The effects of a pre-exercise meal on post-exercise metabolism following a session of sprint interval training

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Abstract

Sprint interval training (SIT) has demonstrated reductions in fat mass through potential alterations in post-exercise metabolism. This study examined whether exercising in the fasted or fed state affects post-exercise metabolism following acute SIT. Ten active males performed a bout of modified SIT (8 x 15 s sprints; 120 s recovery) in both a fasted (FAST) and fed (FED) state. Gas exchange was collected through 3 h post-exercise, appetite perceptions were measured using a visual analog scale, and energy intake was recorded using dietary food logs. There was no difference in energy expenditure between conditions at any time point (p>0.329) or in total session energy expenditure (FED: 514.8±54.9 kcal, FAST: 504.0±74.3 kcal; p=0.982). Fat oxidation 3 h post-exercise was higher in FED (0.110±0.04 g·min\(^{-1}\)) versus FAST (0.069±0.02 g·min\(^{-1}\); p=0.013) though not different between conditions across time (p>0.340), or in total post-exercise fat oxidation (FED: 0.125±0.04 g·min\(^{-1}\), FAST: 0.105±0.02 g·min\(^{-1}\); p=0.154). Appetite perceptions were lower in FED (-4815.0±4098.7 mm) versus FAST (-707.5±2010.4 mm, p=0.022), however energy intake did not differ between conditions (p=0.429). These results demonstrate the fasted or fed state does not augment post-exercise metabolism following acute SIT in a way that would favour fat loss following training.

- Energy expenditure was similar between conditions, while fat oxidation was significantly greater in FED at 3 h post-exercise
- Appetite perceptions were significantly lower in FED, however energy intake was not different between conditions
- Current findings suggest that performing SIT in the fed or fasted state would not affect fat loss following training

Keywords:

exercise metabolism; fat metabolism; energy balance; exercise performance; dietary intake; lipid metabolism
Introduction

Only 15% of Canadians are physically active enough to meet the guidelines of accumulating 150 minutes of moderate-to-vigorous physical activity per week (Colley et al. 2011), and an often-cited reason for this is perceived lack of time (Reichert et al. 2007; Stutts 2002). However, the classic sprint interval training (SIT) protocol consists of four repeated 30 s “all-out” sprints interspersed by 4 min of recovery, for a total exercise session of only 16 min (Gibala et al. 2012), which is a significantly reduced time commitment compared to endurance exercise which typically consists of at least 30 min of continuous exercise (Gibala et al. 2006; MacPherson et al. 2011; Trapp et al. 2008). Despite the reduced time commitment, SIT has been shown to produce similar physiological adaptations and health benefits to traditional endurance training (Boutcher 2011; Burgomaster et al. 2008; Burgomaster et al. 2005; Gibala et al. 2006; MacPherson et al. 2011), including reductions in fat mass (Hazell et al. 2014; MacPherson et al. 2011). Even the modified SIT protocol of 8 x 15 sec sprints followed by 2 min of recovery that maintains the same work:rest ratio has been shown to be successful in eliciting the same acute (Islam et al. 2017a) and chronic (McKie et al. 2018; Yamagishi and Babraj 2017) responses as the traditional protocol. Therefore, SIT can be thought of as a potential time efficient approach to reduce fat mass over time. The potential mechanisms involved in this reduced fat mass include increases in excess post-exercise oxygen consumption (EPOC) (Hazell et al. 2012; Islam et al. 2017a; Laforgia et al. 1997; Townsend et al. 2013), fat oxidation (Boutcher 2011; Burns et al. 2012; Chan and Burns 2013; Islam et al. 2017a), and appetite suppression (Hazell et al. 2017; Islam et al. 2017a; Williams et al. 2013).

EPOC is the increased oxygen utilized post-exercise compared to resting levels (Gaesser et al. 1984). Due to it’s supramaximal intensity, SIT has been shown to lead to elevated EPOC
compared to control conditions (Burns et al. 2012; Chan et al. 2013; Hazell et al. 2012; Islam et al. 2017b; Islam et al. 2017a; Townsend et al. 2014; Williams et al. 2013) and traditional endurance exercise (Laforgia et al. 1997; Townsend et al. 2013). EPOC translates to elevated energy expenditure, which would contribute to generating an energy deficit and potentially lead to a decrease in fat mass. Fat oxidation has also been shown to be elevated during the recovery period after a bout of moderate-intensity endurance exercise (Bielinski et al. 1985; Horton et al. 1998; Kuo et al. 2005) and SIT can lead to similar (Williams et al. 2013), if not greater elevations (Burns et al. 2012; Chan and Burns 2013; Islam et al. 2017a), which could contribute to decreases in fat mass following training.

Another mechanism behind fat loss following SIT is appetite suppression. There is a general consensus that moderate-intensity exercise does not increase energy intake with a recent review suggesting a bout of SIT can lead to acute appetite suppression and subsequently similar or lower energy intake compared to both control conditions and endurance exercise (Taylor et al. 2018). Therefore, decreased appetite perceptions as well as no changes in energy intake following a bout of SIT can act to maintain the negative energy balance achieved through exercise to help promote body fat loss.

