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Metabolic and cardiorespiratory acute responses to fasting versus feeding during high-intensity interval training

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Abstract

Purpose The aim of this study was to investigate the effects of sprint interval training (SIT) and feeding state [fasted (FAST) or fed (FED)] on metabolic and cardiorespiratory parameters.

Methods Twelve active men (age 23 ± 3 years; body mass 76.43 ± 4.06 kg; height 175.6 ± 4.98 cm; body mass index 24.78 ± 0.56 kg/m²; VO_{2peak} 52.33 ± 4.87 mL/min/kg) volunteered to participate in this study. Participants completed a 2-week SIT intervention, comprising two randomized sessions (FAST, FED) of three bouts of 30-s Wingate anaerobic sprints on an electromagnetically braked cycle, with 4 min of rest interspersed between bouts. Metabolic and cardiorespiratory assessments were repeated every 10 min during the 1 h post-intervention time period.

Results The rating of perceived exertion was higher in the FAST condition as compared to FED during bout 3 (20 ± 0.0 vs. 19.42 ± 0.51 ; $p \leq 0.05$). There was no difference in peak power, mean power and minimum power during the SIT protocol in FAST and FED conditions. Glucose values were lower 10, 20, 30, 40 and 50 min following SIT than during bouts 1–3 in the FED condition, whereas glucose values remained stable during all time points in the FAST state. Triglycerides and cholesterol remained unchanged following SIT as compared to pre-exercise in both conditions. Compared to pre-exercise, respiratory exchange ratio was higher 10 and 20 min, and lower 40, 50 and 60 min post-exercise in the FAST condition and was higher at all time points in the FED condition.

Conclusions SIT in the fasted state does not decrease muscle performance and increase fat oxidation 30 min post-exercise without optimizing energy expenditure in healthy active men.

Keywords Exercise performance · Fasting condition · Sprint interval training · Wingate

Introduction

Regular physical activity has been associated with reduced risk of morbidity and mortality [1]. However, epidemiological data show that the majority of the adult population fails to meet the recommended physical activity levels [2]. This contributes to the global epidemic of cardiovascular diseases, obesity, diabetes, hypertension and dyslipidemias [3]. One of the main explanations for failure to participate in regular exercise is the perceived lack of time [4].

Consequently, the development of exercise interventions aimed to counteract chronic diseases and to overcome perceived lack of time is of great value to public health. In this sense, high-intensity interval training (HIIT) could potentially provide health benefits in a time-efficient manner and lead to a range of cardiovascular and metabolic benefits that

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are similar or greater in magnitude than those achieved with regular continuous aerobic exercise [5]. An HIIT exercise program involves alternating bouts of intensive exercise with low-intensity recovery periods [6]. The beneficial cardiorespiratory and metabolic effects of HIIT are an important research topic, especially supra-maximal HIIT, such as sprint interval training (SIT) that require maximal effort during short periods of activity [7–10].

Previous studies utilizing SIT protocols (bouts of 30 s of “all-out” cycling against a braking force on a cycle ergometer, 4–6 sprints separated by 4 min of recovery) observed significant improvements on VO_{2max} , skeletal muscle oxidative and glycolytic capacities, endurance performance and muscle metabolism [5, 11–14]. However, these above-mentioned studies were conducted in “fed state”, while some individuals perform their exercise training sessions in the fasted state [15, 16]. Thus, the impact of combining SIT and “fasting state” factors on cardiorespiratory and metabolic parameters needs to be elucidated.

The responses to fuel supply and oxidation during fasting are well documented [15]. For example, fasting before and during exercise is associated with low circulating insulin levels, elevated plasma epinephrine concentrations [17, 18], increased rate of adipose tissue lipolysis, peripheral fat oxidation [19] and reduced availability of blood glucose [17]. Two recent studies using SIT and fasting [20, 21] and previous studies using continuous cycling [22, 23] have observed reductions in blood glucose (GLU) and triglyceride (TG) levels following acute bouts of exercise. In addition, an overnight fast results in reduced glycogen stores, which may further facilitate fat oxidation processes [24, 25]. Whether this metabolic condition modulates performance and rating of perceived exertion (RPE) during SIT has not been addressed.

Therefore, the aim of the study was to compare the effects of fasting versus fed state on metabolic, cardiorespiratory and performance variables during SIT. We hypothesize that SIT in the fasted state triggers physiological responses to facilitate glucose homeostasis, increasing fat utilization during recovery. In this perspective, we believe that performing SIT in the fed state results in a higher reliance on exogenous carbohydrate oxidation during and after exercise, with an improved performance.

