Title: High-intensity interval training, appetite and reward value of food in the obese

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Abstract:

Purpose: Studies on the impact of chronic interval training on appetite in the obese population are scarce. The aim of this study was to determine the effect of 12 weeks of isocaloric programs of moderate-intensity continuous training (MICT) or high-intensity interval training (HIIT) , or a short-duration HIIT (1/2HIIT), on subjective feelings of appetite, appetite-related hormones and reward value of food in sedentary obese individuals.

Methods: Forty-six sedentary obese individuals (30 women and 16 men), with a BMI of 33.3±2.9 kg/m^2 and age of 34.4±8.8 years were randomly assigned to one of the three training groups: MICT (n=14), HIIT (n=16) or 1/2-HIIT (n=16). Exercise was performed 3 times/week for 12 weeks. Subjective feelings of appetite and plasma levels of acylated ghrelin (AG), polypeptide YY_{3-36} (PYY_{3-36}) and glucagon-like peptide 1 (GLP-1) were measured before and after a standard breakfast (every 30 minutes up to 3h), before and after the exercise intervention. Fat and sweet taste preferences and food reward were measured using the Leeds Food Preference Questionnaire.

Results: A significant increase in fasting and postprandial feelings of hunger was observed with the exercise intervention (P=0.01 and P=0.048, respectively), but no effect of group and no interaction. No significant effect of exercise intervention, group or interaction was found on fasting or postprandial subjective feelings of fullness, desire to eat and prospective food consumption or plasma concentration of AG, PYY_{3-36} and GLP-1. No changes in food preference or reward over time, differences between groups, or interactions were found.

Conclusions: This study suggests that chronic HIIT has no independent effect on appetite or food reward when compared with an isocaloric program of MICT in obese individuals.

Keywords: hunger, GLP-1, PYY_{3-36}, ghrelin, high intensity intermittent training

Introduction:

Exercise is frequently used as a weight loss strategy, since it has the ability to increase energy expenditure and, therefore, theoretically to create a negative energy balance. However, weight loss response to exercise is known to be highly variable, even when exercise is supervised (14). Several compensatory mechanisms have been identified that can undermine the ability of exercise to promote the predicted weight loss (12, 14).

We have previously reported that those who have a suboptimal response to exercise, in terms of weight/fat mass loss, show an immediate post-exercise increase in liking and wanting and a preference for high-fat sweet foods (4). Low-responders also experience a compensatory increase in energy intake (EI) and an increase in hunger feelings (14). Evaluating the impact of chronic exercise on appetite is, therefore, of vital importance if we want to improve our understanding on the role of exercise in weight management. Collectively, our research groups have previously shown that 12 weeks of moderate-intensity exercise (5 times/week) is associated with increased levels of acylated ghrelin (AG) (4) and hunger feelings in the fasting state (13, 18), despite an improved satiety response to a meal (4, 5) and improved sensitivity of the appetite control system (18, 19). However, a study by Guelfi and colleagues (2012) reported no change in either fasting hunger or AG after 12 weeks of aerobic (moderate intensity) or resistance exercise (3 times/week) (7). Differences in the magnitude of weight and fat mass losses, volume of exercise and gender may contribute to the discrepancies between studies.

People usually claim lack of time as a barrier for not exercising (29), and this is likely to contribute to the high dropout rates from exercise programmes observed particularly in the obese (6, 24). High-intensity exercise offers a more time-efficient option and possibly a more enjoyable than MICT (15). High-intensity interval training (HIIT), where bouts of high-intensity exercise alternate with bouts of low-intensity exercise has been proposed as an effective alternative (2). Studies on the impact of chronic HIIT, on appetite in the obese population are scarce and the available single study is limited by the fact that the authors included overweight men only (26).

Therefore, the aim of this study was to compare the effect of 12 weeks of isocaloric HIIT, moderate-intensity continuous training (MICT) and short-duration HIIT (1/2-HIIT) on subjective appetite sensations, appetite-related hormones and liking and wanting in obese individuals.

Methods:

Subjects

Forty-six obese, but otherwise healthy, individuals (30 females and 16 males), with a sedentary lifestyle, mean BMI of 33.3±2.9 kg/m^2 and mean age of 34.4±8.8 years were recruited for this study, through web and paper advertisement posted at the Norwegian University of Science and Technology (Trondheim, Norway) and surrounding community.

Sedentary lifestyle was defined as not engaged in strenuous work or in regular brisk leisure physical activity more than once a week or in light exercise for more than 20 minutes/day on more than three times per week. This was assessed through an exercise history (interview) of the 3 months prior to the study. Those dieting to lose weight, weight unstable on the last 3 months (≤ 2 kg variation), taking any medication known to affect appetite or induce weight loss or with a restraint score derived from the Three Factor Eating Behavior Questionnaire (27) >12 were not included in the study.

