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The Effect of Intensity of Exercise on Appetite and Food Intake Regulation in Post-Exercise Period: A Randomized Trial

Original Research

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Abstract
Introduction: To examine the effect of intensity of exercise on post-exercise appetite in young males.
Methods: This study was a randomized cross-over design. Subjects completed three interventions in 3 sessions in a random order for 30 min: 1) Moderate intensity exercise (MI), 2) High intensity exercise (HI), and 3) Sedentary controls (SD). At each session, male subjects (n=8, age 21.8 ± 2.1 years, BMI 21.8± 1.4) completed one of the interventions and after 30 min, they were instructed to eat pizza ad libitum. Food intake was measured. Desire to eat and feeling of fullness were also evaluated by Visual Analogue Scale (VAS) questionnaires. Plasma glucose, insulin, PYY and ghrelin were measured.
Results: Calorie consumption after MI was higher than after HI. Desire to eat was stronger right after exercise in MI compared with HI, while it was stronger right after meal in HI compared with MI. Plasma insulin was higher after meal in SD than MI and higher in MI than HI. Plasma ghrelin was higher in SD compared with MI and HI after meal.
Conclusion: Exercise intensity influenced appetite and food intake in post-exercise period. Food intake was lower after high intensity exercise compared with others.

Key words: exercise intensity, appetite, food intake, glucose, food intake regulatory hormones

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Introduction

Diet and physical activity are two of the major interventions for the prevention or treatment of obesity. The favorable effect of exercise on body weight in long-term is well-described.[1] The effect of exercise on appetite and food intake regulatory system has been investigated in both adults[2] and children.[3] It has been shown that calorie intake and calorie expenditure during exercise are not variables tightly coupled with each other.[4] Exercise influences differently short- and long-term food intake regulatory systems. There is a better long-term control on energy intake in active vs. inactive individuals. The short-term effect of exercise on appetite and food intake can be determined by several characteristics of exercise, including intensity and the duration.[5] A short-term transient suppression of appetite occurs after high intensity activity in adults[6, 7] which is known as *anorexia of exercise*.[8] However, it does not occur after moderate intensity physical activity.[6, 7] It is in contrast with the enhancing effect of high intensity exercise and sedentary status on calorie intake compared with the effect of light to moderate exercise in the long-term.[1] Moreover, habitual exercise has been shown to increase accuracy of short-term food intake regulation at meals following caloric preloads in adults.[9] Appetite is increased by low- to moderate-intensity, shortduration physical activity in the post-exercise period.[3] However, the effect of intensity of exercise on appetite and short-term food intake, glucose metabolism and food intake regulatory hormones in the post-exercise period in young adults has yet to be investigated.

Therefore, the purpose of this study was to examine the interaction between intensity of exercise, the hormones involved in the regulation of food intake and subjective feelings associated with appetite. We hypothesized that appetite and food intake regulatory hormones will be affected by the intensity of exercise in post-exercise period.

Methods

Experimental Design

A within-subjects repeated measures design is used to examine the effect of moderate vs. high intensity exercise on appetite in young people. Sample size was determined by power analysis using SAS software and the study was approved by University of North Florida Institutional Review Board.

Participants:

Normal-weight (BMI: 20-25) young male (n=8, 19 to 25 y) who participate in recreational activity were recruited. The exclusion criteria include currently trying to lose weight; taking medications which alter metabolic rate or appetite; known cardiovascular, pulmonary or metabolic disease; significant learning, behavioral, or emotional difficulties; and being involved in collegiate athletics.

Protocol:

All subjects went through a pre-participation screening prior to enrollment in the study. Based on that screening, those who were at moderate or high risk of cardiovascular events during exercise were excluded. Informed consent was obtained for all subjects enrolled in the study. Each subject completed four visits comprising one exercise test visit and three intervention visits. Intervention visits were in a random order. Random numbers for each subject were determined by using a random number generator by PI. On the first visit subjects underwent an exercise test to determine their maximal exercise capacity. Subjects consumed a standard breakfast (contained 500 Calories provided by the investigators) three hours prior to arrival to the research center on intervention days. On each of the three intervention visits, subjects performed one of the following in random order: 30 min of sedentary (SD) activity, 30 minutes of moderate intensity (50% HRR) (MI), or 30 minutes of high intensity (75%HRR) (HI) exercise. All subjects completed one bout of each of these activities on separate days with one-week washout period in between. No subject did each activity more than one time. During each activity, metabolic data was collected in order to determine energy expenditure during exercise. Thirty minutes after the conclusion of exercise, subjects were instructed to eat pizza until they were comfortably full. Their food intake was measured by weighing pizza before and after meal. The effect of the exercise on energy intake was assessed by comparing the energy expenditure during exercise and the energy intake during the meal. Several measurements were made at regular intervals corresponding to exercise and eating. A visual analog scale was used to assess the subject's feelings of appetite, fullness, palatability, physical comfort, energy, fatigue and stress. Blood samples were taken to measure levels of glucose and intake regulatory hormones including ghrelin, Peptide YY (PYY), and insulin. The time intervals were: 1) immediately before 2) immediately after exercise 3) 30 minutes, 4) 60 minutes, and 5) 90 min after conclusion of exercise, 6) immediately after and 7) 90 minutes after the conclusion of eating. Weight, BMI, and body composition were also measured. Body composition was determined by each subject's percentage of fat free mass and was assessed by the Gold Standard BOD-POD air displacement plethysmograph (COSMED USA, INC, Concord, CA).

Food intake was measured by weighing pizza before and after meal. Total calories were calculated based on the "Nutrition facts" table provided by the manufacturer.

Blood was obtained through finger prick at seven timepoints and was collected in chilled vacutainer tubes (BD Diagnostic, Franklin Lakes, NJ, USA) containing EDTA + Trasylol® (Bayer AG, Leverkusen, Germany) solution (10% blood volume, 5 × 108 Iu/L). Thereafter, blood samples were centrifuged at 3000 g at 4 °C for 10 min. Plasma was separated and immediately stored at −70 °C.

Plasma glucose concentration was assayed using a handheld commercial glucometer (Contour® Next Blood Glucose Meter, Bayer Healthcare LLC, Mishawaka, IN, USA) using test strips (Bayer Healthcare LLC, Mishawaka, IN, USA). The accuracy and variance of the glucometer and test strips were examined by applying control solutions (levels 1 and 2) provided by the manufacturer (Bayer, Bayer Healthcare LLC).

Enzyme-linked immunosorbent assays (ELISAs) were used to measure plasma concentrations of PYY (catalog no. 48-PYYHU-E01.1, Alpco Diagnostics, Salem, NH, USA), Non-acylated ghrelin (catalog no. 32-5119, Alpco Diagnostics), and insulin (catalog no. 80-INSHU-E01, Alpco Diagnostics). Assay sensitivity for PYY, ghrelin, and insulin was 0.082 ng/mL, 0.6 pg/mL, and 0.399 μIU/mL, respectively.

Percentage of body fat and fat-free mass was estimated through air displacement plethysmography, (COSMED USA, INC, Concord, CA). Percentage of body fat and fat-free mass were calculated by the Siri formula from the body density data. All testing was completed in accordance with the instructions provided by the manufacturer.

A cycle ergometer was used for exercise testing and for the two exercise bouts. To determine each subject's maximal exercise capacity the following protocol was used: each subject performed a 5-minute warm-up on the cycle ergometer at 100 watts; the workload was increased by 50 watts every 2.5 minutes until heart rate exceeds 160 beats/min; once the heart rate exceeded 160 beats/min the workload was increased by 25 watts every 2.5 minutes until the subject could no longer continue due to fatigue or requested the exercise test be stopped. Resting heart rate and peak heart rate during the exercise test were used to determine each subject's heart rate reserve (HRR) and this was used to set each subject's exercise intensity for the exercise bouts.[10, 11] According to the American Heart Association/American College of Sports Medicine moderate intensity is defined as 45-59% of HRR and vigorous intensity is defined as 60-84% HRR.[12] Each subject performed one bout of moderate intensity exercise at 50% HRR and one bout of vigorous intensity exercise at 75% HRR.

Participants were instructed to arrive to the facility 3 hours after having eaten a standard breakfast at home. Exercise began 15 minutes after arrival to the facility. Each subject exercised for a total of 30 minutes at either moderate or high intensity exercise, based on the HRR calculation, during that visit.