Materials and methods

Participants

Twelve men volunteered to participate in this study. The inclusion criteria were as follows: age between 19 and 30 years, health enhancing physical activity (7 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum of at least

3000 MET min/week) assessed by the International Physical Activity Questionnaire [26–28].

The anthropometric, body composition and hemodynamic characteristics of the participants are presented in Table 1.

Experimental design

Participants completed four testing sessions. Briefly, the first visit consisted of baseline anthropometric and hemodynamic measurements. Second, participants performed bioelectrical impedance analysis and completed a test to determine peak oxygen consumption. The third and fourth testing sessions randomly consisted of performing a SIT protocol in a fed (FED) or fasted condition (FAST) separated by 7 days. Data were collected pre-exercise (pre), immediately post-each bout (bout 1, bout 2 and bout 3) and 10, 20, 30, 40, 50 and 60 min post-exercise (Fig. 1).

Peak oxygen uptake test and ventilatory analysis

Peak oxygen consumption (VO_{2peak}) was determined by a graded maximal exercise test on an electronically braked cycle ergometer (Vision Fitness E3200, Taiwan, China) with subjects using the mouthpiece and nose clip to correct gas collection and analysis. After a 3-min warm-up at 35 W, intensity started at 50 W and was increased by 25 W every 60 s until volitional fatigue. The rate of perceived exertion (RPE) was measured using the Borg scale (6–20 points) [29, 30]. During the VO_{2peak} test, oxygen consumption (VO_2), carbon dioxide production (VCO_2) and ventilation (VE) were continuously measured by a previously calibrated gas analyzer (VO2000, Medgraphics, St. Paul, MN, USA). Results were recorded at an average of every 20 s and VO_{2peak} was determined as the highest value achieved obtained during the

Table 1 Anthropometric, body composition and hemodynamic characteristics of the participants

Variables	Mean \pm standard deviation
Age (years)	23 \pm 3
Body mass (kg)	76.43 \pm 4.06
Height (cm)	175.6 \pm 4.98
Body mass index (kg/m ²)	24.78 \pm 0.56
Free fat mass (%)	81.39 \pm 1.60
Fat percentage (%)	18.56 \pm 1.59
Systolic blood pressure (mmHg)	106.6 \pm 29.3
Diastolic blood pressure (mmHg)	73.3 \pm 7.7
Baseline heart rate (bpm)	68 \pm 4
VO_{2peak} (mL/min/kg)	52.33 \pm 4.87
Metabolic basal rate (Kcal)	1640.20 \pm 131.20

Values are mean \pm standard deviation ($n = 12$ participants)

VO_{2peak} maximal oxygen uptake peak

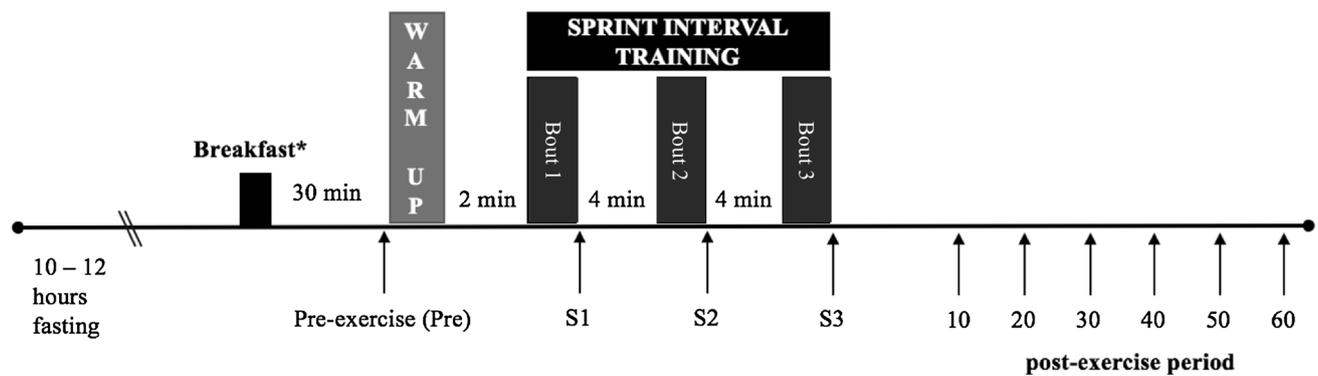


Fig. 1 Experimental design. Breakfast asterisk corresponds only to the experimental protocol in the fed state. Arrows indicate the moments of analysis: baseline, pre-exercise, immediately after and

every 10 min until completing 60 min. SIT, interval training of high intensity. Series 1, 2 and 3, three bouts of 30 s with recovery intervals of 4 min between each

last 20 s of the test. The test was terminated when the pedaling rate was lower than 50 rpm or at voluntary exhaustion and was considered maximal when the subjects attained the following criteria: heart rate higher than 95% of maximal heart rate expected ($220 - \text{age}$) and respiratory exchange ratio (RER) higher than 1.1. For ventilatory analysis, subjects sat in a chair immediately following SIT sessions and were instructed to rest quietly for 1 h. During the rest period, VO_2 , VCO_2 , RER and energy expenditure were measured every 20 s using a previously calibrated gas analyzer and the average of 1 min at pre- and the average of 1 min in the each post-exercise time point were considered for the analysis.