It is apparent that the work done during a bout of SIT provides a stimulus that creates an energy deficit through the mechanisms mentioned above, and thus it is important to investigate how they can be altered in a way that would further enhance fat mass loss. One method of achieving this is through manipulation of the pre-exercise meal. It has been well established that ingesting a carbohydrate-rich meal prior to low-intensity endurance exercise decreases fat oxidation during exercise (Coyle et al. 1997; Horowitz et al. 1997; Jeukendrup 2003; Spriet 2014; Vieira et al. 2016). However, there is a lack of research on how feeding before exercise affects
post-exercise metabolism, and of the evidence that does exist the results are inconclusive. Feeding before exercise resulted in higher EPOC and post-exercise fat oxidation at 12 and 24 h post-exercise (Paoli et al. 2011), however these findings may be due to a pre-exercise meal with high fat content. In contrast, when the pre-exercise meal consisted of mainly carbohydrates, 24 h accumulated fat oxidation was higher when exercising fasted (Shimada et al. 2013). Lack of standardization in feeding protocols significantly limits the ability to interpret results and work toward a conclusion as to how a pre-exercise meal influences post-exercise metabolism. Additionally, there has been little work done on the effects of fasted and fed exercise on appetite perceptions, however some research demonstrates exercising in the fed state enhances the appetite supressing effects of exercise (Cheng et al. 2009; Deighton et al. 2012).

Overall, it is apparent that SIT influences EPOC, fat oxidation, and appetite perceptions in a way that produces an energy deficit. The potential that these physiological responses can be further altered through the ingestion of a pre-exercise meal indicates that SIT and energy intake can potentially interact to enhance the energy deficit generated following exercise. However, the aforementioned work studied endurance exercise only, thus more research is needed to examine this effect on post-exercise metabolism following SIT. Therefore, we investigated the effects of a pre-exercise meal on indices of performance, whole-body metabolism, and appetite following a bout of modified SIT (8 x 15 sec sprints). We hypothesized that EPOC will be higher, fat oxidation will be lower, and appetite perceptions will be further suppressed when SIT is performed after a meal versus in the fasted state.
Methods

Participants

Ten recreationally active males (age 18-24 y) were recruited to participate in this study. Number of subjects needed was estimated based on power calculations using G Power as well as based on previous studies using similar protocols and participants (Islam et al. 2017a). Participants were non-smokers and healthy as assessed by the Physical Activity Readiness Questionnaire (PAR-Q+) health questionnaire (Bredin et al. 2013). All participants were classified as physically active (exercising ~3 times/week), and none were currently involved in a systematic training program nor had been for at least 4 months prior to data collection. Participants were not taking any dietary supplements at the time of the study. The experimental procedures were explained in detail to all participants and all provided written informed consent before any data collection. The Research Ethics Board at Wilfrid Laurier University approved this study in accordance with the ethical standards of the 1964 Declaration of Helsinki.

Study Design

Participants completed two experimental sessions (~5 h each), in a randomized cross-over design, during which oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), heart rate (HR), and appetite perceptions were measured. Experimental sessions consisted of one session where exercise was performed in the fasted state (FAST), and one session where exercise was performed in the post-prandial state (FED). Sessions were separated by at least 7 days and administered in a counterbalanced randomized design to avoid learning effects. Participants were instructed to refrain from physical activity, alcohol, and caffeine 24 h before each session. Participants recorded their food intake the day before the first experimental session and replicated this intake for the second session.
Pre-Experimental Procedures

All participants completed a laboratory familiarization session (>2 days) before data collection to introduce testing procedures and reduce any learning effects during subsequent experimental sessions. Participants first had their height and weight measured using a ‘Health o-meter professional’ scale (Newell Brands Inc, GA, USA). Participants also had their VO$_{2\max}$ determined using a graded exercise test to exhaustion performed on a motorized treadmill (4Front, Woodway, WI, USA). VO$_2$ and VCO$_2$ were measured continuously using an online breath-by-breath gas collection system (MAX-II; AEI Technologies, PA, USA), which was calibrated with gases of known concentrations and a 3-L syringe for flow. Following a 5-min treadmill warm-up, each participant ran at a self-selected pace (5–6.5 m·h$^{-1}$ or 8–10 km·h$^{-1}$) with incremental increases in grade (2%) applied every 2 min until volitional fatigue. HR was recorded beat-to-beat throughout the test using an integrated HR monitor (FT1; Polar Electro, Que., Canada). VO$_{2\max}$ was taken as the greatest 30-s average in presence of a plateau in VO$_2$ values (<1.35 mL·kg$^{-1}$·min$^{-1}$ increase) despite increasing workload, or 2 of the following criteria: (i) a respiratory exchange ratio (RER) value >1.10, (ii) achievement of a HR$_{\max}$ (<10 beats·min$^{-1}$ of age-predicted maximum (220 – age), and/or (iii) voluntary exhaustion. After a 5-min cooldown followed by sufficient rest (>20 min), participants completed a VO$_2$ verification test as recommended by Poole & Jones (2017), where the participant performed a constant work rate at ~110% of the work rate achieved on the initial ramp test to verify that VO$_{2\max}$ was obtained during the ramp test. After another period of rest, participants practiced all-out running efforts on a specialized self-propelled treadmill (HiTrainer, QC, Canada) on which all the exercise sessions would be performed.

Experimental Session
Participants arrived at 0745 h after an overnight (>12 h) fast. They remained in the laboratory for the next ~5 h (Figure 1). Participants were fitted with a HR monitor (Polar FT1, Polar Electro, Que., Canada) and silicon facemask (Vmask, Hans Rudolph Inc., KS, USA) for the continuous measurement of gas exchange ($\dot{V}O_2$ and $\dot{V}CO_2$) from 0745–0815 h. In the FED session, participants were given a standardized breakfast at 0815 h and had 15 min to eat and 60 min to digest. The breakfast consisted of an appropriate amount of Clif bar(s) (7 kcal/kg, 0.14g/kg fat, 1.3 g/kg carbohydrate, and 0.25 g/kg protein) and >500 mL of water. In the FAST session, participants sat quietly for 75 min. From 0930-0955 h participants completed the SIT session. Gas exchange was measured during exercise, as well as the 30 min following exercise. The participants in the FAST session then consumed the same standardized breakfast, while participants in the FED session sat quietly. For the ~3.5 h following exercise, participants sat quietly while gas exchange was measured for 15 min at every hour post-exercise. Finally, appetite perceptions were measured when participants were still fasted, and then subsequently pre-exercise, immediately post-exercise, as well as 30 min, 1 h, 2 h, and 3 h post-exercise.