Statistical Analysis
The effect of the time, tests and groups and their interactions on appetite, food and energy intake, calorie compensation, insulin, glucose, PYY and ghrelin response were analyzed by PROC MIXED MODEL procedure.

Results
Calorie consumption after MI was higher than after HI (1612 ± 311 kcal vs 1127.1 ± 262 kcal, $p<0.05$) but not different from SD (1270.9 ± 290 kcal). (Fig1a) Calorie expenditure was highest for HI (320.4 ± 27.8 kcal) followed by MI and SD (227.4 ± 10.2 kcal vs 45.1 ± 1.9 kcal respectively, $p<0.05$). (Fig1b) Delta calorie intake/expenditure was lower for HI (770 ± 143 kcal) compared with MI and SD (1367 ± 88 kcal vs 1357 ± 124 kcal respectively, $p<0.05$). (Fig 1c)

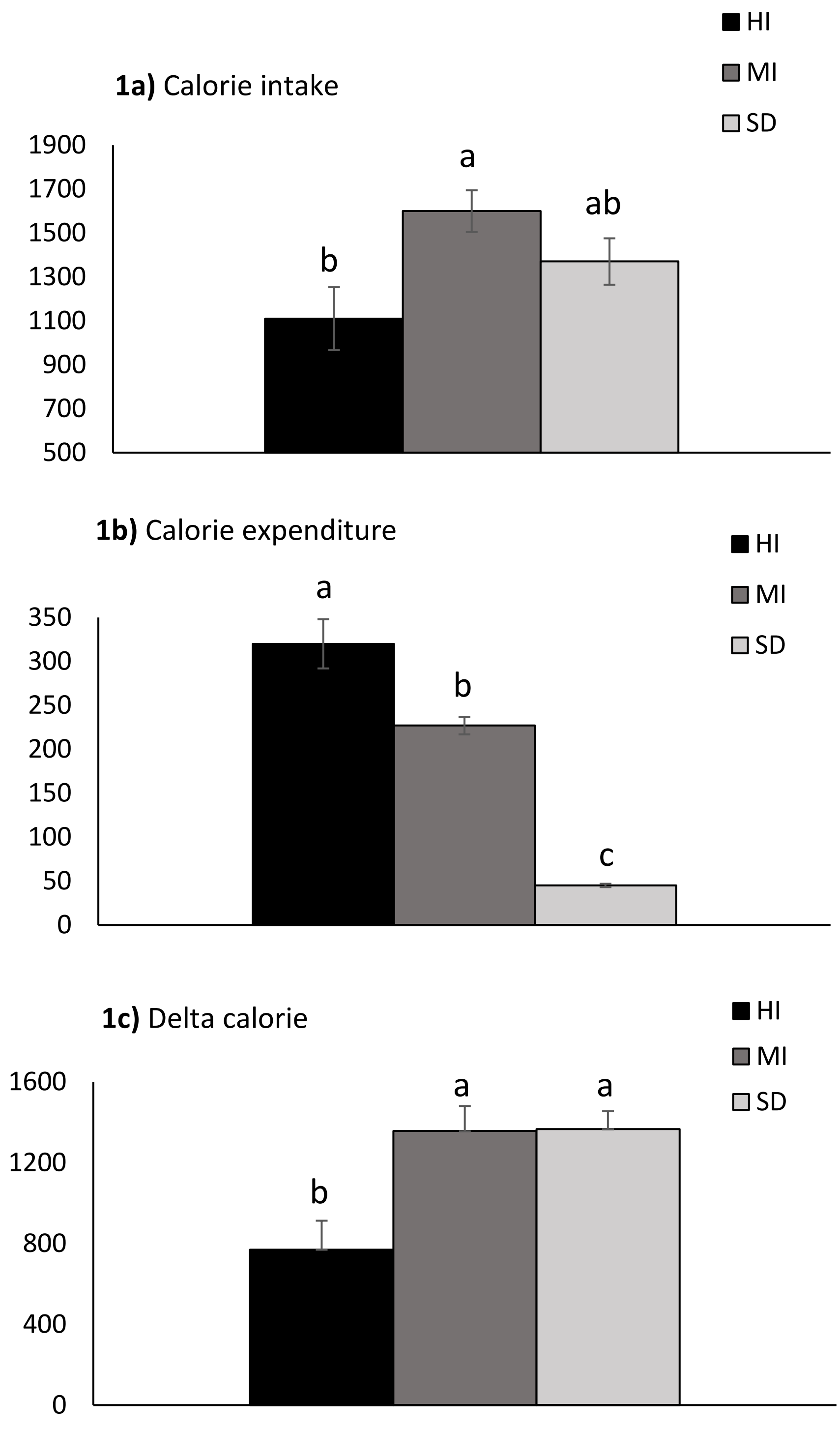


Fig 1: Effect of intensity of exercise on calorie intake and expenditure and delta calorie intake/expenditure. (n = 8/group). Data are means ± SEM; Different letters are significantly different: $p < 0.05$. **HI:** High intensity exercise; **MI:** Moderate intensity exercise; **SD:** sedentary

Desire to eat was stronger right after exercise in MI compared with HI (6.4 ± 0.63 vs 5.04 ± 0.27, p<0.03), while it was stronger right after meal in HI compared with MI (2.99 ± 1.37 vs 0.41 ± 0.1, p<0.05). (Fig 2a) However, stronger desire to eat in HI after meal did not result in further food intake (Fig 2a).