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and was approved by the regional Ethics Committee for Medical Research (REK# 2010/447). Written informed consent was obtained from all participants before enrolling in the study. The study reported here is a component of a larger metabolic study of which portions have been published earlier (17).

Study design

This was a randomized study where participants were randomly allocated to either MICT (n=14), HIIT (n=16) or 1/2-HIIT (n=16) for 12 weeks. There were no significant differences between the three groups in age, male/female ratio, BMI or cardiovascular fitness (VO_{2max}) prior to the training programs.

Detailed description of the study

Participants underwent a 12-week supervised exercise programme and were asked to maintain their habitual diet during the study. Compliance was assessed using three-day self-reported food diaries at baseline and on the last week of training (two weekdays and one weekend day). Food diary data were analyzed using the program Mat på Data (version 5.1). Several measurements were performed before and after the intervention, at least 48h after the last exercise session, including: anthropometric measurements, body composition, maximal oxygen consumption (VO_2max), fasting and postprandial subjective feelings of appetite and plasma concentrations of appetite-related hormones, food reward, among others (for a full description of all the measurements see Martins and colleagues, 2016 (17)). Participants completed the appetite measurements individually in separate rooms.

There was a significant overall reduction in body weight (-1.2±2.5 kg, $p<0.01$) and increase in VO_{2max} ($p<0.001$), when expressed in absolute values (L/min, +9%) and when normalized for body weight (ml/kg/min, +10%), with the exercise intervention, but no significant main effect of group or interaction. Also, significant improvements were seen in body composition and no changes in insulin sensitivity, energy or macronutrient intake, despite no differences between groups - for more details see Martins et al, 2016 (16).

A. *Exercise intervention*

All participants exercised three times per week for 12 weeks and all sessions were supervised. Exercise was carried out on a Monark cycle ergometer (Ergomedic 839E, Monark 2008, Sweden). All participants started the exercise session with 5 minutes warm-up, and finished with a 5 minutes cool down. Heart rate (HR) was recorded during each exercise session using Polar F6M heart rate monitor (Polar type 610, Polar Electro Oy, Finland).

The MICT consisted of continuous cycling at 70% of HR_{max}. The duration of the exercise sessions was estimated for each participant individually, in order to induce a 250 kcal energy deficit, using HR/VO2 data obtained during he VO2max test. The HIIT protocol consisted of 8 seconds of sprint, working at 85-90% of maximal heart rate (HR_{max}) and 12 seconds of recovery phase, during which participants cycled as slowly as possible (28). Participants were instructed when to start and stop each phase using a recorded audio message. The resistance was ramped during the 12 weeks to accommodate increased aerobic capacity. The HIIT protocol was designed to induce a 250 kcal energy deficit and the duration of the exercise session was calculated for each participant individually. Participants in the 1/2-HIIT group followed the same protocol as the HIIT group, but only for the duration needed to induce a 125 kcal energy deficit (using the same approach as for MICT).

In order to account for changes in aerobic capacity and body weight, submaximal VO_{2max} tests were performed at weeks 4 and 8 and exercise prescription adjusted in order to maintain exercise-induced energy expenditure constant overtime. Therefore, exercise-induced energy expenditure, at all time points, was estimated from VO2 data, not directly measured.

B. Subjective sensations of appetite and blood sampling

Participants visited the research unit in the fasting state (at least a 12-h fast), before and after the 12-wk exercise intervention. On each occasion, an i.v. cannula was inserted into an antecubital vein. A fasting blood sample was taken, and participants were asked to rate their baseline appetite using a 10-cm visual analog scale (VAS), as previously described (9). Participants were then instructed to consume a standard breakfast [time (t)=zero] (consisting of bread, orange juice, milk, cheese, and jam (600 kcal, 17% protein,35% fat, 48% carbohydrate) within 10 minutes. Blood samples were taken every 30 minutes for a period of 3 h, and subjective feelings of hunger, fullness, desire to eat and prospective food consumption (PFC) were assessed throughout the morning using VAS.

C. Hormone measurement

Venous blood was collected into EDTA-coated tubes containing 500 KIU aprotinin (Pentapharm, Basel, Switzerland)/ml whole blood for the measurement of gut peptides. Samples were then centrifuged at 2000 x g for 10 min and plasma kept at -80 C for later analyses. For the measurement of AG, 50 µl of 1N hydrochloric acid and 10 µl of phenylmethylsulfonyl fluoride (Sigma, Schnelldorf, Germany) (10 mg/ml of isopropanol) were added to each milliliter of plasma immediately after centrifugation. All samples were batch-analyzed at the end of the study to reduce inter-assay variability.