Sprint interval training protocol

The SIT session consisted of three repeated 30-s “all-out” sprint efforts (S1, S2 and S3) on an electromagnetically braked cycle ergometer (CEFISE Biotec 2100, Nova Odessa, Brazil) with a fixed recovery period of 4 min between each sprint. During each sprint, the braking force was kept constant at 0.05 kg/(kg body mass) and during the recovery period participants were free to choose between active (0.00 kg braking force) or passive (no pedaling). Each individual participant used the same recovery option in both fasted and fed states. Before the tests, a warm-up was allowed with 1 kg of load consisting of two bouts of 1-min pedaled cadence ~ 80 rpm and 5-s sprint at the end of every 1 min. Peak power (PP), average power (AP), power drop (PD), minimum power (MinP) and the fatigue index (FI) were measured/computed online via a hard-wire connection between the cycle ergometer and a computer with the task-specific software (Ergometric 6.0, Nova Odessa, Brazil). The FI was determined by taking the percentage difference between maximal (PP) and minimal (MinP) anaerobic performance during 30 s [33]. Each SIT session was separated

by 7 days and performed at the same period of the day at 08:00 a.m.

Dietary analysis and fasting state

During four consecutive weeks before the SIT protocols, participants completed a 3-day dietary recall (2 weekdays and 1 weekend day) to calculate habitual daily energy intake and macronutrient composition (Diet Win Professional Plus, Porto Alegre, Brazil). Diet diaries were analyzed by a dietitian. Based on dietary recall analysis (2800–3200 kcal, 65% carbohydrates, 20% fat, and 15% protein), a breakfast (25% of total daily diet requirement, 70% carbohydrates, 20% fat, 10% protein and 3.1% of fiber) was provided based on previous recommendations for each participant [31]. The breakfast consisted of multigrain bread, white cheese, cashew or guava juice, and corn cereal. Participants received the breakfast 30 min before the feed protocol and were asked to consume the test meals within 5 min. There was no report of nausea or gastrointestinal discomfort following the consumption of the test meal. During the fasting protocol, participants arrived at the laboratory after 10–12 h of overnight fasting and did not receive breakfast.

Determination of glucose, lactate, triglycerides and total cholesterol

The measurements of GLU, lactate (LAC), TG and total cholesterol (TC) were made by photometric reflectance on a validated Portable Accutrend Plus system (Roche, Sao Paulo, Brazil) [32]. Briefly, capillary blood samples were collected through transcutaneous puncture on the medial side of the tip of the middle finger using a disposable hypodermic lancet. The time points analysis for GLU and LAC were: pre, bout 1, bout 2, bout 3 and 10, 20, 30, 40, 50 and

60 min post-exercise. For TG and TC, the time points were pre- and post-60 min.

Statistical analysis

All participants performed and completed all procedures and were included in statistical analysis. The results are expressed as mean \pm standard deviation (SD). Data were normally distributed as determined using a Shapiro–Wilk test. Cardiorespiratory, metabolic and performance data were analyzed using a linear, mixed model, with factors (condition and time point) as fixed effects and participants as a random, within-group effect, with Tukey Post hoc test. The level of significance was $p \leq 0.05$ and the software GraphPad v. 6.0 was used (Inc., La Jolla, CA, USA).

Results

No significant interaction was observed for all variables. Peak power and mean power in FAST and FED were decreased during bouts 2 and 3 as compared to bout 1 ($p \leq 0.05$; Table 2), and bout 3 compared with bout 2 ($p \leq 0.05$; Table 2). There was no difference in the peak power, mean power and minimum power during the SIT protocol in the FAST and FED conditions ($p \geq 0.05$; Table 2). There was no difference in the fatigue index between the bouts of SIT in the FAST and FED conditions ($p \geq 0.05$; Table 2), while the fatigue index was lower during bout 1, bout 2 and bout 3 in the FED as compared to the FAST condition ($p \leq 0.05$; Table 2). The RPE was higher during bouts 2 and 3 as compared to bout 1 ($p \leq 0.05$; Table 2), and in bout 3 as compared to bout 2 ($p \leq 0.05$; Table 2). In addition, RPE was significantly higher in the FAST condition compared to the FED condition during bout 3 (20 ± 0.0 versus 19.42 ± 0.51 ; $p \leq 0.05$; Table 2).

