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ORIGINAL RESEARCH

Interval Training Intensity Affects Energy Intake Compensation in Obese Men

Shaea A. Alkahtani, Nuala M. Byrne, Andrew P. Hills, and Neil A. King

Purpose: Compensatory responses may attenuate the effectiveness of exercise training in weight management. The aim of this study was to compare the effect of moderate- and high-intensity interval training on eating behavior compensation. ***Methods***: Using a crossover design, 10 overweight and obese men participated in 4-week moderate (MIIT) and high (HIIT) intensity interval training. MIIT consisted of 5-min cycling stages at ±20% of mechanical work at 45%VO_2peak, and HIIT consisted of alternate 30-s work at 90%VO_2peak and 30-s rests, for 30 to 45 min. Assessments included a constant-load exercise test at 45%VO_2peak for 45 min followed by 60-min recovery. Appetite sensations were measured during the exercise test using a Visual Analog Scale. Food preferences (liking and wanting) were assessed using a computer-based paradigm, and this paradigm uses 20 photographic food stimuli varying along two dimensions, fat (high or low) and taste (sweet or nonsweet). An ad libitum test meal was provided after the constant-load exercise test. ***Results***: Exercise-induced hunger and desire to eat decreased after HIIT, and the difference between MIIT and HIIT in desire to eat approached significance ($p = .07$). Exercise-induced liking for high-fat nonsweet food tended to increase after MIIT and decreased after HIIT ($p = .09$). Fat intake decreased by 16% after HIIT, and increased by 38% after MIIT, with the difference between MIIT and HIIT approaching significance ($p = .07$). ***Conclusions***: This study provides evidence that energy intake compensation differs between MIIT and HIIT.

Keywords: appetite sensations, food intake, dietary compensation, intermittent exercise, liking and wanting, macronutrient preferences

It is recommended that weight loss intervention programs should combine reductions in energy intake (EI) with increases in energy expenditure (EE; Seagle et al., 2009). For example, a combination of increased high volume of EE and dietary counseling has been shown to achieve target weight loss (Ross et al., 2000). However, several studies without dietary intervention, involving moderate-intensity continuous training reported a lower than predicted weight loss (Donnelly et al., 2000; Ross & Janssen, 2001). High-intensity interval training has also resulted in variable changes in body weight (Trapp et al., 2008). These variations in weight change could be partly explained by compensatory eating behavior responses (King et al., 2007).

The compensation of eating behavior components such as appetite sensations, food intake, and nutrient preferences could explain individual variations in exercise-induced weight loss. For example, the individual variability in weight loss following 12 weeks of supervised exercise was attributed to behavioral responses via increases in EI and hunger in the compensator group, whose actual weight loss was lower than their predicted weight loss (King et al., 2008). Change in food or nutrient preference could be a strong contributor to increased compensatory food intake, which in turn will undermine the impact of exercise on weight loss. Nutrient preferences can be examined using the concept of liking and wanting, introduced by Berridge (2009) who separated the mediators of food reward in the brain into liking (hedonic effective) and wanting (incentive salience motivation). Finlayson et al. (2007) designed a computer-based paradigm to assess the distinction between liking and wanting for food taste and fat content in humans. Finlayson et al. (2011) found that responders who experienced equal to or more than the expected weight reduction did not show any change in liking for food stimuli after 12 weeks of training, while nonresponders' liking increased independent of taste and fat content, and nonresponders also showed a specific increase in high fat sweet food. Therefore, these eating behaviors were able to discriminate between individuals according to their weight loss in response to training intervention.

Most studies have examined the compensatory responses used moderate-intensity training (King et al., 2008; Rosenkilde et al., 2012). For example, Church et al. (2009) compared three exercise groups based on the volume of weekly EE (4, 8, and 12 kcal/kg/week) at moderate-intensity levels in sedentary overweight women for 12 weeks. Compensatory responses occurred in the 12 kcal/kg/week

Alkahtani is with the Dept. of Health and Fitness, University of Dammam. Byrne and King are with the School of Exercise and Nutrition Sciences & Institute of Health and Biomedical Innovation, Queensland University of Technology, Australia. Hills is with the Mater Mother's Hospital, Mater Medical Research Institute, Griffith University, Brisbane, Australia. Address author correspondence to Shaea A. Alkahtani at saalkahtani@ud.edu.sa.

group only. Investigating the influence of different intensities of interval training on EI is important because there is growing evidence to support the idea that high-intensity interval training can reduce body fat mass more effectively than steady-state endurance training (Boutcher, 2011).