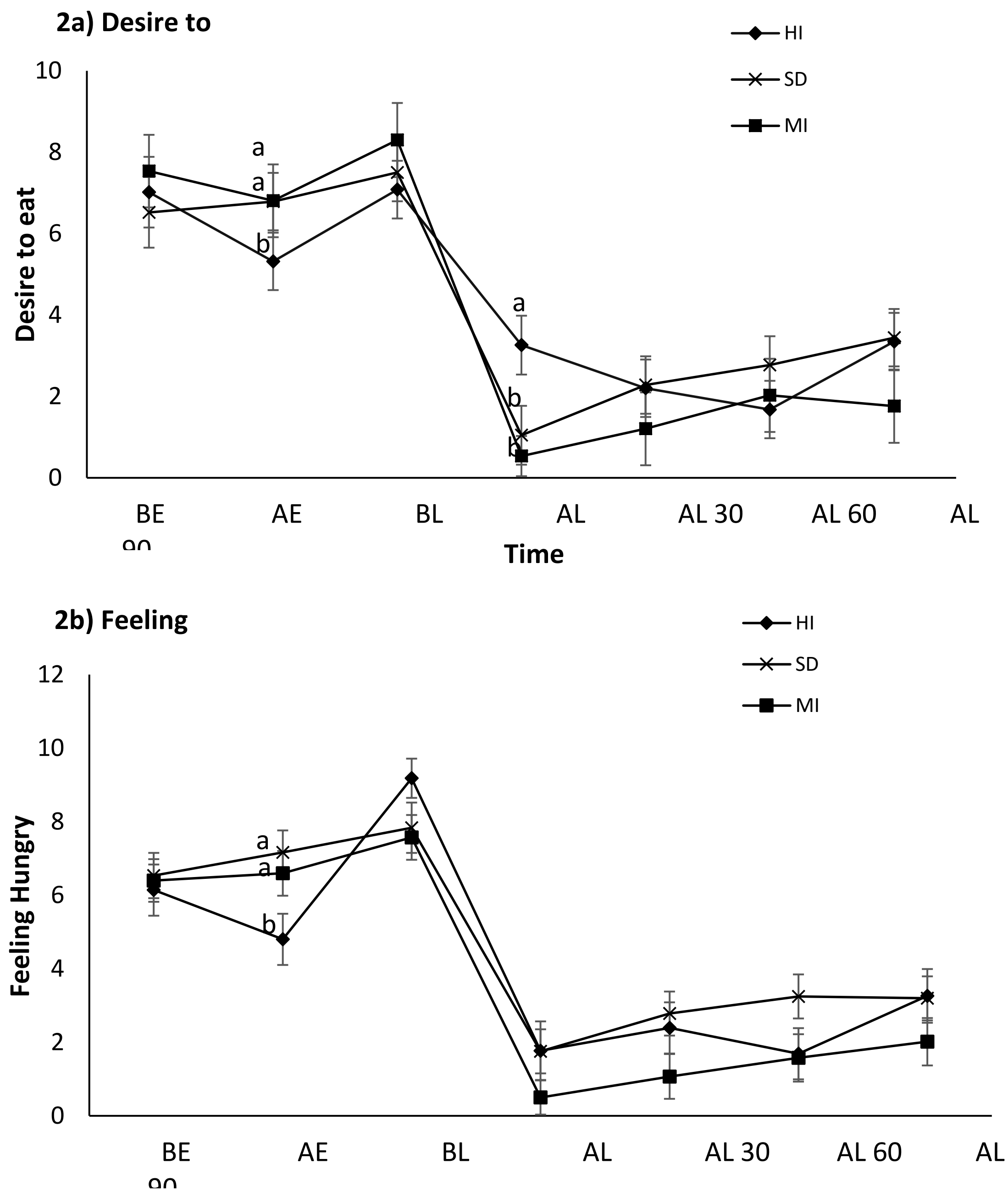
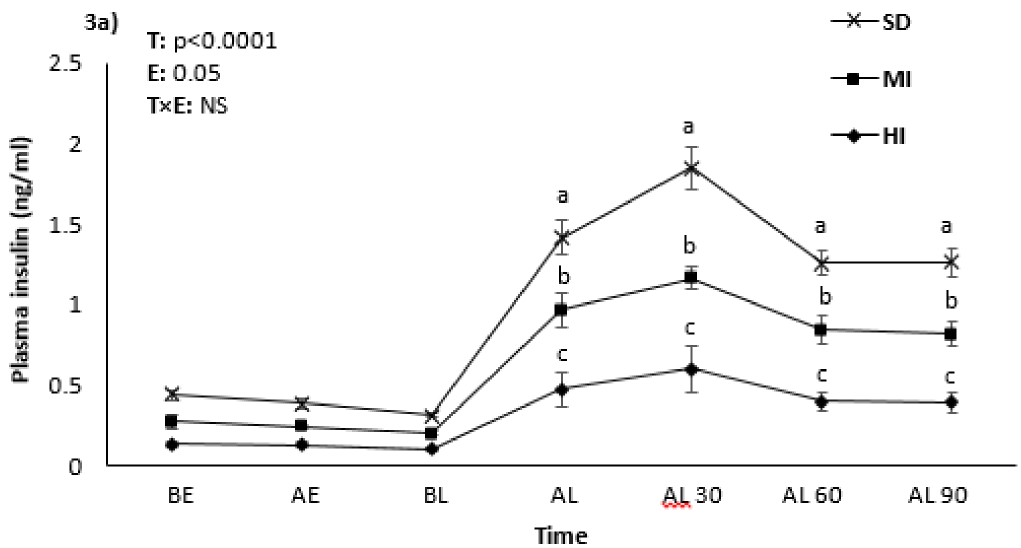