AG and $PYY_{3\text{-}36}$ were quantified using human-specific RIA kits (Linco Research, St. Charles, MO) and GLP-1 with an "in-house" RIA method (22). The sensitivity of the assays was 7.8 pg/ml for AG, 1 pmol/L for GLP-1, and 20 pg/ml for $PYY_{3\text{-}36}$. All samples were assayed in duplicate, and baseline and end samples of the same individual were analyzed in the same batch. The intra-assay coefficient of variation was less than 10% for AG and $PYY_{3\text{-}36}$ and less than 5% for GLP-1.

D. Measurement of Food Preferences and Reward

Fat and sweet taste preference and the reward value of food was measured using a computer-based behavioural procedure called the Leeds Food Preference Questionnaire (LFPQ) (5). The LFPQ provides measures of explicit liking (EL), implicit wanting (IW) and relative food preference (FP) according to the shared sensory properties of foods. Participants were presented with an array of pictures of individual food items common in the diet. A database with food items either predominantly high (>50% energy) or low (<20% energy) in fat, but similar in familiarity, protein content, sweet or non-sweet taste and palatability, and adapted to Norwegian culture, was used for this purpose. For more details about the procedure see Finlayson and colleagues, 2008 (5) .

Power calculation:

This study was powered to determine differences between the MICT and HIIT groups, in terms of changes in subjective feelings of appetite in fasting. For a difference of 2.4 cm in changes in subjective hunger in fasting between groups, given a standard deviation of the outcome variable of 2 cm, at a power of 80% and a significance level of 0.05, 12 participants/group would be needed (18). We assumed that the ½ HIIT would produce the same results as the HIIT.

Statistical analysis

Statistical analysis was carried out using SPSS 20.0 (SPSS Inc., Chicago, IL). All variables were checked regarding normality of distribution using the Kolmogorov-Smirnov test. Statistical significance was assumed at $P<0.05$, unless otherwise stated. A 3-way mixed model ANOVA was used to examine the effect of intervention (pre vs post-intervention), blood sampling time (0, 30, 60, 90, 120, 150 and 180 minutes post-prandially), exercise group (HIIT, 1/2-HIIT and MICT) and interactions, on subjective feelings of appetite and appetite-related hormones. A 2-way mixed model ANOVA was used to examine the effect of intervention (pre- vs post-intervention), exercise group (MICT, HIIT and 1/2-HIIT) and interactions, on the total area under the curve (tAUC) for subjective feelings of appetite and appetite-related hormones. tAUC for appetite hormones and subjective feelings of appetite was calculated from immediately before to 180 minutes after breakfast, using the trapezoidal rule. The reward value of food (explicit liking and implicit wanting response measures and relative food preference) was analyzed using two 4x2 design ANOVA (experimental condition x time (pre/post) for high fat relative to low fat food).

Results:

Compliance with the intervention

For various reasons, one participant from the MICT (due to family reasons), three from the HIIT (one due to muscle discomfort and two due to lack of time) and seven from the 1/2-HIIT group (three due to muscle discomfort, three due to lack of time and one for family reasons) withdrew from the study. There were no significant differences in age, BMI or any of the variables measured, between those who withdrew and those who completed the intervention.
All the participants who finished the intervention performed all the planned exercise sessions (36 sessions over 12 weeks). The average exercise duration/session was 32, 20 and 10 minutes for the MICT, HIIT and 1/2-HIIT, respectively.

Subjective sensations of appetite

Fasting state

Changes in subjective feelings of appetite, in the fasting state, in the different exercise interventions can be seen in table 1. There was a significant increase in fasting subjective feelings of hunger with exercise ($p=0.01$), but no main effect of group or interaction.

No significant effect of exercise, group or interaction was observed for subjective feelings of fullness, desire to eat or PFC in fasting.

Postprandial state

A significant effect of assessment time ($p<0.001$) was observed on subjective feelings of hunger, fullness, desire to eat and PFC, which either decreased or increased after breakfast intake and increased (or decreased) afterwards. No significant effect of intervention (pre vs post exercise), group (MICT, HIIT or 1/2-HIIT) or interactions were found for any of the appetite feelings studied.

tAUC for hunger increased significantly after the 12-week exercise program ($p=0.048$), but there was no significant effect of group or interaction (Fig. 1A). No significant effect of exercise, group or interaction was found for the tAUC for fullness, desire to eat and PFC (Fig. 1B, 1C and 1D).

Plasma concentration of appetite-related hormones

Fasting concentrations

The fasting plasma concentrations of the appetite-related hormones measured, before and after the three exercise interventions, are shown in Table 2. There was no significant effect of exercise (before vs. after the 12-week exercise program), group (MICT, HIIT or 1/2-HIIT) or interaction for any of the appetite-related hormones measured.