A few studies have examined the effect of different intensities of acute and medium-term continuous exercise on one of the eating behavior components, but the findings of these studies were equivocal. A robust finding is the short-lived suppression of hunger after an acute single bout of high-intensity continuous exercise (King et al., 1997). However, the effect of different intensities of medium-term exercise on exercise-induced hunger has not been examined. An increase in fat intake among normal-weight adults in the day following acute high-intensity exercise compared with a moderate-intensity exercise session has been shown, but this increase was insufficient to significantly affect EI (Klausen et al., 1999). In contrast, a 7-week study which compared low- and high-intensity training found a greater reduction in food intake after high-intensity training but this did not reach statistical significance (Dickson-Parnell & Zeichner, 1985). Jakicic et al. (2003) investigated the effect of different combinations of intensity and duration on body weight and fat-reduced EI at Weeks 6 and 12 of the intervention in overweight women, and did not find any influence of the intervention or differences between treatments on EI and the percentage of fat reduction. In short, the effect of different intensities of medium-term exercise on eating behavior is unclear, and the role of interval training has not been examined.

Physiological factors such as substrate oxidation have been proposed as factors influencing changes in nutrient preferences and food intake (Flatt, 1996). For example, a positive relationship between RQ and food intake was reported in lean individuals (Kissileff et al., 1990). Similarly, another study found that low RQ (high fat oxidation) was inversely correlated with food intake (Almeras et al., 1995). It should be noted that participants were divided into two subgroups (low- and high-RQ) based on relatively small differences (~0.02) in exercise-induced RQ, and the energy cost of exercise was significantly different between groups. While these studies revealed a possible directional relationship between exercise-induced substrate oxidation and EI, the role of exercise intensity remains unclear.

The aim of this study was to compare the influence of four weeks of moderate- and high-intensity interval training (MIIT and HIIT) on acute exercise-induced appetite sensations, acute exercise-induced liking and wanting and acute exercise-induced food intake and nutrient preferences in 10 overweight and obese men.

Methods

Participant Characteristics

Participants included 10 sedentary overweight/obese men. The descriptive characteristics of participants were: age (29 ±3.7 years), weight (88.6 ±7.6 kg), BMI (30.7 ±3.4 kg/m^2), fat mass (31.2 ± 4.7%body weight) and VO_2peak (28.7 ±3.4 ml/kg/min). Participants were recruited from the staff and student population at the Queensland University of Technology (QUT) and the Brisbane metropolitan region via e-mail and flyers posted on community noticeboards. A written informed consent was signed and the participant was asked to gain medical clearance from a general practitioner before undertaking the study. The study protocol was approved by the Human Research Ethics Committee at QUT (HREC No. 1000000160).

Design of Training Intervention

The study employed a cross-over design, and involved two 4-week training interventions consisting of 12 cycling sessions in each intervention (MIIT or HIIT) separated by a 6-week detraining wash-out. The intensity of MIIT and HIIT were determined at 45 and 90%VO_2peak respectively. A simple linear regression between VO_2 and workload was performed, and the slope and intercept were calculated to determine the individual workloads that represent 45 and 90%VO_2peak. Participants were allocated to either MIIT or HIIT in a counterbalanced order. The MIIT session consisted of 5-min cycling stages at ±20% of mechanical work at 45%VO_2peak. After the workload was determined at 45%VO_2peak, the workload was multiplied by ± 0.2 to determine the ±20% workload of 45%VO_2peak. The HIIT session consisted of a 30-s work at 90%VO_2peak and 30-s passive recovery interval rests per minute. The researcher supervised all training sessions, and participants were instructed to maintain a cadence of 70 rpm during the session. The current design of training in terms of the duration of intervention, the ±20% workload of MIIT and the period of wash out were modified from the study of Venables and Jeukendrup (2008).

Use of Constant-Load Exercise Test to Assess Eating Behavior and Substrate Oxidation

The acute effects of exercise on eating behavior and substrate oxidation were assessed using a constant-load moderate-intensity exercise test followed by 1-hr recovery and ad libitum test meal at Week 0 (preintervention) and Week 4 (postintervention). Participants performed GXT and body composition measures 48 hr after the last training session, and performed constant-load exercise test 48 hr after GXT. The constant-load exercise bout was different to the exercise sessions in the MIIT and HIIT, and it was performed at 45%VO_2peak at a cadence of 70 rpm for 45 min, using a braked-cycle ergometer (Monark Bike E234, Monark Exercise AB, Sweden). The constant-load exercise test was performed in the afternoon at approximately 1:00 p.m., and participants were asked to refrain from eating for at least 5 hr before the test. It is typical to instruct participants to arrive at the laboratory at 8:00 a.m. to be provided with a standard breakfast so that meal to exercise interval and breakfast intake are standardized. However, the participants were already involved in a high level of commitment. This extra load would have been burdensome. Tests took place in a ventilated air-conditioned laboratory where temperature was set at 21°C. On the preassessment day, participants were asked to abstain from any kind of exercise or physical work, and to abstain from consuming alcohol and caffeine. All participants recorded their food and drink intake in the 24 hr preceding the first test, and were asked to adhere to the same dietary intake preceding the three repeated tests during the experiment.