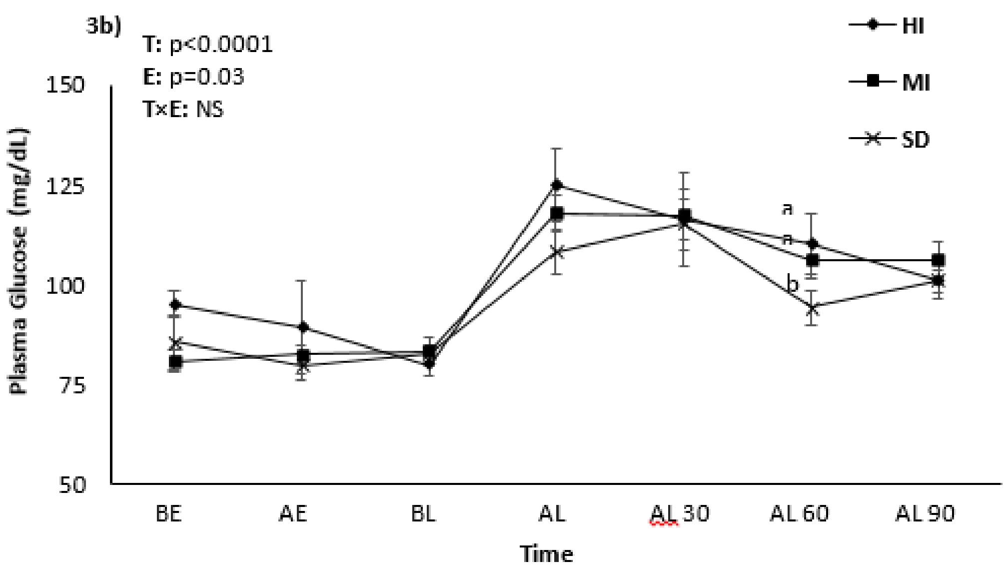