LAC and HR were higher during bout 1, bout 2 and bout 3 compared to pre-exercise during the FAST and FED conditions ($p \leq 0.05$; Table 3), while GLU increased during bouts 1, 2 and 3 as compared to pre-exercise only in the FED condition ($p \leq 0.05$; Table 3).

GLU values at 10, 20, 30, 40, 50 and 60 min post-exercise were not significantly different from pre-exercise ($p > 0.05$). LAC values were increased at all time points after SIT as compared to pre-exercise for both conditions. HR was higher 10 and 20 min following SIT as compared to pre-exercise for both FED and FAST conditions ($p < 0.05$; Table 3).

GLU values were lower 10, 20, 30, 40 and 50 min following SIT as compared to bouts 1, 2 and 3 in the FED condition, while GLU values remained stable during all time points in the FAST state (Table 3). LAC and HR displayed an increase during bouts 1, 2 and 3 during both conditions as compared to pre-exercise. Moreover, LAC was lower 10, 20, 30, 40, 50 and 60 min following SIT as compared to bouts 1, 2 and 3 for both conditions. HR was higher 10 and 20 min following SIT as compared to pre-exercise (Table 3). TG and COL remained unchanged following SIT as compared to pre-exercise in both conditions (Table 3).

The VCO_2 was higher ($p \leq 0.05$) 10, 20, and 30 min following SIT as compared to pre-exercise in the FAST condition, while in the FED VCO_2 was higher 20, 30, 40, 50 and 60 min following SIT as compared to pre-exercise. VO_2 was higher 60 min following SIT as compared to pre-exercise only in the FAST condition (Table 4).

In the FAST condition, RER was higher at 10, 20, and maybe 30 min post-exercise compared to pre-exercise, but it was lower 40–60 min post-exercise. RER was higher ($p \leq 0.05$) in all time points following SIT as compared to pre-exercise in the FED condition. Energy expenditure was higher at all time points following SIT as compared to pre-exercise for both conditions (Table 4).

Figure 2a shows higher values of GLU during bouts 1 and 2 in the FED condition as compared to FAST. LAC

Table 2 Influence of fasting (FAST) and feeding (FED) conditions on peak power, mean power, minimum power, fatigue index and subjective perception of exertion (RPE) during the sprint interval training protocol

	FAST			FED		
	Bout 1	Bout 2	Bout 3	Bout 1	Bout 2	Bout 3
Peak power (W/kg)	8.69 \pm 0.67	7.70 \pm 0.46 ^a	7.22 \pm 0.55 ^a	8.72 \pm 0.71	7.83 \pm 0.51 ^a	7.25 \pm 0.69 ^{ab}
Average power (W/kg)	6.77 \pm 0.52	5.86 \pm 0.40 ^a	5.32 \pm 0.67 ^{ab}	6.94 \pm 0.51	5.90 \pm 0.48 ^a	5.45 \pm 0.70 ^{ab}
Minimum power (W/kg)	4.69 \pm 0.32	4.43 \pm 0.64	4.00 \pm 0.77	4.78 \pm 0.73	4.66 \pm 0.91	4.18 \pm 0.95
Fatigue index (%)	45.12 \pm 5.78	45.60 \pm 8.22	44.63 \pm 12.56	42.94 \pm 5.12 [#]	42.55 \pm 8.57 [#]	41.39 \pm 12.22 [#]
RPE-BORG	17.58 \pm 0.79	18.58 \pm 0.51 ^a	20 \pm 0 ^{ab}	17.67 \pm 0.98	18.50 \pm 0.67 ^a	19.42 \pm 0.51 ^{ab#}

Values are mean \pm SD ($n = 12$ subjects). RPE BORG scale (6–20)

^a $p \leq 0.05$ compared with bout 1 in the same group

^b $p \leq 0.05$ compared with bout 2 in the same group

[#] $p \leq 0.05$ compared with fasting condition

Table 3 Influence of fasting (FAST) and feeding (FED) conditions on concentrations of glucose (GLU), lactate (LAC), triglycerides (TG), cholesterol (COL) and heart rate (HR) during and after the sprint interval training protocol