**Exercise Protocol**

All exercise protocols began with a 5-min warm-up at a self-selected pace followed by a 16 min SIT session and 4 min cool-down. The warm-up and cool-down were performed on a motorized treadmill (Woodway 4Front), while SIT was performed on a specialized self-propelled treadmill (HiTrainer). The SIT session consisted of 8 x 15 sec all-out sprints interspersed with 2 min of recovery (Islam et al. 2017a; McKie et al. 2018). The treadmill interface provides audio prompting to begin and stop running bouts and verbal encouragement was provided for the entirety of all sprints.
Customized treadmill software recorded the speed (m·s\(^{-1}\)) attained during each sprint in 0.5 s intervals. Performance was measured in terms of peak speed, average speed, minimum speed, and fatigue index, during the SIT session. Fatigue index was calculated using the following formula:

\[
FI (\%) = \left( \frac{\text{peak speed} - \text{minimum speed}}{\text{peak speed}} \right) \times 100
\]

Reproducibility was calculated using the following formula:

\[
\text{Reproducibility} (\%) = \left( \frac{\text{average speed}}{\text{peak speed}} \right) \times 100
\]

\(\dot{V}O_2\)

\(\dot{V}O_2\) (L·min\(^{-1}\)) was recorded as 30-s averages over the entire duration of each gas collection period. \(\dot{V}O_2\) during exercise (excluding warm-up and recovery) was taken as the average \(\dot{V}O_2\) over the duration of each SIT protocol (16 min). Post-exercise \(\dot{V}O_2\) was determined by plotting the average \(\dot{V}O_2\) at each time-point (30 min post-exercise and the last 15 min of the first, second, and third h post-exercise) and calculating the area under the curve (AUC) using the trapezoid method. The rate of \(\dot{V}O_2\) was multiplied by the duration of each distinct gas collection period to obtain total \(\dot{V}O_2\) (L). The immediate 30 min post-exercise measurement was included as part of the first post-exercise hour \(\dot{V}O_2\) calculation. Total \(\dot{V}O_2\) during the 30 min resting measure was extrapolated to a duration of 3 h and subsequently subtracted from the total post-exercise \(\dot{V}O_2\) in order to calculate EPOC. Total EE (kcal) was calculated from total \(\dot{V}O_2\) (L) during and post-exercise, assuming 5 kcal per litre \(O_2\) consumed given the limitations of using RER during exhaustive, non-steady-state exercise (Laforgia et al. 1997).

**Fat Oxidation**

The rate of fat oxidation was calculated during each hour post-exercise using the following formula (Péronnet and Massicotte 1991):
Fat oxidation = 1.695 × VO₂ − 1.701 × VCO₂ 

where fat is in g·min⁻¹ and VO₂ and VCO₂ are in L·min⁻¹. The 30 min immediately post-exercise gas exchange measure was not included in the calculation for fat oxidation for the first hour post-exercise as CO₂ production was still elevated due to hyperventilation. Consequently, the 15 min gas exchange measure at the end of the first hour post-exercise was averaged and extrapolated for the full hour.

Appetite Perceptions

Subjective appetite and satiety ratings were assessed in the fasted state, pre-exercise, immediately post-exercise, as well as 1, 2, and 3 h post-exercise using the Visual Analogue Scale (VAS). Questions on the VAS pertain to participants’ feelings of fullness (i.e. “How full do you feel?”), hunger (i.e. “How hungry do you feel?”), and food consumption (i.e. “How much do you think you can eat?”). Values for satiety and fullness were inverted, and then averaged together with values for hunger and prospective energy intake to obtain an overall appetite score. AUC was then calculated using the trapezoid method using changes in overall appetite perceptions relative to baseline values.

Energy Intake

Participants recorded their energy intake via dietary food logs for the day prior to, day of, and day after both experimental sessions. Participants were instructed to replicate their food intake the day prior to each experimental session. Energy intake was then to be compared between sessions for the remainder of the day following the experimental session as well as the next day to examine potential differences in subsequent energy intake between feeding or fasting conditions. Additionally, each day of energy intake was analyzed to determine the percent calories contributed from each macronutrient (carbohydrates, protein, and fat). Food logs were analyzed using the
United States Department of Agriculture (USDA) food composition database, which provides caloric and macronutrient values for various food products.

Statistical Analysis

Two-way repeated measures ANOVA was used to determine differences in performance variables (session (2) x sprint (8)), heart rate (session (2) x time (6)), RER (session (2) x time (6)), energy expenditure (session (2) x time (5)), fat oxidation (session (2) x time (5)), appetite perceptions (session (2) x time (7)), energy intake (session (2) x day (3)), and macronutrient composition (session (2) x day (3)). Paired t-tests were used to determine differences between sessions in total energy intake, total post-exercise fat oxidation, and index of decrease in appetite perceptions. Additionally, a paired t-test was also used to compare energy intake and macronutrient composition the day before the experimental trial of both sessions. All statistical analyses were performed on Prism statistics software (GraphPad Software, San Diego, CA), and Bonferroni post hoc analyses were used when necessary. Significance was set at p<0.05, and all data is presented as means±SD.