Fig 2: Effect of intensity of exercise on Desire to eat (2a) and Feeling hungry (2b). (n = 8/group). Data are means ± SEM; Different letters are significantly different: p < 0.05. **HI:** High intensity exercise; **MI:** Moderate intensity exercise; **SD:** sedentary

Plasma glucose was influenced by intensity of exercise and was higher in HI and MI (110 ± 7.58 and 106.14 ± 4.53 respectively) compared with SD (94.13 ± 4.12, p=0.03) at 60 min after meal. (Fig 3b) Plasma insulin was higher in SD than MI and was higher in MI than HI throughout post-meal period (p<0.05). (Fig 3a) Plasma insulin/glucose ratio was not affected by intensity of exercise. (Fig 3c)





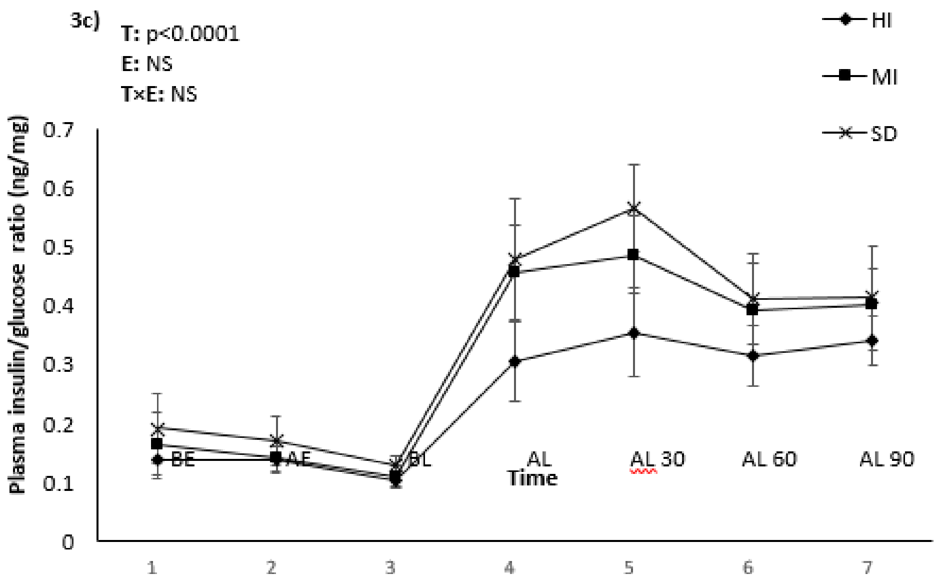


Fig 3: Effect of intensity of exercise on insulin (3a), glucose (3b) and insulin/glucose ratio (3c) (n = 8/group). Data are means ± SEM; Different letters are significantly different: $p < 0.05$. **HI:** High intensity exercise; **MI:** Moderate intensity exercise; **SD:** sedentary

Plasma total PYY was affected by intensity of exercise and was higher in SD compared with HI and MI ($p=0.02$) (Figure 4a). Plasma ghrelin was not affected by intensity of exercise but was affected by the time ($p<0.0001$) and by their interaction ($p<0.05$). (Fig 4b) Moreover, it was higher in SD (1001.7 ± 94.5) compared with HI and MI right after lunch (600.6 ± 80.22 and 698.76 ± 72.13 respectively, $p<0.05$).

