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ORIGINAL ARTICLE

Combined effects of very short "all out" efforts during sprint and resistance training on physical and physiological adaptations after 2 weeks of training

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Abstract

Purpose The aim of this study was to compare the combined effects of resistance and sprint training, with very short efforts (5 s), on aerobic and anaerobic performances, and cardiometabolic health-related parameters in young healthy adults.

Methods Thirty young physically active individuals were randomly allocated into four groups: resistance training (RTG), sprint interval training (SITG), concurrent training (CTG), and control (CONG). Participants trained 3 days/week for 2 weeks in the high-intensity interventions that consisted of 6–12 "all out" efforts of 5 s separated by 24 s of recovery, totalizing ~ 13 min per session, with 48–72 h of recovery between sessions. Body composition, vertical jump, lower body strength, aerobic and anaerobic performances, heart rate variability (HRV), and redox status were evaluated before and after training. Total work (TW), rating of perceived exertion (CR-10 RPE) and mean HR (HR_{mean}) were monitored during sessions. Incidental physical activity (PA), dietary intake and perceived stress were also controlled.

Results Maximum oxygen consumption (VO_{2max}) significantly increased in SITG and CTG ($P < 0.05$). Lower body strength improved in RTG and CTG ($P < 0.05$), while countermovement jump (CMJ) was improved in RTG ($P = 0.04$) only. Redox status improved after all interventions ($P < 0.05$). No differences were found in TW, PA, dietary intake, and psychological stress between groups ($P > 0.05$).

Conclusions RT and SIT protocols with very short "all out" efforts, either performed in isolation, or combined, demonstrated improvement in several physical fitness- and health-related parameters. However, CT was the most efficient exercise intervention with improvement observed in the majority of the parameters.

Keywords High-intensity interval training · Sprint interval training · Concurrent training · Cardiometabolic health · Performance

Abbreviations

α1	Detrended fluctuations of short-term fractal scaling
BPSS-10	Brazilian 10-item version of the perceived stress scale
CAT	Catalase
CMJ	Countermovement jump
CO_2	Carbon dioxide
CT	Concurrent training
CTG	Concurrent training group
CONG	Control group
CR-10	RPE Category-ratio 10 scale rating of perceived exertion
EE	Energy expenditure
GSH	Glutathione reduced
HIIT	High-intensity interval training

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HRV	Heart rate variability
IPAQ	International physical activity questionnaire
MF	Mean force
MP	Mean power
MV	Mean velocity
P_{max}	Maximum power
PP	Peak power
RER	Respiratory exchange ratio
RT	Resistance training
RTG	Resistance training group
RMSSD	Root mean square of successive differences between R–R intervals
RPM_{max}	Maximal pedaling rate
SDNN	Standard deviation of all R–R intervals
SIT	Sprint interval training
SITG	Sprint interval training group
SOD	Superoxide dismutase
TBARS	Thiobarbituric acid reactive substances
TW	Total work
UA	Uric acid
VE	Ventilation
VO_{2max}	Maximum oxygen consumption

Introduction

High-intensity interval training (HIIT) is defined as the repetition of high-intensity exercise bouts separated by short recovery periods of low-intensity exercise (Batacan et al. 2017). HIIT can be an optimal exercise strategy for improving cardiometabolic health, since even a short-time intervention was shown to increase maximum oxygen consumption (VO_{2max}), decreased body fat, blood pressure, and fasting glucose (Batacan et al. 2017). Sprint interval training (SIT) is a category of HIIT which involves supramaximal “all out” efforts, proving to be a great time-efficient strategy to generate several systemic and metabolic adaptations (Sloth et al. 2013). The most commonly used SIT model (4–6 sprints × 30 s) has been widely questioned due to its extreme physical and psychological demands (Biddle and Batterham 2015). Recently, SIT has been adapted to shorter sprints ($\leq$ 20 s), demonstrating equally effective results (Vollaard and Metcalfe 2017). Therefore, it can be suggested that shortened sprint bouts could induce similar cardiometabolic adaptations associated with classical SIT (Gillen et al. 2016; Vollaard and Metcalfe 2017). In this context, some recent studies have shown that SIT of very short sprints (i.e. 5 s) induces a higher neuromuscular response and cardiorespiratory activity, while being less fatiguing and more tolerable (Islam et al. 2017; Townsend et al. 2017; Benitez-Flores et al. 2018). In addition, McKie et al. (2017) observed that 4 weeks of modified SIT (24–36 running efforts of 5 s) enhanced VO_{2max} similarly to a classical SIT. Further, Jabbour et al. (2018) revealed that a low training volume of very short bouts (6 s) was able to promote improvements in hemodynamic function after 18 training sessions. Furthermore, Tong et al. (2018) found that 12 week of this type of SIT reduced whole body and regional fat mass in obese young women. Therefore, it would be suggested that adapted SIT protocols of very short sprints are a promising strategy for improving both health and performance parameters without the commitments related to other traditional SIT interventions.