Effect sizes were calculated using Cohen’s $d$ for all t-tests and post hoc comparisons, whereas partial eta-squared ($\eta_p^2$) was used to calculate Cohen’s $f$ for interaction and main effects of all two-way ANOVAs using the following equation:

$$\text{Cohen’s } f = \sqrt{\frac{\eta_p^2}{1-\eta_p^2}}$$

For Cohen’s $d$, 0.2 indicated a small effect size, 0.5 indicated a medium effect size, and 0.8 indicated a large effect size, whereas for Cohen’s $f$, 0.1 indicated a small effect size, 0.25 indicated a medium effect size, and 0.4 indicated a large effect size.

Results

Participant Characteristics
Participants were 21.3±2.0 y with a VO\textsubscript{2max} of 48.31±3.49 mL·kg\textsuperscript{-1}·min\textsuperscript{-1}, a body mass of 83.3±7.8 kg, a height of 180.2±5.2 cm, and a body mass index (BMI) of 25.7±2.9 kg/m\textsuperscript{2}. All participants were healthy as assessed by the PAR-Q+ and classified as recreationally active based on the Godin leisure scale.

**Performance**

There was no session x time interaction for any performance variable (p>0.450). There were also no main effects of condition (p=0.442, f=0.07, no effect) or sprint bout number for fatigue index (p=0.212, f=0.27, medium). However, there was a significant main effect of sprint bout number for peak speed (p<0.001, f=0.67, large), minimum speed (p=0.001, f=0.43, large), and average speed (p<0.001 f=0.64, large), which is depicted in Figure 2.

There was no significant session x time interaction for heart rate (p=0.369, f=0.23, small) and no main effect of session (p=0.980, f<0.01), though there was a significant main effect of time (p<0.001, f=2.5, large) where heart rate was significantly higher (p<0.001, d>2.55, large) during exercise (FAST: 140±17 bpm, FED: 149±10 bpm) than all other time points (FAST: rest = 64±10 bpm, 0.5 h = 98±14 bpm, 1 h = 85±7 bpm, 2 h = 79±9 bpm, 3 h = 70±8 bpm, FED: rest = 64±9 bpm, 0.5 h = 102±9 bpm, 1 h = 81±17 bpm, 2 h = 73±11 bpm, 3 h = 67±12 bpm). Additionally, heart rate was significantly elevated (p<0.031, d>0.54, medium) at 30 min (FAST: 98±14 bpm, FED: 102±9 bpm), 1 h (FAST: 85±7 bpm, FED: 81±17 bpm), and 2 h post-exercise (FAST: 79±9 bpm, FED: 73±11 bpm) compared to rest (FAST: 64±10 bpm, FED: 64±9 bpm).

**Oxygen Consumption**

There was no significant difference in total oxygen consumed between sessions (p=0.579, d=0.18, no effect; FAST: 100.8±14.9 L O\textsubscript{2}, FED: 103.0±11.0 L O\textsubscript{2}). Additionally, there was no significant session x time interaction for VO\textsubscript{2} (p=0.363, f=0.25, medium). There was no main
effect of session (p=0.705, f=0.02, no effect), though there was a significant main effect of time (p<0.001, f=0.21, small) where VO₂ was significantly greater (p<0.001, d>1.06, large) during exercise (FAST: 28.3±4.4 L O₂, FED: 28.8±4.2 L O₂) than all other time points (FAST: rest = 8.6±1.1 L O₂, 1 h = 23.8±2.8 L O₂, 2 h = 20.3±4.4 L O₂, 3 h = 19.8±3.8 L O₂; FED: rest = 8.6±0.7 L O₂, 1 h = 25.8±3.3 L O₂, 2 h = 20.7±2.7 L O₂, 3 h = 19.1±2.1 L O₂). Additionally, VO₂ during rest was significantly lower than all time points (p<0.001, d>5.63, large), and 1 h post-exercise (FAST: 23.8±2.8 L O₂, FED: 25.8±3.3 L O₂) was significantly (p<0.001, d>2.78, large) greater than 2 h (FAST: 20.3±4.4 L O₂, FED: 20.7±2.7 L O₂) and 3 h post-exercise (FAST: 19.8±3.8 L O₂, FED: 19.1±2.1 L O₂). Finally, there was no significant difference in EPOC between sessions (p=0.379, d=0.29, small; FAST: 12.3±5.7 L O₂, FED: 14.2±5.5 L O₂) (Figure 3a).

Energy Expenditure

There was no significant difference in total energy expended between sessions (p=0.798, d=0.18, no effect; FAST 504.0±74.3 kcal, FED: 514.8±54.9 kcal) (Figure 3b). Additionally, there was no significant session x time interaction for energy expenditure (p=0.408, f=0.25, medium) and no main effect of session (p=0.751, f=0.13, small). There was a significant main effect of time (p<0.001, f=3.78, large) (Figure 3c) where energy expenditure was significantly greater (p<0.001, d>1.27, large) during exercise (FAST: 141.3±21.8 kcal, FED: 143.0±20.8 kcal) than all other time points (FAST: rest = 43.1±5.6 kcal, 1 h = 119.1±14.2 kcal, 2 h = 101.3±22.0 kcal, 3 h = 98.6±18.9 kcal, FED: rest = 42.9±3.5 kcal, 1 h = 127.9±16.9 kcal, 2 h = 101.7±14.9 kcal, 3 h = 94.3±11.7 kcal). Additionally, energy expenditure at rest was lower (p<0.001, d>5.63, large) compared to all time points. Energy expenditure was significantly greater (p<0.001, d>2.78, large) at 1 h post-exercise (FAST: 119.1±14.2 kcal, FED: 127.9±16.9 kcal) than 2 h (FAST: 101.3±22.0 kcal, FED: 101.7±14.9 kcal) and 3 h post-exercise (FAST: 98.6±18.9 kcal, FED: 94.3±11.7 kcal).
Fat Oxidation