Data Management

Data Management of Body Composition. Fat mass was estimated using the Imp^{TM} SFB7 tetra polar bio-impedance spectroscopy (BIS) (ImpediMed Limited, Queensland, Australia). This device is valid against total body water (TBW) in healthy individuals (Moon et al., 2008; Wabel et al., 2009).

Participants were asked to void before the test, and then lie supine on a nonconductive surface, extending their arms by their sides, hands resting next to their body with palms down, and with their legs slightly apart, and stay calm for 20 min. Electrode sites on the skin were wiped with alcohol and allowed to dry. Electrodes were applied to the wrist, the ankle and the dorsal surface of the right hand and foot.

Data Management of Indirect Calorimetry. The Parvo Medics Analyzer Module (TrueOne2400, Metabolic Measurement System, Parvo Medics, Inc. USA) was used in the measurement of respiratory gas exchange. The calibration of the system was undertaken before each test.

Participants cycled at 35 W for 4 min followed by a 4-min rest interval, and the work rate was increased at the start of each stage by 17.5 W until the workload at which RER reached 1.0. After a 4-min rest, participants commenced the second phase which the mechanical work was increased by 17.5 W every minute until volitional exhaustion to obtain a measurement of VO_2max. Five threshold criteria were used to determine maximal aerobic performance. All participants reached the RER_{peak}, BLa_{peak} and RPE_{peak} criteria before MIIT and HIIT. Individual 50% increment of VO_2 was used to calculate the VO_2 plateau, and its average was 1.25 ±0.3 ml/kg/min (R^2 = .96 ±0.09) in pre-MIIT and HIIT.

During the constant-load test, VO_2 and VCO_2 were averaged for every 30 s automatically via the Parvo Medics Analyzer. The average of 5 min at minute 10–15 and 25–30 and 40–45 during exercise were calculated. Rates of fat oxidation (g/min) were calculated using stoichiometric equations of the energy equivalents of oxygen for nonprotein RQ developed by Frayn (1983).

Data Management of Appetite Sensations and Liking and Wanting. Subjective appetite sensations were measured using a computerized version of Visual Analog Scale (VAS). A computerised version has been developed and validated (Stubbs et al., 2000). All participants used this procedure immediately before and after the acute constant-load exercise test to record subjective appetite sensations for hunger, desire to eat, and fullness.

The measurement of liking and wanting were assessed using a computer-based paradigm (E-prime v 1.1.4) (Finlayson, et al., 2007), immediately before and after the acute constant-load exercise test. This paradigm uses 20 photographic food stimuli varying along two dimensions, fat (high or low) and taste (sweet or nonsweet). The categories of foods could be organized into combined categories of high-fat nonsweet (HFNS), low-fat nonsweet (LFNS), high-fat sweet (HFSW), and low-fat sweet (LFSW).

Explicit liking—the hedonic impact of each food—was assessed using a 100 unit VAS anchored at each end with *not at all* and *extremely* combined with the statement "How pleasant would it be to experience a mouthful of this food now?" The rating scale was presented on the monitor beneath each food stimulus. Participants used the mouse to move a centered cursor along the line to indicate their response. When a rating had been made, a continue button cycled the program to the next stimulus.

Implicit wanting—the incentive salience of each food category—was assessed by a forced choice methodology. In this task, a food stimulus from each of the four food categories was paired with a stimulus from another category to form one trial in which the subjects were given the standardized instruction to select the food they "would most like to eat now." Each choice, made via key-press on the keyboard, triggers the next pair of stimuli and so on until all possible pairs of combinations (n = 150) have been presented. The time taken to select a food (reaction time) is automatically measured in milliseconds (ms).