Variables	Pre	Bout 1	Bout 2	Bout 3	Post-10 min	Post-20 min	Post-30 min	Post-40 min	Post-50 min	Post-60 min
GLU (mg/dL)										
FAST	83.75 ± 5.32	85.66 ± 5.51 ^a	88.08 ± 6.02 ^a	90.5 ± 5.37 ^a	87.90 ± 5.88	85.91 ± 6.08	84.25 ± 6.62	84.72 ± 6.38	86.33 ± 5.21	87.25 ± 5.83
FED	83.16 ± 6.89	125.16 ± 7.47	111.72 ± 6.45 ^b	96.83 ± 8.21 ^{bc}	91.66 ± 7.20 ^{bcd}	90.08 ± 7.19 ^{bcd}	88.41 ± 9.07 ^{bcd}	85.66 ± 6.63 ^{bcd}	87.66 ± 5.45 ^{bcd}	89.33 ± 5.93 ^{bc}
LAC (mmol/L)										
FAST	1.34 ± 0.26	2.97 ± 0.23 ^a	4.40 ± 0.50 ^{ab}	7.79 ± 0.26 ^{abc}	6.2 ± 0.46 ^{abcd}	5.61 ± 0.61 ^{abcd}	5.17 ± 0.68 ^{abcd}	4.9 ± 0.69 ^{abcd}	3.95 ± 0.6 ^{abdefgh}	3.36 ± 0.81 ^{adefghij}
FED	1.53 ± 0.29	2.48 ± 0.29 ^a	4.29 ± 1.08 ^{ab}	7.3 ± 0.71 ^{abc}	6.27 ± 0.74 ^{abcd}	5.78 ± 0.87 ^{abcd}	5.04 ± 0.82 ^{abcd}	3.86 ± 0.91 ^{abdefg}	3.16 ± 0.83 ^{adefg}	2.41 ± 0.40 ^{bcdefgh}
HR (bpm)										
FAST	68.25 ± 6.46	174.45 ± 3.93 ^a	175.58 ± 5 ^a	177.41 ± 4 ^a	84.16 ± 5.09 ^{abcd}	85.41 ± 6.66 ^{abcd}	68.66 ± 5.80 ^{bcdef}	66.6 ± 4.22 ^{bcdef}	65.33 ± 5.21 ^{bcdef}	67.25 ± 5.83 ^{bcdef}
FED	68.33 ± 4.12	172.58 ± 4.11 ^a	174.91 ± 3.75 ^a	175.91 ± 5.26 ^a	86.33 ± 3.61 ^{abcd}	75.25 ± 5.18 ^{abcde}	70.08 ± 4.36 ^{bcde}	67 ± 4.09 ^{bcdef}	67.66 ± 4.51 ^{bcde}	65.63 ± 3.36 ^{bcdef}
TG (mg/dL)										
FAST	185.83 ± 10.77	-	-	-	-	-	-	-	-	184.33 ± 10.88
FED	179 ± 11.88	-	-	-	-	-	-	-	-	178.66 ± 11.46
COL (mg/dL)										
FAST	203.16 ± 9.72	-	-	-	-	-	-	-	-	200.83 ± 7.72
FED	202.08 ± 9.49	-	-	-	-	-	-	-	-	201.25 ± 9.09

Values are mean ± SD (n = 12 subjects)

^ap ≤ 0.05 compared with pre-exercise

^bp ≤ 0.05 compared with bout 1 in the same group

^cp ≤ 0.05 compared with bout 2 in the same group

^dp ≤ 0.05 compared with bout 3 in the same group

^ep ≤ 0.05 compared with post-10 min

^fp ≤ 0.05 compared with post-20 min

^gp ≤ 0.05 compared with post-30 min

^hp ≤ 0.05 compared with post-40 min

ⁱp ≤ 0.05 compared with post-50 min

Table 4 Carbon dioxide production (VCO_2), oxygen consumption (VO_2), respiratory exchange rate (RER) and energy expenditure (EE) in the fasting (FAST) and feeding (FED) conditions during and 1 h after sprint interval training