When fat oxidation was averaged across the total post-exercise period, there was no significant difference (p=0.198, $d=0.44$, small) between sessions (FAST: $0.105\pm0.04 \text{ g\cdot min}^{-1}$ vs FED: $0.123\pm0.02 \text{ g\cdot min}^{-1}$) (Figure 4a). There was no significant session x time interaction for fat oxidation (p=0.063, $f=0.38$, medium) (Figure 4b), however there was a main effect of time (p<0.001, $f=0.69$, large) where 1 h ($0.132\pm0.05 \text{ g\cdot min}^{-1}$), 2 h ($0.121\pm0.04 \text{ g\cdot min}^{-1}$), and 3 h ($0.090\pm0.03 \text{ g\cdot min}^{-1}$) post-exercise were significantly greater than rest ($0.065\pm0.02 \text{ g\cdot min}^{-1}$) (p<0.004, $d>1.18$, large). Additionally, 1 h post-exercise ($0.132\pm0.05 \text{ g\cdot min}^{-1}$) was significantly higher than 2 h ($0.121\pm0.04 \text{ g\cdot min}^{-1}$) and 3 h post-exercise ($0.090\pm0.03 \text{ g\cdot min}^{-1}$) (p<0.001, $d>2.36$, large), and 2 h post-exercise ($0.121\pm0.04 \text{ g\cdot min}^{-1}$) was significantly greater than 3 h post-exercise ($0.090\pm0.03 \text{ g\cdot min}^{-1}$) (p=0.002, $d=2.21$, large).

There was a significant session x time interaction for RER (p=0.022, $f=0.39$, medium) (Figure 4c). In both sessions, RER was significantly higher (p<0.001, $d>4.46$, large) during exercise (FAST: $1.29\pm0.10$, FED: $1.29\pm0.20$) than all other time points (FAST: rest = $0.87\pm0.04$, 0.5 h = $0.81\pm0.09$, 1 h = $0.73\pm0.05$, 2 h = $0.88\pm0.03$. 3 h = $0.86\pm0.04$, FED: rest = $0.87\pm0.19$, 0.5 h = $0.85\pm0.04$, 1 h = $0.74\pm0.03$, 2 h = $0.81\pm0.02$, 3 h = $0.78\pm0.01$). In the FAST session, RER at 1 h post-exercise ($0.73\pm0.05$) was significantly lower (p<0.001, $d=4.42$, large) than rest ($0.87\pm0.04$), 2 h post-exercise ($0.88\pm0.03$), and 3 h post-exercise ($0.86\pm0.04$). In the FED session, RER at 1 h post-exercise ($0.74\pm0.03$) was significantly lower (p=0.008, $d>0.62$, medium) than rest ($0.87\pm0.19$) and 0.5 h post-exercise ($0.85\pm0.04$), and 3 h ($0.78\pm0.01$) was significantly lower (p=0.050, $d=5.21$, large) than rest ($0.87\pm0.19$). Additionally, RER at 3 h post-exercise was significantly lower (p=0.040, $d=2.44$, large) in the FED session ($0.78\pm0.01$) compared to the FAST
There was no significant difference (p=0.759, d=0.1, no effect) in absolute values for overall appetite perceptions between sessions at baseline (FAST: 75.8±11.1 mm vs FED: 77.8±19.3 mm). There was a significant interaction effect (session x time) for overall appetite perceptions (p<0.001, f=0.80, large) (Figure 5a). Relative to baseline values, overall appetite perceptions were lower (p<0.004, d>1.28, large) at pre-exercise (-38.6±23.3 mm), post-exercise (-38.4±20.1 mm), 30 min post-exercise (-35.5±26.2 mm), and 1 h post-exercise (-19.8±15.5 mm) in the FED session. In the FAST session, overall appetite perceptions were only lower (p<0.001, d=1.89, large) than baseline at 1 h post-exercise (-34.5±23.8 mm), and 1 h post-exercise was significantly lower than all other time points (p<0.001, d>0.81, large). Appetite perceptions immediately post-exercise (69.4±29.2 mm) were significantly lower (p=0.003, d=0.67, medium) than pre-exercise (84.6±13.5 mm) in the FAST session, but not the FED session (pre-exercise: 39.2±17.9 mm vs post-exercise: 39.4±15.3 mm; p=0.977, d=0.01, no effect).

FED had lower appetite than FAST at pre-exercise (39.2±17.9 mm vs. 84.6±13.5 mm), immediately post-exercise (39.4±15.3 mm vs. 69.4±29.2 mm), and 30 min post-exercise (39.4±15.3 mm vs. 79.5±21.6 mm; p<0.001, d>1.38, large). There were no significant differences (p>0.077, d<0.82, large) in appetite between sessions at 1 h (FED: 58.0±13.3 mm, FAST: 41.3±16.1 mm), 2 h (FED: 71.1±10.5 mm, FAST: 62.9±16.8 mm) or 3 h (FED: 83.6±7.4 mm vs. 79.4±11.6 mm) post-exercise. The AUC for overall appetite perceptions was significantly lower (p=0.022, d=0.87, large) in the FED session (-4815.0±4098.7 mm) compared to the FAST session (-707.5±2010.4 mm) (Figure 5b).
Running Head: Pre-exercise meal and sprint interval training

Energy Intake

There was no significant difference (p>0.238, d<0.14, no effect) in energy intake (FAST: 2187.8±263.4 kcal vs FED: 1953.2±526.3 kcal) or macronutrient composition (FAST: protein = 20.58±5.65%, fat = 30.57±6.06%, carbohydrate = 49.02±6.55% vs FED: protein = 23.18±8.55%, fat = 29.39±5.46%, carbohydrate = 47.69±9.89%) on the day before the experimental session between sessions.