Variables of appetite sensations (hunger, desire to eat, and fullness) and liking and wanting (explicit liking and implicit wanting) were measured immediately before and after the constant-load exercise test in Weeks 0 and 4. Therefore, changes in acute-exercise-induced and medium-term-induced exercise were calculated using the formulas below:

Acute-Ex: difference between end of acute exercise and resting value.

$$\Delta\text{Acute-Ex} = \text{End-Ex} - \text{Rest}$$

Medium-term-Ex: difference between Acute-Ex in Week 4 and Acute-Ex in Week 0.

$$\Delta\text{Medium termEx} = \Delta\text{Acute-Ex } 4 - \Delta\text{Acute-Ex } 0$$

Data Management of Food Intake. Ad libitum test meal was provided after the acute exercise test. The meal comprised eight types of food to present the two factors of fat content (high and low) and taste (sweet and nonsweet); similar to the food stimuli presented in the liking and wanting test. Therefore, the test meal included carrot and rice crackers to represent LFNS food, fruit sweets, and apple to represent LFSW food, butter twists, and chips to represent HFNS food and shortbread and milk chocolate bar to represent HFSW food.

All eight food-types were provided in separate bowls, and bowls were weighed to the nearest 0.1g on a digital scale before and after eating. The fat, CHO and protein values of each food were used based on the manufacturers' nutritional information, to calculate the total amounts of energy and macronutrient consumed.

Statistical Analysis

Data were presented as mean values and standard error of mean (SEM), unless otherwise indicated. A mixed linear model univariate ANOVA was used to assess the interaction between time (Weeks 0 and 4) and intensity (MIIT and HIIT) on ΔAcute-Ex appetite sensations, liking and wanting, and food intake. Fat oxidation was inserted as a covariate in the analysis of the linear model univariate ANOVA for food intake. Effect size, power and required sample size to attain power of 0.8 at alpha level of 0.05 were calculated. The Microsoft Excel program (version 12.0, 2007, Microsoft Corporation, Seattle, WA, USA) was used to compile the main results. Statistical analyses were carried out with SPSS for Windows (version 18.0.1, 2010, PASW Statistics SPSS, Chicago, IL, USA).

Results

Description of Exercise Training Sessions

The workloads were 76 ±4 W for MIIT and 71 ±5 for HIIT, and the duration of 12 training sessions were 450 min for both MIIT and HIIT. As a result, average distance (18.3 ±0.2 km/session and 8.9 ±0.1 km/session at MIIT and HIIT respectively) and duration of cycling per session (37.5 min/session and 18.7 min/session at MIIT and HIIT respectively) were significantly higher during MIIT than HIIT ($p \leq .001$). Total energy expenditure for all 12 training sessions was predicted using participants' energy expenditure data from the constant-load exercise test at Week 0, and was approximately 2880 kcal (6.4 kcal/min × 450 min). Therefore, fat mass did not change over the intervention.

Appetite Sensations

There were no significant effects of time on ΔMedium term-Ex appetite sensations. The interaction between intensity and time on ΔMedium term-Ex approached significance for desire to eat (p = .07). Figure 1 shows ΔMedium term-Ex appetite sensations for MIIT and HIIT.

Liking and Wanting

The interaction between intensity and time on ΔMedium term-Ex explicit liking for HFNS food approached significance (p = .09), whereas the interactions between intensity and time on ΔMedium term-Ex implicit wanting were not significant for all food categories. Delta value of ΔMedium term-Ex of explicit liking is presented in Figure 2.