Variables	Pre	Post-10 min	Post-20 min	Post-30 min	Post-40 min	Post-50 min	Post-60 min
VCO_2 (mL/kg min)							
FAST	3.37 ± 0.91	4.88 ± 0.71 ^a	5.37 ± 0.61 ^a	6.38 ± 0.60 ^a	3.88 ± 0.76 ^{fg}	3.75 ± 0.84 ^{fg}	4.15 ± 0.84 ^{fg}
FED	3.35 ± 0.93	4.46 ± 0.82	4.45 ± 0.79 ^a	4.87 ± 1.06 ^a	5.07 ± 0.93 ^a	5.13 ± 0.86 ^a	5.28 ± 0.82 ^a
VO_2 (mL/kg min)							
FAST	4.41 ± 1.12	4.69 ± 0.61	5.04 ± 0.64	5.52 ± 0.73	4.93 ± 1.32	4.93 ± 1.39	5.94 ± 1.32 ^{aj}
FED	4.11 ± 1.18	4.46 ± 0.69	4.56 ± 0.76	4.81 ± 0.99	5.03 ± 0.86	5.08 ± 0.84	5.17 ± 0.80
RER							
FAST	0.81 ± 0.01	1.01 ± 0.05 ^a	1.01 ± 0.07 ^a	0.83 ± 0.03 ^{ef}	0.75 ± 0.03 ^{acfg}	0.72 ± 0.03 ^{acfg}	0.70 ± 0.01 ^{acfgh}
FED	0.82 ± 0.03	0.98 ± 0.04 ^a	0.98 ± 0.05 ^a	1.00 ± 0.04 ^a	1.00 ± 0.03 ^a	0.99 ± 0.03 ^a	1.01 ± 0.05 ^a
EE (Kcal)							
FAST	74.33 ± 10.05	244.33 ± 18.48 ^a	250.83 ± 18.98 ^a	251.5 ± 17.8 ^a	251.25 ± 15.48 ^a	252.33 ± 12.02 ^a	255.33 ± 14.38 ^a
FED	70 ± 14.51	241.33 ± 32.53 ^a	246.16 ± 35.13 ^a	249.91 ± 33.39 ^a	249.58 ± 32.85 ^a	251.75 ± 30.44 ^a	178.66 ± 11.46 ^a

Data are presented as mean ± standard deviation ($n = 12$)

^a $p \leq 0.05$ compared with FAST

^e $p \leq 0.05$ compared with post-10 min

^f $p \leq 0.05$ compared with post-20 min

^g $p \leq 0.05$ compared with post-30 min

^h $p \leq 0.05$ compared with post-40 min

^j $p \leq 0.05$ compared with post-50 min

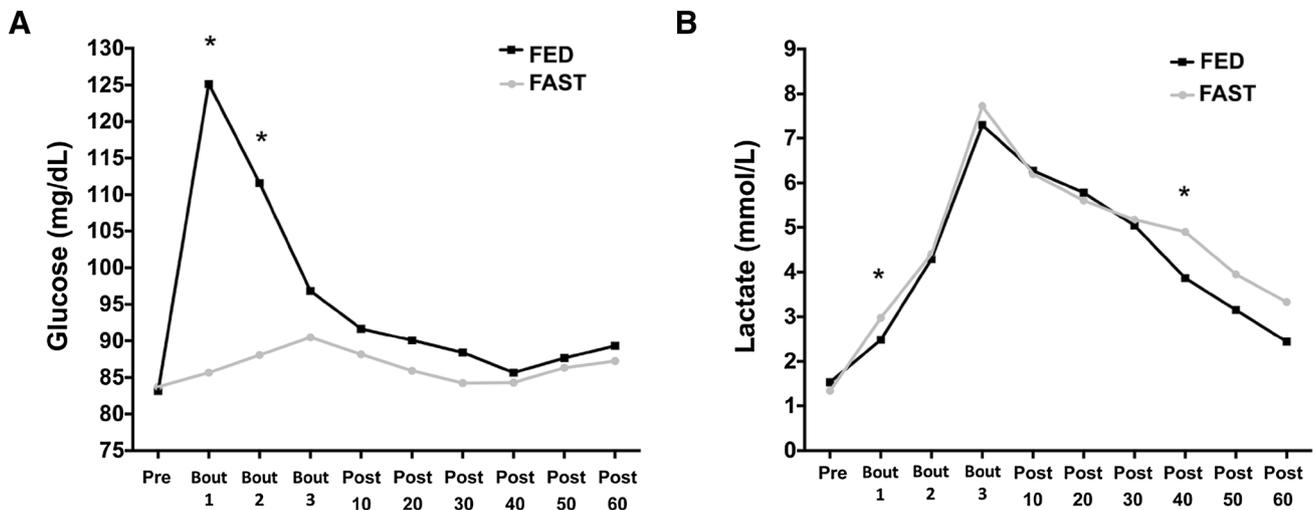


Fig. 2 Responses in blood glucose and lactate concentrations in fasting and fed protocols. Data presented as mean ± SD ($n = 12$). Paired ANOVA test. * $p < 0.05$ compared to the fasting protocol at the same time

was higher during bout 1 and 40 min following SIT in the FAST condition as compared to FED (Fig. 2b). VCO_2 was higher 20 min and lower 40, 50 and 60 min following SIT in the FAST condition as compared to FED (see Fig. 2).