Additionally, there was no significant session x day interaction for energy intake (p=0.429, f=0.23, small). There was no significant main effect of session (p=0.960, f=0.02, no effect), though there was a significant main effect of day (p=0.013, f=0.56, large) where energy intake was significantly higher (p=0.013, d=0.42, small) on the day of the experimental session (2644.3±859.7 kcal) than the day before the experimental session (1953.2±526.3 kcal). There was no significant interaction (p>0.205, f=0.13, small) or main effect of session (p>0.341, f=0.11, small) or day (p>0.081, f=0.23, small) for macronutrient composition (Table 1).

Discussion

This study examined the effects of a pre-exercise meal before a bout of modified SIT on indices of performance, whole-body energy metabolism, appetite, and energy intake. Whether SIT was performed in the fed or fasted state had no effect on sprint performance, energy expenditure, or fat oxidation during exercise. Post-exercise energy expenditure and fat oxidation remained similar between conditions for 3 h. Overall appetite perceptions were significantly lower in FED vs FAST, however, energy intake was not significantly different. Overall, these post-exercise measurements have the potential to be important to fat loss following training, however these results suggest that fasting or feeding prior to performing a bout of SIT has little influence.
No differences in performance were apparent whether performing the modified SIT session in the fasted or fed state. In contrast, previous research regarding aerobic exercise generally finds that feeding 2-4 h before exercise improves time trial and time to exhaustion performance by ~2% and ~20%, respectively (Chen et al. 2009; Ormsbee et al. 2014; Sherman et al. 1991), which is likely due to increased glycogen availability (Coyle et al. 1985). While an overnight fast significantly reduces glycogen stores in the liver, and consequently has a negative impact on endurance performance (Coyle et al. 1985), the modified SIT protocol relies on the PCr system more than muscle and liver glycogen for energy (Bogdanis et al. 1996; Bogdanis et al. 1998).

Considering the pre-exercise meal would act to replenish glycogen stores with no effect on the PCr system, and sprints rely heavily on PCr for energy production, it is logical that performing SIT in either the fed or fasted state would have no influence on sprint performance.

Oxygen consumption, and thus energy expenditure, was elevated compared to rest through the entire 3 h post-exercise period, indicating that significant EPOC was present in response to a modified SIT protocol (Islam et al. 2017a). The EPOC was 12.3 and 14.1 L in FAST and FED, respectively, in line with previous research with similar populations (Chan and Burns 2013; Islam et al. 2017a; Townsend et al. 2014; Williams et al. 2013). Total energy expenditure in both FAST and FED (504.0 and 504.8 kcal, respectively) was also similar to energy expenditure observed in previous studies with similar participants and protocols (Chan and Burns 2013; Islam et al. 2017a). However, whether SIT was performed in either the fed or the fasted state had no influence on EPOC or energy expenditure in the post-exercise period. This indicates that regardless of whether SIT is performed in the fed or fasted state, the increases in energy expenditure are similar, therefore energy expenditure would not contribute to greater fat loss following training in either state. The lack of differences in energy expenditure could be due to the relatively minor contribution of
EPOC – 12.3 L (12.2%) and 14.2 L (13.8%) in FAST and FED, respectively – to total oxygen consumption (Laforgia et al. 1997). Although the contribution of EPOC may seem small, oxygen consumption was still elevated 2.6 L (14.6%) in FAST and 1.9 L (11.3%) in FED 3 h post-exercise compared to rest. Consequently, an additional 12.6 and 9.6 kcal, in FAST and FED respectively, was being expended 3 h post-exercise. It has been shown that SIT can produce significant EPOC up to 9 (Laforgia et al. 1997) and even 24 h post-exercise (Hazell et al. 2012; Sevits et al. 2013) in similar populations, suggesting the duration of EPOC observed in the current study may continue beyond 3 h post-exercise could have important implications for weight loss and potential differences between FAST and FED.

Fat oxidation was elevated by >60% compared to rest during the post-exercise period, which is in line with previous research regarding fat oxidation and SIT (Burns et al. 2012; Chan and Burns 2013; Islam et al. 2017a; Williams et al. 2013). Although research shows that exercising in the fasted state leads to greater fat oxidation during endurance exercise than the fed state (Coyle et al. 1997; Horowitz et al. 1997; Jeukendrup 2003; Spriet 2014; Vieira et al. 2016), it is not possible to measure fat oxidation during or immediately after SIT with gas exchange due to hyperventilation and increased VCO₂ (Hazell et al. 2014). Additionally, research has shown that at exercise intensities above 60% VO₂max there are no differences in fat oxidation between exercise performed in the fed or fasted state (Bergman and Brooks 1999; Vieira et al. 2016). Therefore, as SIT is a supramaximal exercise regimen that relies mainly on carbohydrate oxidation for energy production (Brooks and Mercier 1994), it is likely that there would be no differences in fat oxidation during exercise when performing it in the fed or fasted state.