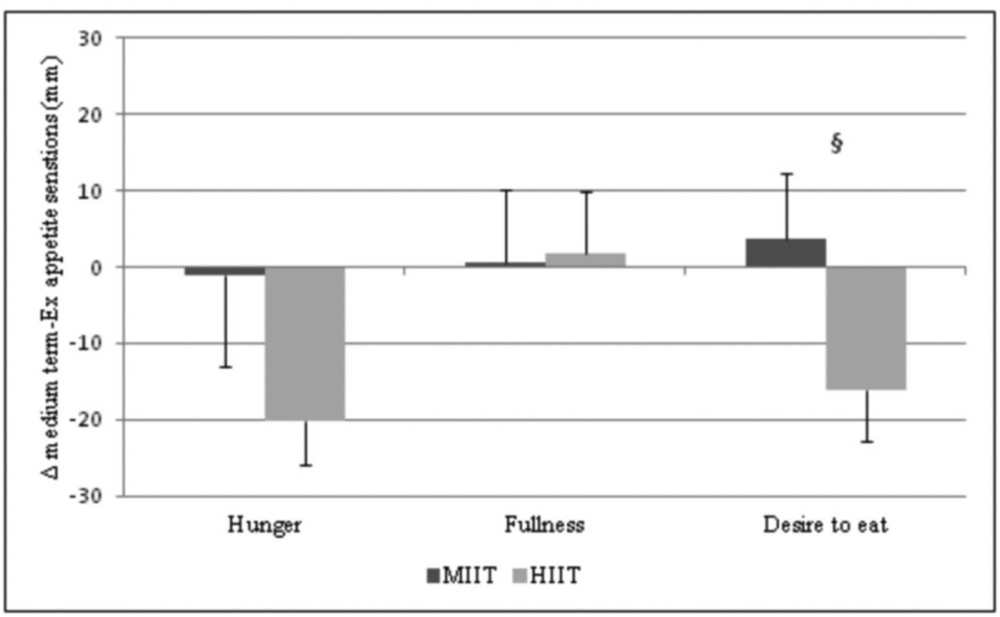

Figure 1 — DMedium term-Ex appetite sensations in MIIT and HIIT; data represented as mean ±SEM; §: the interaction between intensity and time on desire to eat approached significance (p = .07); MIIT: moderate-intensity interval training; HIIT: high-intensity interval training; ΔMedium term-Ex = ΔAcute-Exe 4—ΔAcute-Exe 0.

Food Intake and Nutrient Preferences During Ad Libitum Test Meal

There were no significant interactions between intensity and time for food (g) and energy (kcal) intake (Figure 3). Fat intake (g) increased by 38% after MIIT and decreased by 16% after HIIT (Figure 4). The interaction between intensity and time on fat intake approached significance ($p = .07$), and the effect size (partial eta squared) was 12.4%. The percentage contribution of macronutrients to energy intake (%EI) did not change after HIIT, whereas energy intake from fat increased by 11% after MIIT.

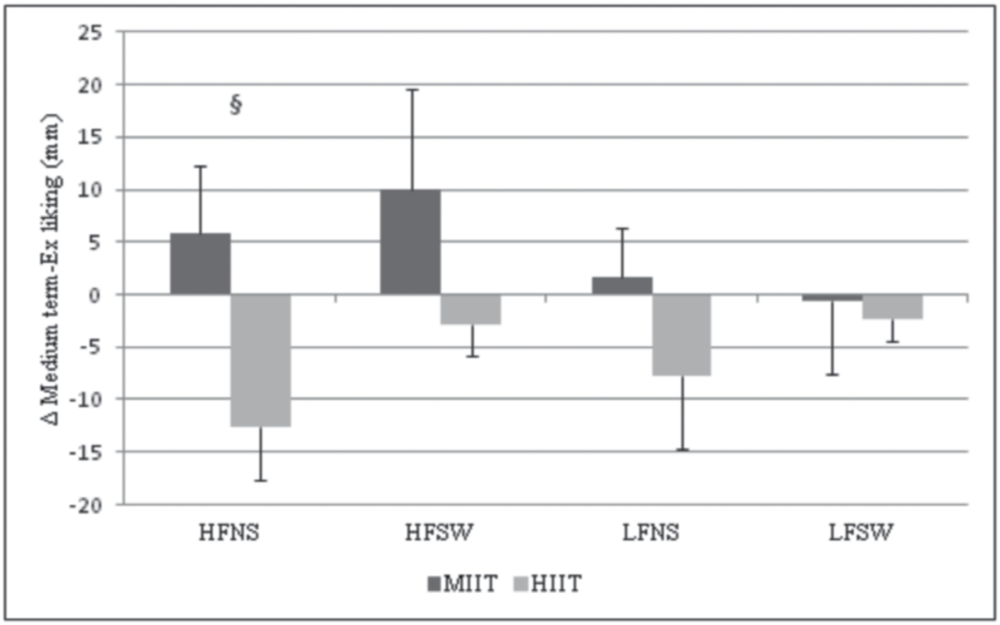

Figure 2 — DMedium term-Ex for explicit liking in MIIT and HIIT; data represented as mean ±SEM; MIIT: moderate-intensity interval training; HIIT: high-intensity interval training; DMedium term-Ex: difference between Acute-Exe in week 4 and Acute-Exe in Week 0; §: the interaction between intensity and time on HFNS ($p = .09$).