Postprandial concentrations

A significant effect of sampling time ($p<0.001$) was observed on AG plasma levels, which decreased up to 60 minutes and increased afterwards until 180 minutes post-prandially. No significant effect of exercise intervention (pre vs. post) or group was found on AG plasma levels (data not shown). A significant effect of sampling time ($p<0.001$) was observed for GLP-1 plasma levels, which increased up to 90 minutes and decreased afterwards until 180 minutes post-prandially. No significant effect of intervention or group was found on GLP-1 plasma levels (data not shown). A significant effect of sampling time ($p<0.001$) was also observed for PYY_{3-36} plasma levels, which gradually increased over time up to 180 minutes post-prandially. No significant effect of intervention or group was found on PYY_{3-36} plasma levels.

No significant effect of exercise, group, or interaction, was found on tAUC for AG, GLP-1 or PYY_{3-36} (Fig. 2A, B and C).

When the data from the three groups were pooled, there was a significant correlation between magnitude of weight loss and changes in ghrelin concentration in fasting (r-0.538, n=34, p=0.001), but not for changes in ghrelin concentration after the test meal (AUC) (r=-0.308, n=34, p=0.076), denoting greater increases in ghrelin fasting concentrations with larger weight losses.

Food preference and reward

Breakfast intake significantly decreased explicit liking, implicit wanting and relative preference for high-fat relative to low-fat foods (all $P<0.001$) and savory relative to sweet foods (all $P<0.001$). No effect of intervention (pre vs post-exercise), group (MICT, HIIT or 1/2-HIIT) or interactions were found (Table 3).

Discussion

The main findings of this study were that no significant differences between exercise groups (MICT, HIIT and 1/2-HIIT) were found for any of the variables measured. Moreover, there were no significant main effects of time, with the exception of fasting and post-prandial subjective sensations of hunger, which increased significantly. These findings may indicate that at this low level of exercise-induced energy expenditure, exercise intensity has no major impact on appetite.

Only a handful of studies have addressed the impact of chronic exercise on subjective feelings of appetite and appetite-related hormones (7, 13, 18, 23) in overweight or obese individuals. King et al. were the first to demonstrate that chronic exercise (12 weeks duration at moderate intensity, inducing an average 3.2 kg weight reduction, mainly fat mass) has a dual impact on appetite in obese individuals; it increases the orexigenic drive to eat (hunger feelings), both in fasting and throughout the day, while also improving meal-induced satiety, i.e., inducing a stronger suppression of hunger after a mixed meal (13). Martins et al. later showed (18), using the same exercise intervention, that exercise-induced weight loss (average 3.5 kg) leads to an increase in AG levels and hunger feelings in fasting, despite an improved satiety response to a meal (tendency towards increased release of PYY and GLP-1 in the late post-prandial period). In the study of Guelfi and colleagues (2013), overweight and obese men exercised at moderate intensity (70–80% HRmax), 3 times/week for 12 weeks (7). They reported no change in either fasting hunger or AG after the exercise intervention, despite an average weight loss of 2 kg. It is possible that a minimum threshold of weight loss, and/or exercise-induced energy expenditure, are needed to induce, not only an increase in hunger and AG, but also an improvement in the satiety response with exercise. This is strengthened by previous findings showing that it is weight loss, not exercise that leads to increased ghrelin plasma levels (17) and by our findings that greater increases in ghrelin fasting concentrations are seen with larger weight loss. However, Rosenkilde and colleagues (2013) showed that despite significant weight reduction (3.5 vs 2.5 kg, respectively), neither moderate (30 minutes/day) nor high doses of MICT (60 minutes/day) increase fasting or postprandial measures of appetite (hunger feelings or total ghrelin). Moreover, they reported that a high dose of exercise (double that used in the present study) was associated with an increase in fasting and meal-related ratings of fullness and a tendency towards increased postprandial release of PYY (23). However, this study was run in overweight, non-obese individuals, and differences in BMI, as well as the measurement of total vs active ghrelin, may modulate the results.

Studies on the impact of chronic HIIT on appetite are however lacking. A recent study by Sim and colleagues (2015), where overweight men were randomized to isocaloric programs of HIIT (15 s at a power output equivalent to approximately 170% VO_{2peak}, with an active recovery period (60 s at a power output approximately 32% VO_{2peak}) between efforts) or MICT (60% VO_{2peak}) , or a no-intervention control group, for 12 weeks, reported no change in either subjective feelings of appetite or appetite related hormones (AG, PYY and pancreatic polypeptide) (in fasting or post-prandially), or differences between groups (26). This is consistent with our findings in obese men and women. The only difference was that in our study we report an overall increase in subjective feelings of hunger in fasting and postprandially. This may be due to differences in the amount of weight loss between the two studies (average -0.7 vs -1.2 kg). The changes in subjective feelings of appetite, in the absence of significant changes in the plasma concentration of appetite-related hormones, described in the present study, is not unexpected and has been previously reported (3). This discrepancy may be related with changes in the sensitivity to the appetite-related hormones.