HIIT or SIT sessions can be combined with other training modalities, such as resistance training (RT), thus featuring a concurrent training (CT) model (Sabag et al. 2018). CT, defined as the simultaneous integration of resistance and endurance exercises into a periodized training regime (Fyfe et al. 2014), has emerged as an interesting option for physical conditioning and the prevention and treatment of a number of diseases (Chtara et al. 2008; Chudyk and Petrella 2011; Cadore et al. 2012; Fyfe et al. 2016; Robinson et al. 2017; Varela-Sanz et al. 2017). Previous studies have indicated that the gains in muscle strength may be compromised when resistance and endurance exercises are undertaken concurrently (Wilson et al. 2012; Coffey and Hawley 2017). In addition, Doma et al. (2017) have recently suggested that RT-induced fatigue may impair the quality of endurance training sessions thereby limiting optimization of endurance development. The physiological adaptations of CT depend on the specific physical stimuli, with intensity and volume being the two most important variables in mediating the interference effect (Wilson et al. 2012; Doma et al. 2017). Thus, overreaching or overtraining caused by traditional, high-volume, high-intensity or high-frequency endurance and/or resistance training have been proposed to elicit competing responses (Wilson et al. 2012; Doma et al. 2017). In this regard, modified SIT could be an interesting solution to minimize the interference effect. For instance, Cantrell et al. (2014) combined modified SIT (i.e. 20-s bouts) with resistance training (four to six repetitions with 85% of 1RM) and found similar improvement in upper and lower body maximum strength to the resistance training group after 12 weeks. Thus, it is reasonable to assume that the neuromuscular effects of very short efforts (i.e. 5 s) in a CT program could minimize the interference phenomenon, given that they provoke less metabolic disturbances and residual fatigue (Balsom et al. 1992a; Benitez-Flores et al. 2018). In addition, to the best of our knowledge, there are no data on the potential benefits of CT methods integrating shorter SIT for cardiometabolic health, as previous studies have mainly focused on neuromuscular adaptations (Cantrell et al. 2014; Laird et al. 2016). Such findings would improve our understanding of the benefit that SIT protocols may have on aerobic and anaerobic performance development, as well as cardiometabolic health-related parameters.

Thus, the aim of this study was to verify the effects of 2 weeks of RT, SIT and CT, using very short "all out" efforts of 5 s, on body composition, vertical jump capacity, lower body strength, aerobic and anaerobic performance, heart rate variability (HRV), and redox status. It was hypothesized that CT would provide the best results as training qualities from both modes of exercises (i.e. RT and SIT) would optimize several physiological-, physical- and health-related parameters.