VO_2 was higher 60 min following SIT in the FAST condition as compared to FED (Fig. 3b). RER was lower 30, 40, 50 and 60 min following SIT in the FAST condition as

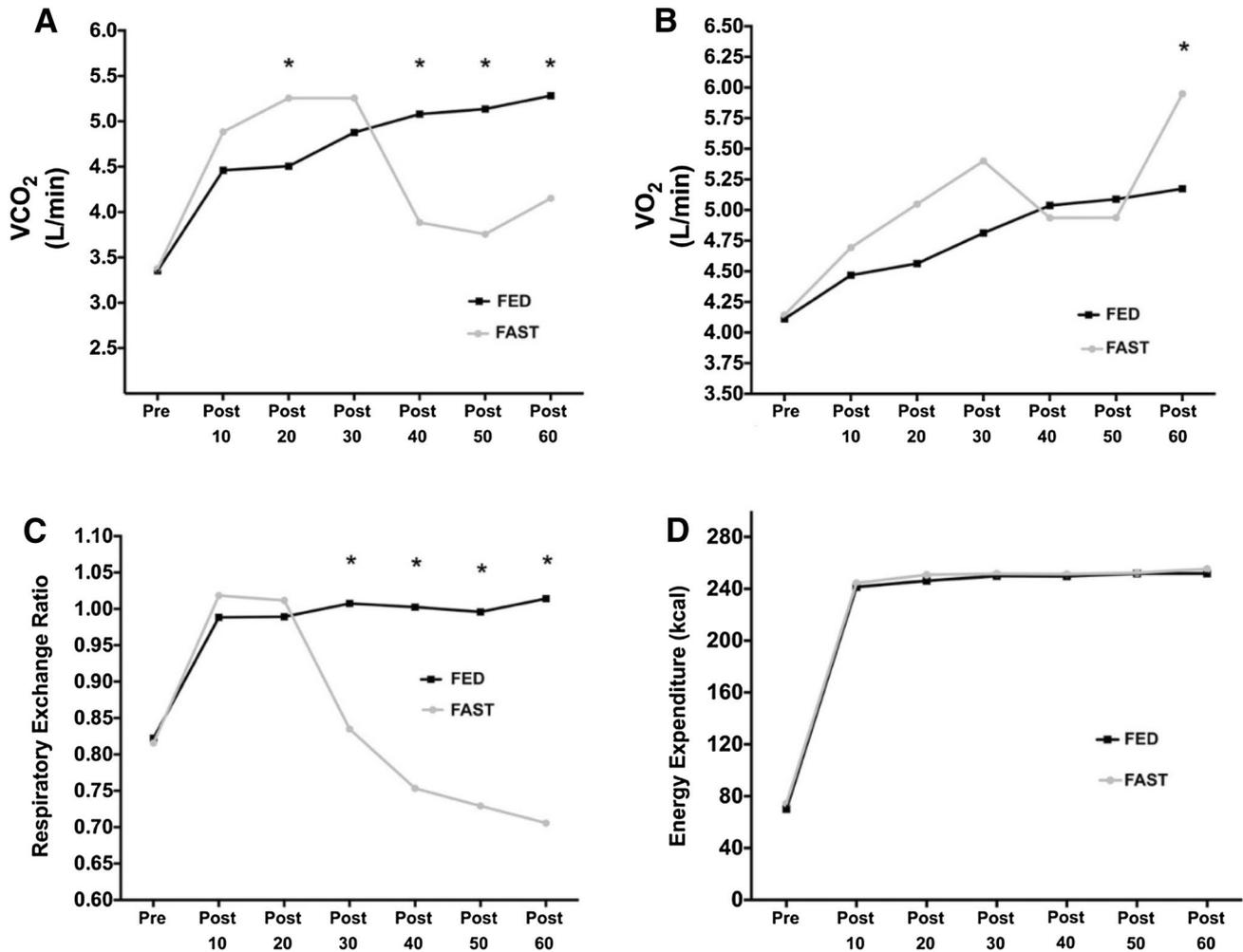


Fig. 3 Values of carbon dioxide produced (a), oxygen volume consumed (b), respiratory exchange ratio (c) and energy expenditure (d) during fasting and fed conditions. Data presented as mean ± standard

deviation ($n=12$). VO_2 , volume of oxygen consumed; VCO_2 , volume of carbon dioxide produced; EE energy expenditure. Test t paired. * $p < 0.05$ compared to the fasting protocol at the same time

compared to FED (Fig. 3c). There was no difference in EE following SIT between conditions (Fig. 3d).