Blood flow redistribution and lactate production have been proposed as two potential mechanisms mediating the impact of acute exercise on appetite, in particular the transitory appetite suppression seen after high-intensity exercise, characterized by hypoxia and lactate accumulation (8). Given that post-intervention appetite measurements were completed at least 48h after the last exercise session, it is unlikely that hypoxia and lactate accumulation are involved in appetite changes in response to chronic exercise. However, more studies are needed in this area.

A decrease in the relative preference for high vs. low fat foods has been reported after an acute bout of MICT in normal weight individuals (21). However, no changes in the reward value of food were seen after isocaloric bouts of MICT or HIIT (20) or 1 session of MICT and HIIT in obese individuals (1), or differences between exercise modalities (10, 20). However, studies on the impact of chronic exercise, including HIIT and/or HIIT, on food hedonics are lacking, and to the best of our knowledge the present study is the first to show that chronic MICT or HIIT have no significant impact on the reward value of food.

Our research group (20) and others (25) have shown that an acute session of HIIT leads to similar appetite responses as MICT in obese individuals, both in terms of subjective appetite feelings and appetite-related hormones. The present findings and the available literature (26) suggest that the impact of chronic HIIT on appetite may also not differ from MICT. A review by Kessler and colleagues concluded that HIIT has the potential to induce a similar weight loss, and similar or larger improvements in aerobic fitness in the obese, compared with MICT (11). Later studies in obese individuals, using HIIT have shown similar improvements in aerobic fitness as isocaloric protocols of MICT (17, 26). This has important practical implications. The time saving component associated with performing HIIT, and the fact that it may be more enjoyable (15), gives HIIT an advantage. However, at the end, exercise needs to be individualized and overweight and obese individuals should potentially choose the exercise program that best fits them and that has the best chance of compliance and long-term commitment. The current study benefits from a robust design (a randomized, controlled study), and the methodology used tackled several aspects of appetite: subjective feelings, objective measures (levels of appetite-related hormones in the plasma) and food hedonics. However, we are also aware of several limitations: first, a larger sample size would be preferable, particularly given the known large inter-individual variation in compensatory responses to exercise (12). Second, this was an efficacy study and, as such, our analysis was restricted to completers, which may distort the results and practical implication of our findings. Third, the volume of exercise used, and as a result the attained weight loss, might not have been enough to activate the expected changes in appetite (13, 18). Forth, we did not account for changes in bicarbonate pool/buffering, which were likely larger after HIIT compared with MICT and might have distorted the calculations of energy expenditure. Fifth, the estimation of energy expenditure during HIIT was based on the HR/VO_2 relationship obtained during continuous exercise. Even though this is a common procedure (25, 26), the validity and accuracy of this approach has never been tested. Lastly, we did not measure excess post-exercise oxygen consumption (EPOC), which has been shown to be larger after HIIT compared with isocaloric MICT (16). Given the approach used to estimate energy expenditure during HIIT and the fact that EPOC was not measured, the isocaloric nature of the MICT and HIIT protocols cannot be guaranteed.

We can conclude that the impact of chronic MICT vs. HIIT on appetite, in obese previously sedentary individuals, does not seem to differ. Neither exercise modality seems to induce meaningful changes in either subjective or objective appetite measures or food hedonics, at least when weight loss is minimal. More and larger studies are needed to confirm the present findings.