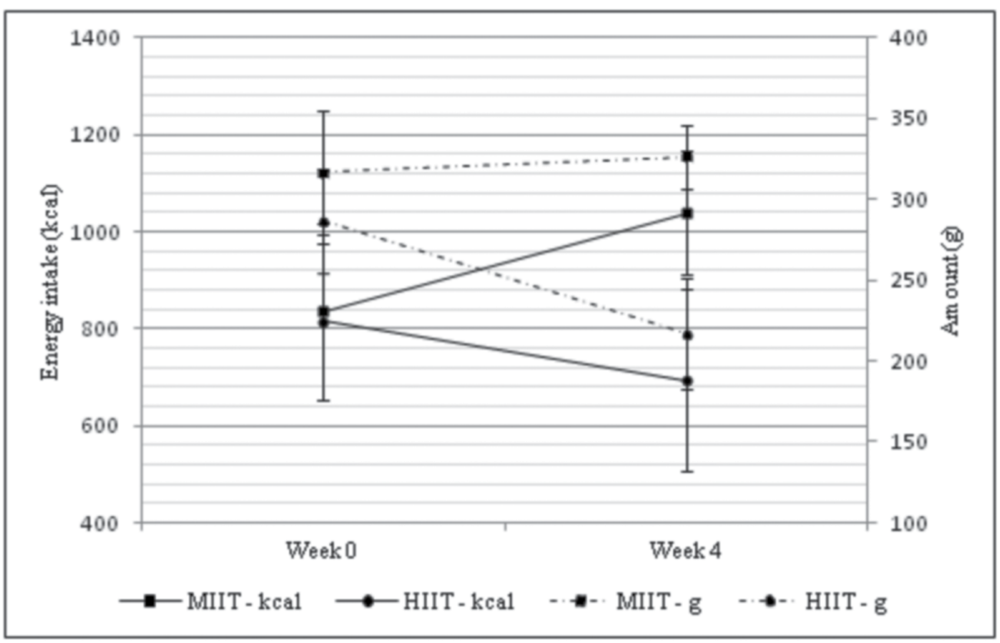

Figure 3 — Food (g) and energy (kcal) intake during MIIT and HIIT at Weeks 0 and 4; data represented as mean ±SEM; MIIT: moderate-intensity interval training; HIIT: high-intensity interval training.

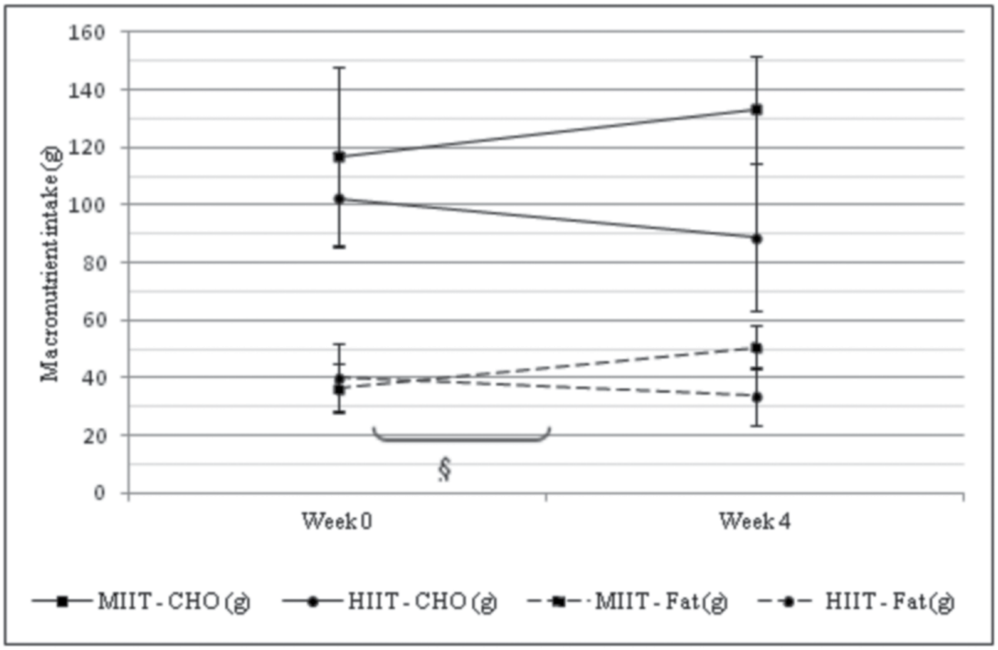

Figure 4 — Total amount of macronutrient component (CHO and fat) during MIIT and HIIT at weeks 0 and 4; data represented as mean ±SEM; §: the interaction between intensity and time on fat intake (g) approached significance ($p = .07$); MIIT: moderate-intensity interval training; HIIT: high-intensity interval training.

Interaction Between Fat Intake and Fat Oxidation

There was no interaction between change in exercise-induced fat oxidation and change in fat eaten (Figure 5). In line with this, statistical analysis revealed that there was an interaction between time and fat oxidation ($p = .04$), which means fat oxidation increased after the intervention, independent of intensity.