Methods

Participants

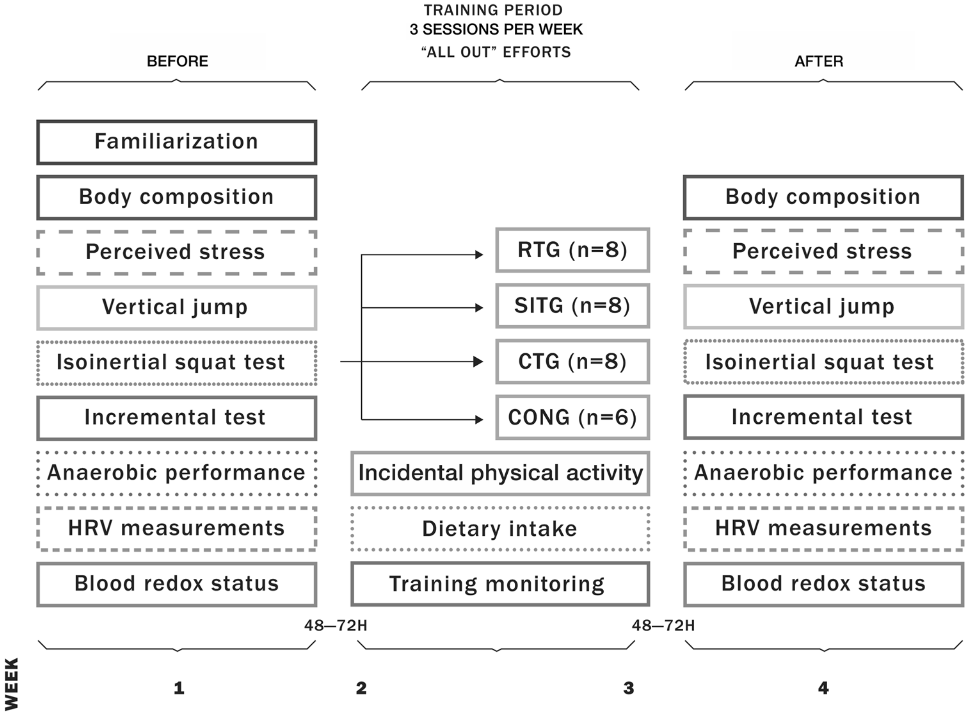
Forty-one volunteers contacted the primary investigator after a publicity campaign between May and September of 2017 in the University Campus. From this sample, 33 individuals met the inclusion criteria and were subsequently enrolled in the study (16 males and 17 females). The inclusion criteria were: (1) being physically active according to the *International Physical Activity Questionnaire* (*IPAQ*); (2) not consuming any type of nutritional supplement or tobacco products; (3) to be free of risk factors associated with cardiometabolic diseases, and free of any musculoskeletal injury; (4) not having previously participated in HIIT programs; and (5) being between 18 and 35 years old. The participants were randomly allocated into four groups: RT group (RTG; $n=9$); SIT group (SITG; $n=9$); CT group (CTG; $n=9$); and control group (CONG; $n=6$). In addition, they were instructed not to consume foods that could interfere in their redox status, maintain their incidental lifestyle (work, hours of sleep, etc.) while avoiding other exercises during the experiment. Prior to participation, the experimental procedures and potential risks were fully explained to all participants in written and verbal forms. Thereafter, they were asked to sign the informed consent form. This study was approved by the Ethics Committee of Catholic University of Brasilia (protocol number CAAE 54813016.0.0000.0029) and was conducted in accordance with the principles stipulated in the Declaration of Helsinki.

Experimental design

This study adopted a randomized controlled design. Participants performed nine sessions during 3 weeks, including 1 day of familiarization, 2 days of testing before and after training, and six training sessions (Fig. 1). Each training session had 48–72 h of recovery. All the sessions were carried out at the same time of day (morning at 8–12 h or afternoon at 14–18 h), with constant environment conditions (temperature = 21–23 °C, relative humidity = 65–75%), and at an altitude of ~ 1200 m.

Informed consent and various questionnaires were completed at the beginning of the first session and, subsequently, body composition was evaluated. After that, familiarization with vertical jump, squat exercise, and cycle sprints was performed. On the second session, the tests were completed with the following sequence: (1) vertical jump; (2) isoinertial squat test; (3) incremental endurance test; and (4)

Fig. 1 HRV measurements and blood redox status were evaluated pre- and post-incremental tests. *RTG* resistance training group, *SITG* sprint interval training group, *CTG* concurrent training group, *CONG* control group



anaerobic performance. Blood samples and HRV measurements were collected pre- and post-incremental tests after 8 h of fasting, and without consuming alcohol or any product with caffeine 24 h before.

The training period included six sessions for all groups, with CTG combining both RT and SIT in the one session. Every session was composed of 6–12 efforts of 5 s at maximum effort with 24 s of recovery between bouts (Benitez-Flores et al. 2018), and with an exercise volume similar to previous studies that used modified SIT protocols (Hazell et al. 2010; Gillen et al. 2016; Jabbour et al. 2018). The researchers provided strong verbal encouragement for participants to achieve maximum effort in each session. Halfway through every training session, 3 min of rest was implemented to facilitate recovery (Balsom et al. 1992b). The training intensity was monitored in the 2nd, 3rd, 5th and 6th sessions by internal and external loading parameters. The incidental PA and dietary intake were recorded throughout the experiment. After the training period, the preliminary tests were repeated as described.