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The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work. Moreover, the authors also declare that the results of the present study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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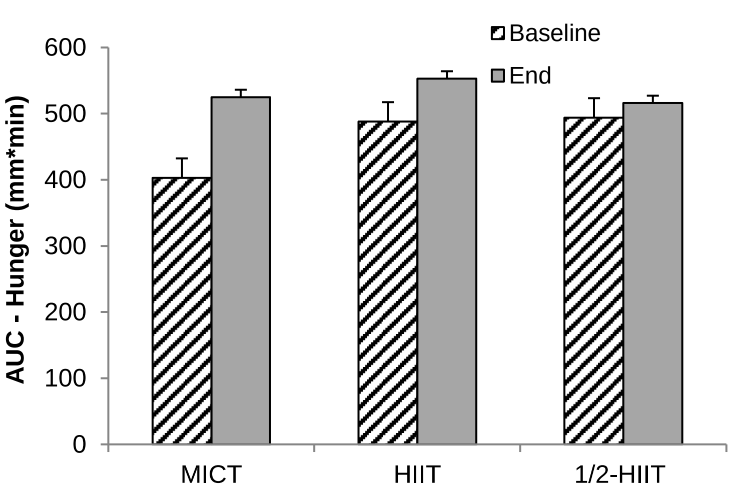
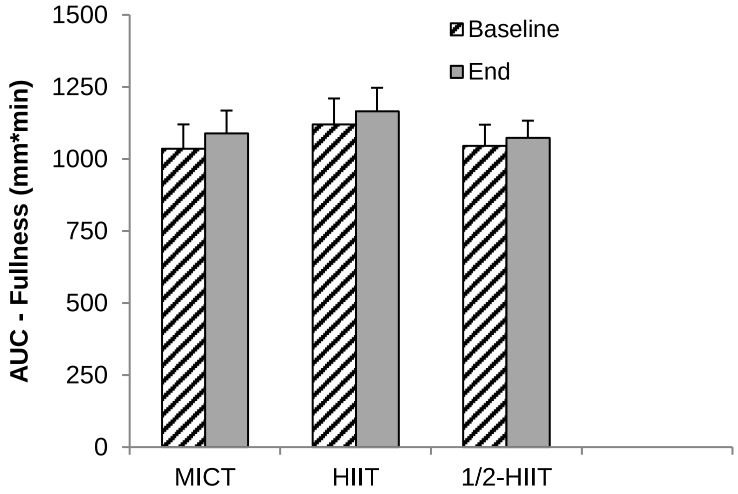
Figure legends:

Figure 1 (A, B, C, D). tAUC (0-180 min) for hunger, fullness, desire to eat and prospective food consumption (PFC) before and after the 12 weeks exercise intervention. Results are expressed as mean ±SD. HIIT, sprint interval training; 1/2-HIIT, short-duration HIIT; MICT, moderate-intensity continuous training. A main effect of exercise ($p=0.048$), but no effect of group or interaction was found for AUC hunger. No main effect of exercise, group or interaction, were found regarding AUC for the other appetite ratings.

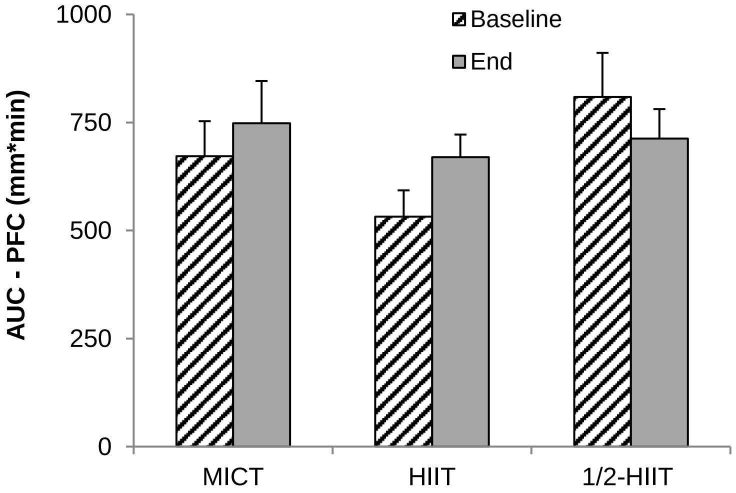
Figure 2 (A, B, C). tAUC (0-180 min) for AG (A), GLP-1 (B) and $PYY_{3\text{-}36}$ before and after the 12 weeks exercise intervention. Results are expressed as mean ±SD. HIIT, sprint interval training; 1/2-HIIT, short-duration HIIT; MICT, moderate-intensity continuous training. No main effect of exercise, group or interaction, were found regarding AUC for any of the appetite hormones.


AUC - Hunger (mm*min)
600
500
400
300
200
100
0
Baseline
End
MICT
HIIT
1/2-HIIT

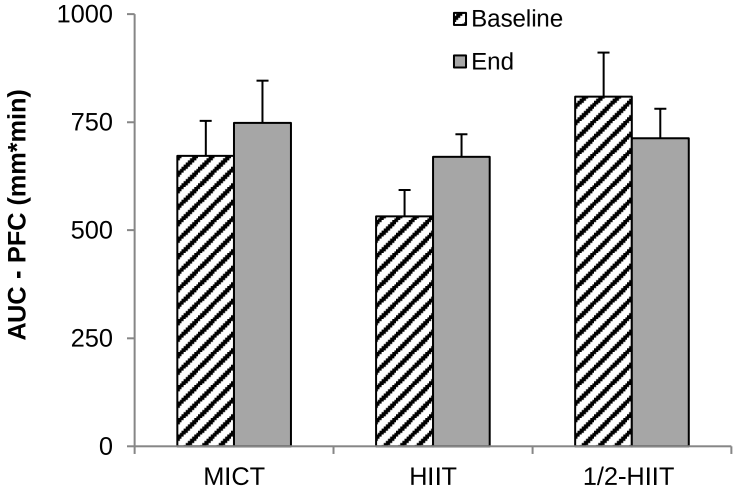
A


AUC - Fullness (mm*min)
1500
1250
1000
750
500
250
0
Baseline
End
MICT
HIIT
1/2-HIIT