As several eating behavior variables approached significance of .07 and .09, post hoc power analysis was calculated for these variables to identify required sample size to attain power .8 at an alpha level of .05. The effect size of medium-term exercise-induced food intake was .29, and 16 participants were required to attain power of .8. The effect size of medium-term exercise-induced fat intake was 0.36, and 12 participants were required to attain power of 0.8. The effect size of medium term-Ex explicit liking for HFNS was 0.35, and 20 participants were required to attain power of 0.8.

Discussion

The main finding of the current study was that there was a trend toward a compensatory response in eating after MIIT than after HIIT. This was reflected in desire to eat, explicit liking for HFNS food, and fat intake after the medium term training.

Appetite Sensation

HIIT suppressed medium term-Ex hunger and desire to eat which approached significance. The outcomes were in agreement with previous studies that suggested transitory suppression of hunger in response to acute high-intensity exercise known as 'exercise-induced anorexia' (King et al., 1997b; Kissileff et al., 1990). However, these results were not in agreement with other acute-exercise studies that found a similar suppression of hunger after high- and low-intensity exercise in men (Ueda et al., 2009). The small effect of MIIT on appetite sensations was in line with several studies which did not find any notable effects of moderate-intensity short- and medium-term training on appetite sensations (Martins et al., 2008a; Whybrow et al., 2008). It can be concluded that interval training may not increase medium term-Ex appetite sensations, and the suppression of medium term-Ex hunger and desire to eat could be found after HIIT.

Several metabolic mechanisms such as gut hormones (Martins et al., 2010; Martins et al., 2008b) have been identified to explain the suppression of hunger after exercise including high-intensity intervals. In contrast, less information is available regarding behavioral mechanism that may regulate appetite sensations in response to high-intensity exercise. For example, feelings of tension and irritability (King et al., 1997a) and willingness to start eating (King et al., 1994) as well as rewarding systems (Finlayson et al., 2008) in response to high-intensity exercise could enhance or suppress appetite sensations.

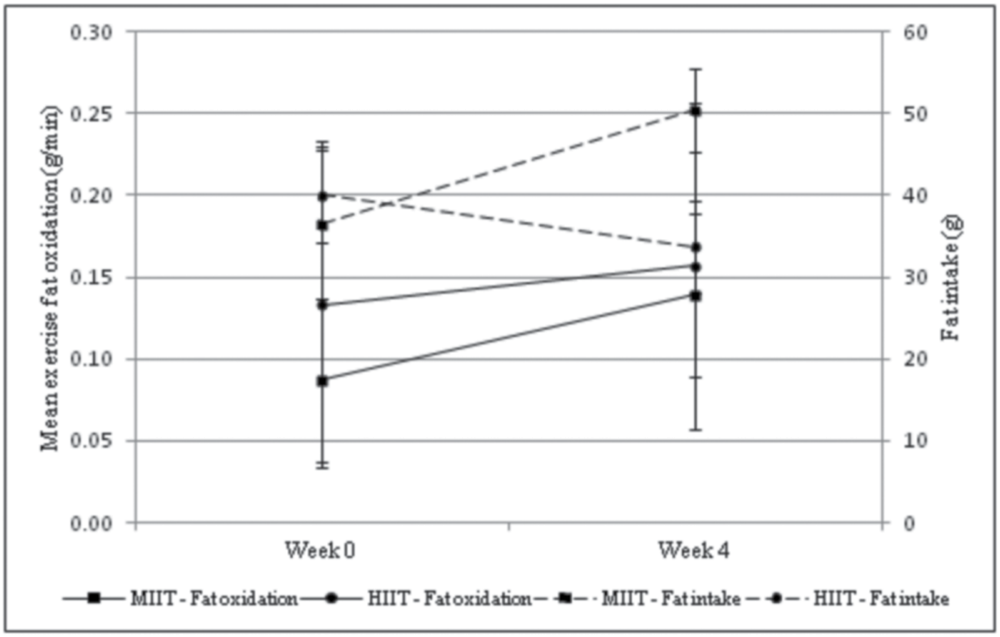

Figure 5 — The interaction between the intervention and exercise-induced fat oxidation (g/min) on fat intake; data represented as mean ±SEM; MIIT: moderate-intensity interval training; HIIT: high-intensity interval training.