Body composition and familiarization

Participants arrived on the first day at the laboratory and completed informed consent, the *IPAQ* and the *Brazilian 10-item version of the perceived stress scale* (*BPSS-10*) (Reis et al. 2010). After that, body mass was measured with a digital balance (Toledo, Toledo2286PP, São Paulo, Brazil), stature with a stadiometer (Stadi-O-Meter, Novel Products Inc., Rockton, Illinois, USA), and body fatness was determined by DEXA (Lunar DPX-IQ, Wisconsin, USA). Subsequently, the adjustments in the cycle-ergometer (Model 828 E, Monark, Vansbro, Sweden) were completed according to the morphological characteristics of the subjects. The participants started a 2-min warm-up on a cycle-ergometer with 1kp at 50 rpm, which was followed by two maximal sprints of 5 s with 24 s of recovery and with 2kp of load. Immediately after the warm-up, participants performed two to four countermovement jumps (CMJ).

Finally, participants were familiarized with the squat exercise on a Smith machine, with no counterweigh mechanism (Multi Exercitador, Righetto, São Paulo, Brazil). Each participant lowered with the barbell until reaching a knee angle of 90°, which was measured with a steel goniometer (BaseLine, Patterson Medical, Warrenville, Illinois, USA). An elastic band was placed on the Smith machine to determine the end of the eccentric phase and standardize squat depth for each participant. The participants completed ten repetitions without any load and it was required to lightly touch the elastic band during each repetition prior to performing the concentric phase. Afterward, mean bar displacement was calculated from the upright position to the bottom position in other five repetitions using a linear position transducer at a sampling rate of 1000 Hz (Chronojump, Barcelona, Spain).

Perceived stress

To monitor subjective stress, the *BPSS-10* was used, which is a valid and reliable stress scale, consisting of ten items of the adapted perceived stress scale (Reis et al. 2010). In this scale, participants described how often they experienced stressful situations in the last month. Six items are negative (1, 2, 3, 6, 9, 10) and the remaining four are positive (4, 5, 7, 8). The response format in each item was rated on a five-point Likert-type scale (1 = never to 5 = very often). To produce the final score, the four positive items were scored in reverse, and the remainder was summed to a score ranging from 0 to 40, with higher scores inferring elevated stress levels.

Vertical jump

The CMJ is a jump test used to determine lower body muscular power capacity, which was measured and analyzed with an iPhone 5S (Apple Inc, Cupertino, California, USA) via the app My Jump (Apple Inc, Cupertino, California, USA) (Balsalobre-Fernández et al. 2015). First, a standardized warm-up was undertaken for 2 min at a cadence of 50 rpm and at a load of ~ 50W on a cycle-ergometer (Model 828 E, Monark, Vansbro, Sweden). Subsequently, four repetitions of CMJ were performed with 1 min of passive recovery between each attempt. The average of the last two CMJs was used for analyses.

Isoinertial squat test

The isoinertial squat test involved squatting with increasing loads performed on a Smith machine (Multi Exercitador, Righetto, São Paulo, Brazil). The test uses submaximal loads and is an easy and simple way to measure the lower body strength without the risk of injury associated with high loads. An elastic band was placed on the Smith machine to standardize squat depth, as per the previous familiarization. Participants performed five sets with the following sequence: (1) five repetitions with the load of the bar (17 kg) at a free velocity; (2) five repetitions with ~ 30% of body mass at a free velocity; (3) five repetitions with 50% of body mass at a free velocity; (4) five repetitions with 50% of body mass at maximal voluntary velocity; and (5) five repetitions with 50% of body mass at maximal voluntary velocity. Participants had 2 min of passive recovery between sets. Mean velocity (MV), mean power (MP), and mean force (MF) during the concentric phase for each repetition were recorded with a linear position transducer (Chronojump, Barcelona, Spain). The mean values were considered because a recent work reported that MV might be the most appropriate variable for monitoring and testing load-velocity parameters (García-Ramos et al. 2018). Afterward, the mean of the last five repetitions for each variable was calculated and recorded.