Discussion

The favorable effects of exercise on body weight, body composition, and mental health is well-described.[13, 14] Individuals who engage in routine exercise are less likely to be overweight or obese.[15] Exercise can influence energy balance by its effect on food intake regulatory system and its effect on energy expenditure. Although exercise influences energy balance by increasing energy intake in the long-term[16], its acute effect during the post-exercise period on food intake is not strongly correlated with the energy expenditure during exercise.[17] The results from previous studies collectively show a variation in appetite and food intake in response to exercise. [18] It can be due to the multiplicity of factors influencing appetite and food intake regulatory system including dietary habits, body weight status, sex, age and habitual exercise and similarly multiple variations for exercise including the intensity, duration, frequency, and exercise regimen (a single type or a combination of various exercises). Various interval times between exercise and food intake may explain the inconsistency in results in previous studies. Moreover, the acute effect of exercise on food intake is quite different from its chronic effect. While, a "J" shape chronic exercise model suggested by Mayer[7] indicating a higher energy intake after sedentary activity and high intensity exercise compared with low/moderate intensity exercise received support from many studies, the acute effect of exercise on food intake shows a lower food intake after high intensity exercise compared with moderate intensity exercise and sedentary status. [19, 20] This is consistent with our observation: While energy expenditure was greater for HI exercise compared with the MI exercise and SD, energy intake was lower after HI exercise. Interestingly, the delta of energy intake/expenditure was lower after HI exercise compared with MI and SD activity. Consistently, the VAS score for "feeling hungry" and for "desire to eat" were lower after HI exercise compared with after MI exercise and SD activity although this difference was disappeared right before meal intake.

The acute effect of exercise on blood flow, GI tract movement, gastric emptying rate, muscle cell metabolism and their effect on food intake regulatory hormones including PPY, ghrelin and GLP-1 as well as changes in substrate oxidation in muscle and liver are potential factors influencing post-exercise appetite and food intake.[21, 22] Relatively lower level of ghrelin after HI exercise observed in this study