Liking and Wanting

The preference for medium term-Ex HFNS food decreased after HIIT (≤–10 mm), and increased after MIIT (≥ +5 mm). In addition, the preference for medium term-Ex HFSW food increased after MIIT (≥ +10 mm). These data could be used as predictors of weight loss. For example, Finlayson et al. (2011) found that individuals who did not lose the expected weight after exercise (ie, nonresponders) experienced an increase in exercise-induced explicit liking for HFSW food (+10 mm). Responders reported a decrease in exercise-induced explicit liking for HFSW stimuli at the baseline in Week 0 (–10 mm). In Week 12, the researchers found that nonresponders experienced an increase in exercise-induced explicit liking in all food categories (≥10 mm), and responders' explicit liking did not increase at Week 12. Therefore, the increase in medium term-Ex explicit liking for HFSW food after MIIT was in agreement with the increase in medium-term exercise-induced explicit liking for HFSW food in nonresponders.

Food Intake

The tendency of the decrease in food intake after HIIT was not confirmed in some previous studies. For example, Kissileff et al. (1990) found that meals consumed after strenuous exercise were smaller than those consumed after moderate-intensity exercise. In contrast, another study found that food intake did not increase after moderate-intensity exercise at 50W (+8g) and after high-intensity exercise at 100 W (+3g) compared with the rest condition in sedentary individuals (Erdmann et al., 2007). Although it was found that high-intensity training tended to decrease EI greater than moderate-intensity training (Dickson-Parnell & Zeichner, 1985), it is unclear whether the reduction in EI was due to a reduction in the amount of food eaten or a change in macronutrient components.

Nutrient Preferences

The tendency of moderate-intensity training to influence nutrient preferences was not confirmed in previous acute and medium-term studies. For example, a moderate-intensity exercise bout for 1 hr compared with the rest condition did not alter macronutrient intake of a buffet meal consumed 1-hr after the exercise (Martins et al., 2007). Several acute studies that involved brisk walking for 60 min (King et al., 2010) or cycling at 60%VO_2max for 90 min (Almeras et al., 1995) did not find changes in exercise-induced nutrient preferences. Likewise, two long-term moderate-intensity training interventions, one intermittent (Snyder et al., 1997) and one continuous (Donnelly et al., 2003), did not find significant alterations in the preferences for fat and CHO intake. Therefore, few available studies of acute moderate-intensity exercise within a 60-min period and long-term moderate-intensity training did not confirm the potential of moderate-intensity exercise to alter nutrient selection.

Role of Fat Oxidation on Fat Preference

It is unlikely that the increase in fat oxidation after MIIT caused the increase in fat intake. While the increases in CHO and protein oxidation can induce increases in CHO and protein intake (Griffioen-Roose et al., 2012; Joosen & Westerterp, 2006), fat reserves are very large in the human body (Galgani & Ravussin, 2008). In addition, the change in fat oxidation was small, and the participants predominantly relied on CHO (70 to 75%EE) during the acute constant-load exercise test at Weeks 0 and 4 of MIIT and HIIT. It was reported that sedentary obese individuals have an impaired ability to oxidize fat in skeletal muscles (Corpeleijn et al., 2009), and they rely predominantly on CHO particularly when the demand on energy increases (Hopkins et al., 2010). Therefore, changes in fat oxidation might not explain the trend toward an increase in fat intake after MIIT.

The trend toward an increase in fat intake after MIIT could be driven by psychological rather than physiological factors. The assumption of the role of psychological factors during low-intensity exercise is based on the findings that peripheral factors can affect human perception at high-intensity levels, whereas psychological factors such as cerebral activity and cognitive processes affect the perception during low-intensity exercise (Pires et al., 2011).

Summary and Implication

The tendencies of eating behavior including medium term-Ex hunger and desire to eat, medium term-Ex explicit liking for energy-dense food, medium-term constant-load exercise-induced food and fat intake collectively suggested that HIIT is a better strategy than MIIT to minimize the compensation of eating behavior during interval training among males. It was proposed by others (Boutcher, 2011) that the greater fat loss with HIIT may be attributed to HIIT having a greater impact on food intake and appetite sensations. The findings presented here provide some support for this assertion. Furthermore, many studies used self-report food diaries to monitor changes in food and macronutrient intake. We suggest the utilization of ad libitum test meal, appetite sensations, and liking and wanting methods to examine the compensation of eating behaviors. Lastly, some studies found that high dose of moderate-intensity steady-state training led to dietary compensations which resulted in lower than expected weight loss (Church et al., 2009; Rosenkilde et al., 2012). Future studies may replicate the current design combined with different doses of EE during weight-loss exercise-induced intervention (e.g., 12-week training intervention) to examine the combined effects of interval training intensity and exercise-induced EE on eating behavior compensations during weight-loss intervention.

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