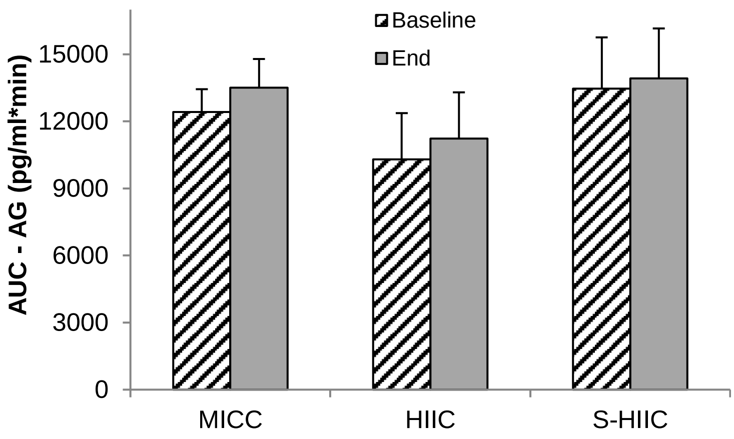
B


AUC - PFC (mm*min)
1000
750
500
250
0
Baseline
End
MICT
HIIT
1/2-HIIT

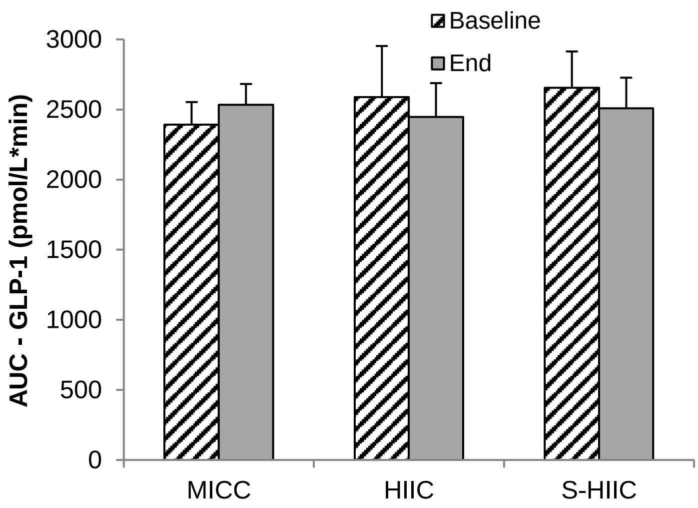
C


AUC - PFC (mm*min)
1000
750
500
250
0
Baseline
End
MICT
HIIT
1/2-HIIT

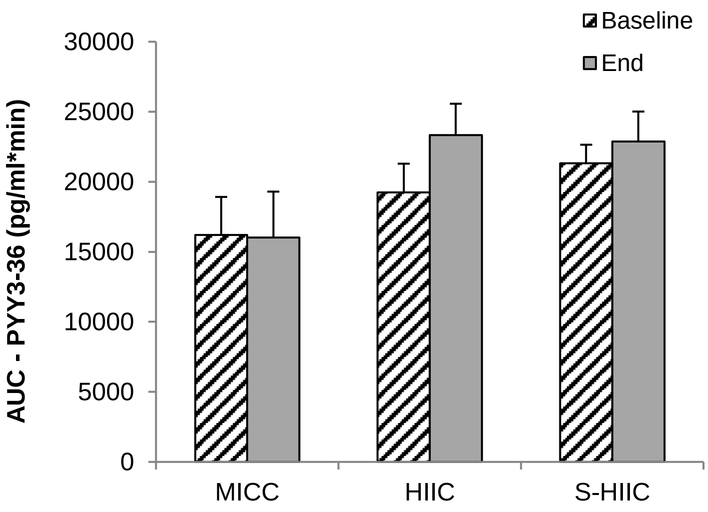
D


Baseline
End
AUC - AG (pg/ml*min)
15000
12000
9000
6000
3000
0
MICC
HIIC
S-HIIC

A


Baseline
End
AUC - GLP-1 (pmol/L*min)
3000
2500
2000
1500
1000
500
0
MICC
HIIC
S-HIIC