Discussion

The present study demonstrates that during SIT performed in the FED state, glucose could be the main source of energy highlighted by the decreased values of GLU observed in this condition. In the recovery period, RER values were 0.83–0.7 at 30–60 min post-exercise, indicating that fat was the main source of energy in the FAST condition, while RER values were close to 1.0 in the FED condition, indicating a higher use of glucose as an energy source. Moreover, EE and performance were similar during both conditions, while RPE was higher after set 3 in the FAST state, thus partially confirming the initial hypothesis.

The FI was lower during bout 1, bout 2 and bout 3 in FED as compared to FAST condition, and has been used as an indicator of anaerobic fatigue during the Wingate test [33]. However, there was no difference in PP, mean power and MinP during the SIT protocol in the FAST and FED conditions. Future studies need to provide accurate approaches when designing an observation attempt to observe the effect of anaerobic performance just using FI.

It is well known that carbohydrate intake inhibits fatty acid oxidation during exercise. These results in the fed state can be attributed to an insulin-mediated attenuation of adipose tissue lipolysis, an increased glycolytic flux and/or a decreased expression of genes involved in fatty acid transport and oxidation [34]. In this sense, it is well documented that the utilization of peripheral fatty acids as well as intramyocellular lipids for energy provision is markedly enhanced during exercise in the fasted state [17, 18].

However, these above-mentioned studies were conducted during continuous aerobic exercise.

To the best of our knowledge, this is the first study designed to compare the effects of SIT and feed state (fasting or feeding) on metabolic and cardiorespiratory parameters. A novel finding in the present study is that the FED state after SIT glucose was the main source of energy, and fat oxidation was enhanced after SIT only in the fasted state. Moreover, unexpectedly there was no difference in peak power, mean power and minimum power during the SIT protocol in the FAST and FED conditions.

Paoli et al. [35] compared the differences in 24-h fat metabolism associated with performance of moderate-intensity exercise (36 min of cardiovascular training on treadmill at 65% maximum heart rate) in the fasted versus fed state. Consumption of breakfast for the fed condition resulted in a significant increase in RER compared to fasting (0.96 vs. 0.84, respectively). However, at 12 h post-exercise, RER was significantly lower in the fed versus fasting condition and the difference remained significant after 24 h. Furthermore, De Bock et al. [17] found that intramyocellular triglyceride breakdown was enhanced during prolonged submaximal exercise (2 h of constant load bicycle exercise ~75% VO_{2max}) in the fasted state as compared with the fed state (~150 g of carbohydrates before). However, these studies were performed with continuous aerobic exercise, which is different from the SIT performed in the present study. The mechanisms mediating the increase in fat oxidation following SIT performed in a fasted conditioning remain elusive. The large hormonal response associated with SIT may be important, as catecholamines are known to drive lipolysis of both subcutaneous and intramuscular fat store.

Regarding the lipemia response post-exercise, TG and COL remained unchanged following SIT as compared to pre-exercise in both conditions. Previous studies have shown that high-intensity intermittent exercise can reduce post-prandial TG for several hours after a high-fat breakfast [21, 36] and this response of exercise on attenuation of post-prandial lipemia can be dependent on the apolipoprotein E genotype [36]. Recently, Freese et al. [37] found that high-intensity interval training induced a larger reduction in the total TG iAUC response ($p < 0.05$, $d = -1.49$) than aerobic ($d = -0.58$) or resistance ($d = -0.13$) exercise. However, in the above-mentioned studies, the individuals performed an oral high-fat tolerance test, which it has been traditionally used to assess the metabolic responses following consumption of a high-fat meal (0.7–1.5 g fat/kg body weight) [37]. In the present study, we did not perform this high-fat tolerance test, which may explain why TG and COL remained unchanged following SIT as compared to pre-exercise in both conditions.

This study has some limitations: the possibility that the subjects had not reach a post-digestive state during the FED

trial, the lack of mechanistic measures, the acute response of oxygen consumption being measured only 60 min following exercise and the acute nature of the study. Moreover, the sample comprised healthy adult men; so findings should not be generalized to populations with obesity. Therefore, a randomized controlled follow-up study including an obese group and longer intervention periods is needed to reinforce the importance of these results.

Conclusions

An overnight fast may increase perceived exertion, but does not decrease muscle performance during sprint interval training in healthy young men. The fasting condition alters substrate partitioning 30 min post-exercise compared to the fed condition by stimulating a higher level of fat oxidation without impacting energy expenditure.

Compliance with ethical standards

Conflict of interest We declare that we have no conflicts of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and the Declaration of Helsinki.

Informed consent All of the subjects provided written consent.

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