It is important to note that though fat oxidation appeared similar between FED and FAST throughout the 3 h post-exercise period (interaction not significant), it was tending toward...
significance with a p-value of 0.063 and had a moderate-high effect size ($f=0.38$). This was likely
driven by the difference in fat oxidation at 3 h post-exercise, with FED oxidizing $0.041 \text{ g.min}^{-1}$
more than FAST, which had a large effect size ($f=1.53$). Consequently, 6.6 g of fat was oxidized
in FED whereas only 4.1 g of fat was oxidized in FAST, producing a difference of 2.5 g of fat over
the hour. Although energy expenditure was similar, 63% of energy was derived from fat in FED,
whereas fat only contributed 37.4% to energy expenditure in FAST. However, this difference may
be due to the standardized breakfast which was carbohydrate dense, consequently increasing
carbohydrate oxidation and suppressing fat oxidation (Whitley et al. 1997). At 3 h post-exercise,
participants in the fed condition ate ~ 4.5 h ago, whereas participants in the fasted condition ate
only ~ 2.5 h ago, thus a more recent meal may have acted to suppress fat oxidation in FAST. This
could have important implications for fat loss following SIT if individuals are able to delay food
consumption >3 h post-exercise. However, whether it is practical or feasible for individuals to
wait more than three hours after exercise to consume a post-exercise meal is debateable.

Prolonging a post-exercise meal to >3 h post-exercise may be possible, as appetite has been
shown to be significantly suppressed following a bout of SIT (Deighton et al. 2013; Hazell et al.
2017; Islam et al. 2017a). Additionally, research regarding the effects of fed and fasted exercise
on appetite perceptions have also noted the appetite suppressing effects of exercise in either state
(Cheng et al. 2009; Deighton et al. 2012; Gonzalez et al. 2013). In line with these propositions,
appetite perceptions in FAST and FED at 0.5 h post-exercise did not increase from pre-exercise
perceptions like they do in control or moderate-intensity continuous exercise conditions (Islam et
al., 2017b), demonstrating appetite suppression.

Appetite perceptions returned to baseline in both FAST and FED by 2 h post-exercise,
however the index of decrease was significantly greater in FED than FAST, indicating that more
time was spent with appetite perceptions below baseline values. This was evident through appetite perceptions being lower than baseline from pre-exercise through to 2 h post-exercise in FED, whereas appetite perceptions were only lower than baseline at 1 h post-exercise in FAST, illustrating a greater suppression of appetite when exercising in the fed state. This indicates that the pre-exercise meal may interact with the exercise bout to maintain appetite-suppression for longer into the post-exercise period, leading to overall greater suppression of appetite experienced in the FED.

Appetite perceptions returned to baseline levels in both conditions at 2 h post-exercise. This is important, as it is likely that participants would have eaten at this time if they were permitted to. If a meal was consumed at 2 h post-exercise, then the elevated fat oxidation observed at 3 h post-exercise in the FED would have been suppressed and no longer significant. Therefore, appetite perceptions at 2 h post-exercise suggest that individuals may not be able to wait >3 h before consuming a post-exercise meal, and consequently would not benefit from the elevated fat oxidation at this time.

Ideally, for differences in appetite perceptions to play a role in fat loss following exercise training, there would need to be a link between perceptions and energy intake such that an energy deficit is induced. However, there were no differences in energy intake between conditions on either the day before, day of, or day following exercise, therefore suggesting that decreased appetite perceptions in FED would not contribute to an increased energy deficit and consequently fat loss following continued training. These discrepant findings are potentially due to the difficulties in measuring free-living energy intake, as the subjective nature of the food logs used to measure energy intake can lead to large variability in energy intake data between and within
participants, thus potentially providing inconsistent and inaccurate results (Dhurandhar et al. 2015).

Although energy intake was not affected throughout the remainder of the day following exercise, it is possible that due to differing appetite perceptions during the experimental session, administration of an ad libitum meal post-exercise may have led to significant findings related to energy intake between conditions. However, in studies utilizing an endurance exercise protocol followed by an ad libitum lunch, there were no significant differences in energy intake whether exercise was performed in the fed or fasted state, despite differences in appetite perceptions (Deighton et al. 2012; Farah et al. 2013; Gonzalez et al. 2013). Overall, despite appetite perceptions being significantly lower following exercise in the fed state, there are no differences in energy intake that would contribute to a greater energy deficit post-exercise, and consequently greater fat loss following continued training.

The overall lack of difference in post-exercise metabolism following a bout of SIT in either the fasted or fed state indicates that performing exercise in either state would lead to a similar energy deficit. Therefore, superior fat loss following continued training in either the fasted or fed state would not occur. However, it is important to note that the current study was acute in nature, and it is possible that continued training could lead to varying adaptations between FAST and FED that would contribute to altered fat loss. For example, enzymes such as citrate synthase, β-hydroxyacyl-CoA dehydrogenase (βHAD), and plasma membrane fatty acid-binding protein (FABPpm), have been shown to be elevated following continued sprint interval training (Burgomaster et al. 2008; Burgomaster et al. 2005a; Jacobs et al. 1987; Rodas et al. 2000; Talanian et al. 2007). The current study did not examine activity of these enzymes, and therefore it is possible that performing SIT in the fasted or fed state may alter these adaptations in a way that
would favour greater fat loss following training without any acute changes in fat oxidation immediately post-exercise (<3 h). However, previous research has shown that 6 weeks of both fasted and fed HIIT led to significant fat loss in overweight women, with no difference between groups (Gillen et al. 2013). Although a similar training study has not been done using a SIT protocol, based on the findings of the current study, it is likely that similar results would occur.