Incremental endurance test

Adjustments in cycle-ergometer (Excalibur Sport, Lode BV, Groningen, Netherlands) were repeated according to the first session. The same protocol was used in previous studies (Gillen et al. 2016), and consisted of a warm-up of 1 min at 50 W with subsequent progressive increases of 1 W every 2 s until exhaustion or when pedal cadence fell below 50 rpm. The oxygen consumption (VO_2), carbon dioxide (CO_2) and ventilation (VE) were measured every 20 s using a metabolic cart (Cortex, Metalyzer, Leipzig, Germany) that was previously calibrated following manufacturer's instructions. The $VO_{2\max}$ was defined as the highest VO_2 value registered during a 20-s period and was confirmed when a minimum of two of the following criteria were met: (1) a respiratory exchange ratio (RER) higher than 1.2; (2) peak HR ≥ 90% of the age-predicted maximum (i.e. 220 minus age); and (3) visible exhaustion. Maximum power ($P_{\max}$), and maximum RER ($RER_{\max}$) were determined during a 20-s period at the end of the test.

HRV measurements

R–R intervals were recorded (RS800CX, Polar Electro Oy, Kempele, Finland) pre- and post-incremental tests during 10 min on a cycle-ergometer (Excalibur Sport, Lode BV, Groningen, Netherlands). Only the last 5 min of every recording was used for HRV analyses. Data collection was carried out with the participants pedaling at a steady cadence of 50 rpm with a load of 50 W. Subsequently, R–R data were transferred to a computer and filtered with specific software (Polar Pro-Trainer 5 version 5.40.170, Polar Electro Oy, Kempele, Finland). The filtered recordings were exported and analyzed with a custom-designed software (Kubios HRV Analysis version 3.0.2, The Biomedical Signals Analysis Group, University of Kuopio, Finland). The variables selected for analyses were: (1) R–R intervals (R–R); (2) standard deviation of all R–R intervals (SDNN); (3) root mean square of successive differences between R–R intervals (RMSSD); and (4) detrended fluctuations of short-term fractal scaling (α1) (Boullosa et al. 2014).

Blood redox status

Pre- and post-30 min to the incremental test, blood collection was applied from the antecubital vein, using disposable syringes of 10 ml. The blood was stored in two empty Vacutainer® 4-ml EDTA tubes (Becton–Dickinson, Franklin Lakes, New Jersey, USA). All blood samples were stored at 5 °C and were centrifuged at 3000 rpm for 10 min, with plasma separated in triplicates (1.5-ml tubes). Subsequently, the blood samples were stored at − 80 °C for further analysis of antioxidant enzymes such as catalase (CAT) and superoxide dismutase (SOD), as well as glutathione levels (GSH), thiobarbituric acid reactive substances (TBARS), and uric acid (UA). CAT activity was measured using the Amplex™ Red CAT assay kit (Thermo fisher Scientific®, MA, USA) with a final spectrophotometric reading with 1-min incubation at 560 nm. The GSH levels and SOD activity were measured using the GSH and SOD assay kits from Sigma-Aldrich® (St. Louis, MO, USA), with a final spectrophotometric reading at 450 nm. The formation of TBARS to estimate oxidative damage was measured using a protocol adapted from Ohkawa et al. (1979).

Anaerobic performance

Ten-minute post-incremental test, participants were evaluated in two "all out" sprints of 5 s with 24 s of recovery. The torque factor was set to 0.7 N·m (Wingate for Windows software version 1, Lode BV, Groningen, Netherlands). Two seconds before every effort, the load was applied and participants were asked to achieve the highest possible pedaling frequency and to maintain it until the end. The peak power (PP), total work (TW), and maximal pedaling rate ($RPM_{\max}$) were recorded during each effort. PP was the highest single value of power output, TW was obtained by multiplying mean power by the duration of the bout, and $RPM_{\max}$ was the maximum number of revolutions per minute achieved. The mean of the two sprints was calculated for further analyses.

Incidental PA

PA was measured during the training period with an accelerometer (GT1M, Actigraph, LCC, Fort Walton Beach, Florida, USA) during 7 consecutive days. Participants were instructed to use the monitor on their right hip and to only remove it for sleeping or taking baths. Epoch lengths were selected at 15 s and summed as counts per minute. The cut-points to identify time spent in different intensities of PA were: (1) light < 1951 counts/min; (2) moderate 1952–5724 counts/min; (3) vigorous 5725–9498 counts/min; and (4) very vigorous > 9499 counts/min. The average energy expenditure (EE) in kcals/day was also calculated (Freedson et al. 1998).