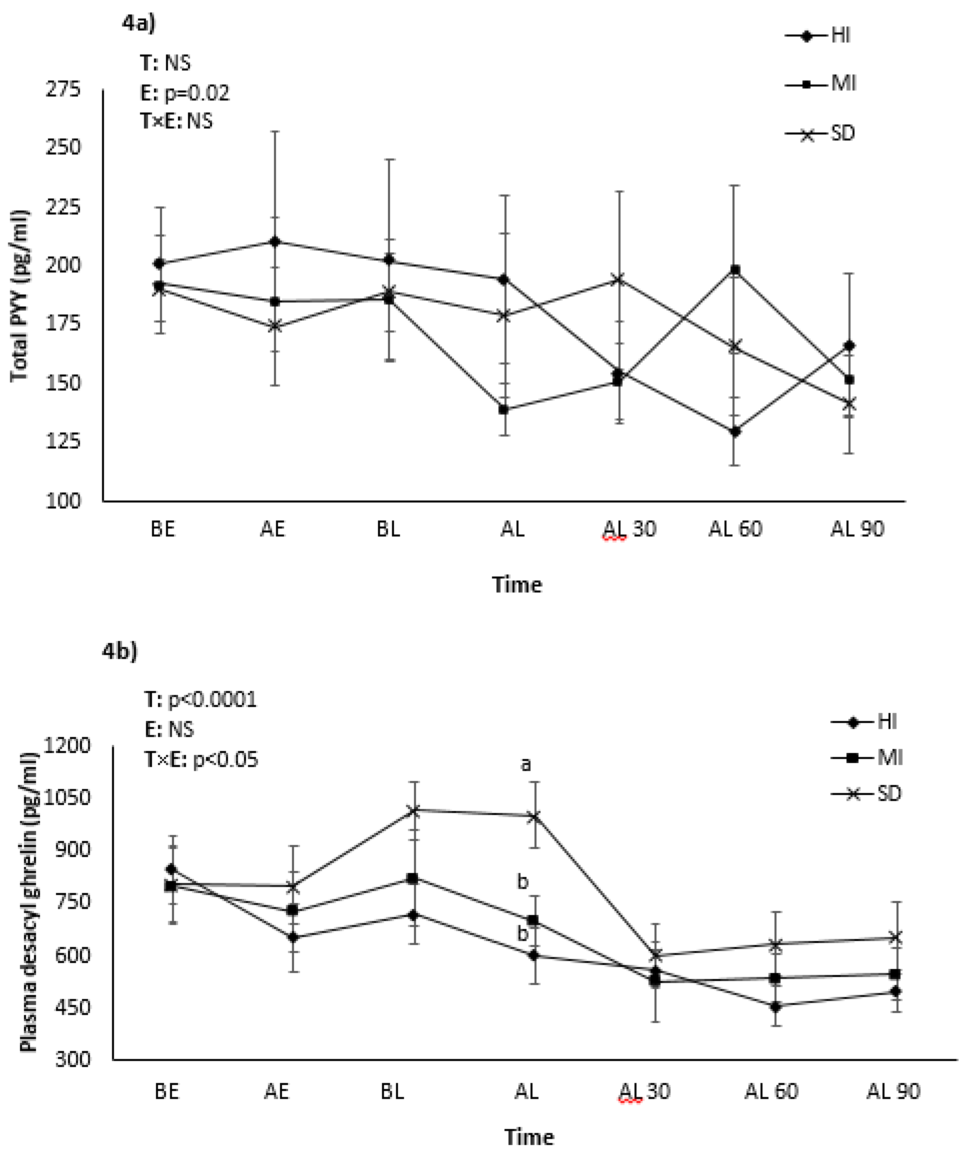


Fig 4: Effect of intensity of exercise on plasma PYY (3a) and desacyl ghrelin (3b) (n = 8/group). Data are means ± SEM; Different letters are significantly different: $p < 0.05$. **HI:** High intensity exercise; **MI:** Moderate intensity exercise; **SD:** sedentary

can be a potential mechanism. More importantly, an elevated plasma IL-6 after HI exercise is reported.[20] IL-6 is an inflammatory factor that also acts as a satiety signal.[23]

Although not statistically significant, plasma ghrelin was relatively lower after HI exercise in post-exercise period compared with the SD activity which is consistent with previous studies.[24, 25] The fact that deacylated ghrelin was measured instead of acylated ghrelin in this study may explain the insignificancy of the results. Moreover, consistent with previous studies [26-28], plasma PYY concentrations was influenced by the intensity of exercise and was greater after HI exercise. However, no significant difference at any single time point among groups was observed. PYY was relatively greater after HI exercise compared with the sedentary status.

The favorable effects of exercise on insulin sensitivity in the long-term has been reported.[29, 30] A reduction in adipose tissue is suggested as potential mechanism. However, the mechanisms by which a single episode of exercise may influence glucose and insulin metabolism is quite different: In this study, plasma insulin concentrations were lower after HI exercise compared with MI and it was lower after MI exercise compared with sedentary status. Increased need to available glucose during the exercise that is directly correlated with the intensity of exercise may explain this observation. During the exercise, upregulation of counter-regulatory hormones along with downregulation of insulin warrants adequate glucose supply to the muscle cells during exercise. It is consistent with similar plasma glucose concentrations and plasma insulin/glucose ratio observed during and after the exercise among groups. Reduction of blood glucose in post-exercise period can be explained by: 1- Increase in blood flow to exercising muscle (which facilitates increased delivery of glucose); 2- The exercise induced increase in glucose transporters to the membrane of exercising muscle enhances glucose uptake independent of insulin; and 3- Exercise improves skeletal muscle sensitivity to insulin.[31-32]

As future direction, studies examining the effect of gender (male vs. female) can help to understand the gender-specific factors related to exercise metabolism and food intake regulation. Moreover, comparing normal weight subjects vs. obese subjects can help to understand the effect of obesity on metabolic and physiologic response to exercise and dietary behaviors. Moreover, measuring active forms of ghrelin, PYY and GLP-1 will give us a better understanding of interaction of intake regulatory hormones and exercise with various intensities.

The main potential limitation was the sample size. A greater sample size and including both male and female subjects will examine the reproducibility of the results and will increase their applicability.

Media-Friendly Summary

Subjects ate more after moderate intensity exercise than after high intensity exercise. Plasma insulin and ghrelin were higher after meal in sedentary status than after moderate and high intensity exercise.

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