Although the current study provides important insights to the effects of fed state on post-exercise metabolism important to fat loss, there are some limitations that must be considered. First, energy intake was measured via self-reported food logs. Although participants were instructed on how to measure and record food intake accurately, it is difficult to determine the extent to which the food log accurately represents the actual energy intake of the participant. Second, the administration of the standardized breakfast post-exercise in the fasted condition confounds the results of post-exercise fat oxidation. Consequently, the difference observed in fat-oxidation 3 h post-exercise is likely due to the post-exercise meal rather than the fed state exercise was performed in. However, providing the standardized breakfast to the fasted condition post-exercise was chosen because it was considered impractical not to allow food intake for > 5 h in the laboratory while performing strenuous exercise. Finally, as the current study involved healthy and active young males, it is difficult to generalize findings to other populations (ie. females, unfit, overweight, sedentary, etc.).

**Conclusion**

In summary, there are no differences in energy expenditure or energy intake following a bout of SIT in either the fasted or fed state. Although fat oxidation and appetite perceptions were altered following exercise in a way that would favour fat loss following training in the fed
condition, it is difficult to determine if these changes are meaningful enough to produce significantly more fat loss following continued training. These findings have important implications for the general fitness community, as it is often recommended to perform fasted exercise to improve fat loss. While evidence suggests that this may be the case for moderate-intensity endurance exercise, the current study shows that fasted SIT would provide little benefit to fat loss when performing high-intensity exercise. This indicates that individuals would be able to perform SIT in either the fed or fasted state, whichever is most comfortable for them, without sacrificing potential benefits to fat loss.

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Conflict of Interest

The authors have no conflicts of interest to report.
Running Head: Pre-exercise meal and sprint interval training

References


Running Head: Pre-exercise meal and sprint interval training


Running Head: Pre-exercise meal and sprint interval training


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Running Head: Pre-exercise meal and sprint interval training

Figure 1: Experimental session timeline

Figure 2: A: Peak speed across sprint bouts. *, significantly greater than sprints four, five, six, seven, and eight. B: Average speed across sprint bouts. *, significantly lower than sprint 1. ^, significantly lower than sprint 2. C: Minimum speed across sprint bouts. *, significantly lower than sprint 1. D: Fatigue index across sprint bouts.

Figure 3: A: Total litres of O\textsubscript{2} consumed and EPOC (checkered areas) over the entire 3 h post-exercise period. B: Total energy expenditure across the duration of the session in both experimental conditions. C: Changes in energy expenditure across all time points in both experimental conditions. *, significantly greater than rest. #, significantly lower than 1 h. ^, significantly greater than all other time points.

Figure 4: A: Total fat oxidation across the duration of the post-exercise period in both experimental conditions. B: Changes in fat oxidation across all time points in both experimental conditions. *, significantly greater than rest. ^, significantly lower than 1 h post-exercise. C: Respiratory exchange ratio across time in both experimental conditions. *, significantly greater than all other time points. ^, significantly lower than rest. #, significantly lower than 2 h and 3 h post-exercise. $, FED significantly lower than FAST.

Figure 5: A: Changes in overall appetite perceptions across all time points relative to baseline. * significant difference between FED and FAST. ^, significantly lower than baseline. B: Index of decrease in overall appetite perceptions in both conditions. *, p<0.05 vs. FAST.
Figure 1: Experimental session timeline

380x137mm (72 x 72 DPI)
a) 35 of 38

b) 20  

Fat oxidation (g/minute)

(c) Respiratory exchange ratio

**Fast Post-exercise Fat Oxidation (g/minute)**

- **REST 1 h 2 h 3 h**
- **Time**
- **Fat oxidation**
- **FAST**
- **FED**

**Respiratory Exchange Ratio**

- **FED**
- **FAST**

References (a, b, c)
Change in overall appetite (mm) relative to baseline

Condition

Index of decrease in overall appetite perceptions

a) b)
**Table 1**: Energy intake (kcal) and macronutrient composition (%) across days and between conditions

<table>
<thead>
<tr>
<th></th>
<th>Day 1 (before)</th>
<th>Day 2 (exercise)</th>
<th>Day 3 (after)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FAST</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy intake (kcal)</td>
<td>2187.8±263.4</td>
<td>2519.8±741.0</td>
<td>2196.0±638.5</td>
</tr>
<tr>
<td>PRO (%)</td>
<td>20.6±5.7</td>
<td>19.9±6.9</td>
<td>18.1±7.0</td>
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<tr>
<td>FAT (%)</td>
<td>30.6±6.1</td>
<td>32.4±3.8</td>
<td>33.7±7.7</td>
</tr>
<tr>
<td>CHO (%)</td>
<td>49.0±6.6</td>
<td>49.0±6.9</td>
<td>48.4±11.1</td>
</tr>
<tr>
<td><strong>FED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy intake (kcal)</td>
<td>1953.2±526.3</td>
<td>2644.3±859.7*</td>
<td>2347±870.0</td>
</tr>
<tr>
<td>PRO (%)</td>
<td>23.2±8.6</td>
<td>17.4±5.6</td>
<td>19.1±6.6</td>
</tr>
<tr>
<td>FAT (%)</td>
<td>29.4±5.5</td>
<td>27.8±5.8</td>
<td>33.9±9.7</td>
</tr>
<tr>
<td>CHO (%)</td>
<td>47.7±9.9</td>
<td>55.9±8.6</td>
<td>47.2±12.7</td>
</tr>
</tbody>
</table>

NOTE: *: significantly different from Day 1 (p<0.05)