B


Baseline
End
AUC - PYY3-36 (pg/ml*min)
30000
25000
20000
15000
10000
5000
0
MICC
HIIC
S-HIIC

C

Table 1. Fasting subjective appetite sensations before and after each exercise intervention

	MICT		HIIT		½ HIIT	
	Baseline	End	Baseline	End	Baseline	End
Hunger (cm)	4.3±2.4	5.4±2.2	5.4±2.5	6.7±1.2	4.2±2.6	4.8±.9
Fullness (cm)	2.3±2.1	2.0±2.6	2.0±2.0	1.3±1.2	2.6±1.6	2.7±1.8
Desire to eat (cm)	4.9±2.0	5.4±2.4	5.5±2.1	6.2±2.2	5.2±2.1	4.5±1.6
PFC (cm)	5.3±2.2	5.9±1.7	4.9±2.0	6.3±1.5	5.3±2.3	5.2±1.7

Results expressed as mean ± SD. PFC – prospective food consumption, MICT – moderate intensity continuous training; HIIT – high-intensity interval training; 1/2-HIIT – short duration HIIT. A significant main effect of exercise ($p=0.01$), but no main effect of group or interaction was found for hunger feelings in fasting. No significant main effect of exercise, group or interaction was found for other appetite feelings.

Table 2. Fasting plasma levels of AG, PYY_{3-36} and GLP-1 before and after each exercise intervention

	MICT		HIIT		½ HIIT	
	Baseline	End	Baseline	End	Baseline	End
AG (pg/ml)	86.6±63.6	87.2±50.5	71.7±32.5	75.2±34.1	95.4±56.1	104.8±60.6
PYY_{3-36} (pg/ml)	74.7±41.5	72.8±43.6	110.8±56.0	108.0±47.4	100.6±25.9	108.1±31.7
GLP-1 (pmol/L)	10.7±7.1	9.3±5.1	10.7±3.5	9.8±2.5	8.8±3.6	8.7±3.7

Results expressed as mean ± SD. MICT – moderate intensity continuous training; HIIT – high-intensity interval training; 1/2-HIIT – short duration HIIT. No significant main effect of exercise, group or interaction was found for fasting plasma levels of any appetite hormone.

Table 3. Food preference and food reward pre and post breakfast, pre and post each exercise intervention

		MICT				HIIT				½ HIIT			
		Baseline		End		Baseline		End		Baseline		End	
		pre BF	post BF	pre BF	post BF	pre BF	post BF	pre BF	post BF	pre BF	post BF	pre BF	post BF
Fat bias	Ex L	-8.7±4.5	3.2±3.8	-10.7±4.4	-2.9±2.9	7.1±4.3	2.1±3.6	-7.3±4.2	1.3±2.8	-7.1±5.2	2.8±4.3	-0.7±5.1	3.1±3.3
	Im W	-15.1±9.3	-4.0±7.8	-12.8±9.2	-7.8±8.4	0.8±8.9	20.1±7.5	-1.7±8.9	12.9±8.0	8.1±10.7	14.2±9.0	5.0±10.6	13.0±9.6
	Rel P	-4.4±3.3	0.4±2.8	-4.8±3.4	-2.3±3.2	0.0±3.2	5.9±2.7	0.1±3.3	5.2±3.0	2.8±3.8	4.7±3.3	2.2±3.9	5.7±3.6
Sweet bias	Ex L	-5.7±3.9	9.9±4.6	-10.1±4.3	5.5±3.3	-9.8±3.7	4.4±4.4	-10.1±4.4	4.8±3.2	-10.4±4.5	14.5±5.3	-3.2±5.1	11.5±3.8
	Im W	-15.4±11.1	18.0±14.3	-11.1±9.0	10.6±11.9	-29.7±10.7	10.4±13.7	-26.0±8.6	9.3±11.4	-18.5±12.8	13.8±16.5	-11.7±10.4	25.2±13.7
	Rel P	-5.6±3.6	5.8±4.8	-4.2±3.1	3.4±4.3	-11.4±3.5	2.5±4.6	-9.5±3.0	3.0±4.2	-7.7±4.2	3.2±5.5	-5.4±3.6	8.3±5.0

Results expressed as mean ± SEM. Fat bias: High fat – low fat; Sweet bias: sweet – savory. BF – breakfast; Ex L – explicit liking, Im W – implicit wanting, Rel P – relative preference, MICT – moderate intensity continuous training; HIIT – high-intensity interval training; 1/2-HIIT – short duration HIIT. BF – breakfast. A significant main effect of time ($p<0.001$), but no main effect of group, intervention or interaction was found for all endpoints.