total PYY (12 h or 2 h AUC, $D$ or percent change per
meal) between the study conditions. The continuous physiological
stimulus of the 1-h morning exercise bout may have been sufficient
in increasing the total PYY concentration or action, which may have
inhibited insulin release. A similar strengthening of the relationship
between glucose-stimulated insulin production and PYY has been
demonstrated in older, obese individuals with impaired glucose tol-
erance following a strict, 12-week exercise intervention (23). It was
postulated that this response was due to the incretin effect of glu-
cose-dependent insulninotropic polypeptide (GIP) (23). Additional
investigations in obese individuals concerning the relationship
between PYY and insulin levels with exercise are needed to better
understand these phenomena. In addition, the complex milieu of
appetite hormones, including the redundant physiological mediators

![Figure 3](a) Satiety pattern of response over 12 h for the three study conditions. No significant differences by condition ($P > 0.05$). Down arrows, meal ingestion. Rectangular filled boxes, exercise condition; 1-h walking bout. Open boxes, intermit-
tent exercise condition; hourly 5-min walking bouts. (b) 2 h tAUC for satiety VAS scores. *Significantly different from SED and INT conditions ($P < 0.05$).
and pathways, that control appetite regulation (23,24), both at rest and during exercise, warrant further study.

The strength of this project is that we have extended previous research by frequently sampling blood over a 12-h period, providing insight into the hormonal profile to subsequent meals and not just the meal immediately following the exercise bout. This study design also allowed us to examine the effect of intermittent exercise throughout the day, which is now being widely prescribed. Discrepancies in our findings from the previous report can be attributed to the extended period of sampling done in the present study. The six-meal, 1,500-kcal diet utilized in this project was selected, since this would approximate the energy needs throughout the study days, and mimics the frequent snacking often observed in the general public. This 1,500-kcal diet represented a reasonable caloric intake for adults, considering we did not include a dinner time meal. It is possible that subjects were in a slight caloric deficit on the exercise days, which may have somewhat influenced the subjective hunger and satiety responses. The decision to adopt a study design, where participants consumed a meal immediately prior to exercise participation in the EX and INT conditions, was imperative to prevent an extreme energy deficit following the 12-h fast. Previous work has demonstrated that a large energy deficit can potentially affect insulin concentrations and appetite perception (25), and may in turn influence insulin sensitivity.

A limitation of the present study was that total PYY was measured rather than PYY1-36. Much of the previous research concerned with circulating PYY has reported total PYY levels using assays, which detect both the PYY1-36, and PYY3-36 (3,26-28). PYY3-36 is the predominant form both in the fed and fasted states and in lean and obese subjects (29,30); thus, it is possible that we may have noted different findings if we had measured PYY1-36 only. However, since both PYY1-36 and PYY3-36 are considered physiologically relevant to appetite regulation, particularly over the course of an entire day, the decision was made to measure total PYY (31,32).

In conclusion, total PYY concentration was not affected in obese individuals following either a 1 h bout of exercise or multiple short bouts of exercise over a 12-h time period. However, short bouts of exercise over the course of the day improved subjective measures of appetite; a finding that is particularly significant, considering that intermittent exercise is expected to have resulted in increased energy expenditure over the SED condition. Future work should examine whether short, intermittent exercise bouts throughout the day will lead to decreased food intake over the long term and assist with weight management in obesity.

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