Dietary intake

Before the first testing day, participants listed all food and drink ingested in the last 24 h using a food recall questionnaire. It was requested to repeat these patterns 24 h before the final day of evaluations. In addition, during the training period, participants tracked their dietary intake for six random days (4 days a week and 2 days of the weekend). To improve the quality of information, participants were asked to take pictures of each food intake during the selected day and send them by cell phone to the researcher. A dietician instructed participants how to complete the food diary, and analyzed the information referent to total kcals, proteins, carbohydrates, fats, vitamin C, vitamin E, and vitamin A intake using a custom software (Smart data, São Paulo, Brazil). The average of 6 days for macronutrients and micronutrients were subsequently calculated.

Training programs

The training programs involved three sessions per week for 2 weeks. RTG trained the squat exercise in a Smith machine (Multi Exercitador, Righetto, São Paulo, Brazil) with a load equivalent to 50% of the body mass. This exercise was chosen because a recent study reported that multi-joint exercises could be better to enhance general fitness (Paoli et al. 2017), and that heavy-load resistance training causes greater interferences on the quality of endurance training sessions (Doma et al. 2017). The SITG trained in a cycle-ergometer with a torque factor 0.7 N·m. CTG combined SIT in cycle-ergometer followed by the squat exercise. It has been previously suggested that both exercise modes (i.e. squat and sprint) have a similar muscle activation nature (Bloomer et al. 2006). This intra-session sequence was selected based on previous studies (Fyfe et al. 2016; Varela-Sanz et al. 2017). The recovery between sessions was 48–72 h. An undulating periodization (Rhea et al. 2002) with 6–12 sets (6 sets in 1st and 2nd sessions, 12 sets in 3rd, 4th and 5th sessions, and 6 sets in the 6th session) was performed. In the last session, the volume was reduced to ensure supercompensation. Every set had a 5-s "all out" effort with 24 s of recovery (Benitez-Flores et al. 2018).

The warm-up and the cooling down were on a cycle-ergometer at ~ 50 W with 50 rpm, with duration of 2 and 3 min, respectively (Excalibur Sport, Lode BV, Groningen, Netherlands and Model 828 E, Monark, Vansbro, Sweden). In the middle of every session, 3 min of active recovery was applied because the mechanical production seems to decrease over SIT sessions (Hazell et al. 2010; Islam et al. 2017; Benitez-Flores et al. 2018). The recovery of RTG and SITG was performed in the cycle-ergometers with the same load of the warm-up, whilst recovery during CTG was completed by walking at a self-selected velocity from one laboratory to another. The training protocols were equated by time, with the same work-to-rest ratio:

(1) 6 sets × 5 s × 24 s of recovery = 5 min 6 s of exercise (30 s of bouts and 4 min 36 s of recovery), and 10 min 6 s for total time (5 min 6 s of exercise, 2 min of warming up and 3 min of cooling down);

(2) 12 sets × 5 s × 24 s of recovery = 8 min of exercise (1 min of bouts and 7 min of recovery), and 13 min for total time (8 min of exercise, 2 min of warming up and 3 min of cooling down).

A similar volume of total time training was used in previous studies showing improvements in cardiometabolic health indices (Metcalfe et al. 2012; Gillen et al. 2016; Jabbour et al. 2018).

Training monitoring

The 2nd, 3rd, 5th and 6th sessions were selected to monitor internal (1 and 2) and external (3) load parameters with three different tools: (1) the *Category-ratio 10 scale rating of perceived exertion* (*CR-10 RPE*) (Borg et al. 1998); (2) the mean HR (HR_{mean}) during sessions (Polar Pro-Trainer 5 version 5.40.170, Polar Electro Oy, Kempele, Finland); and (3) the TW. During RTG and CTG sessions, the number of repetitions completed in every set in the squat exercise, served to calculate the TW per session, according to the formula: work (kJ) = *1.33* × displacement (m) × [(body mass (kg)*0.88) + load (kg)] × 9.81 (Bloomer et al. 2006). For SITG, TW of the session was calculated by summing the work of all sprints (Excalibur Sport, Lode BV, Groningen, Netherlands). For CTG, the TW of both exercises was summed. Then, the mean of *CR-10 RPE*, HR_{mean} and TW was calculated during the four selected sessions for further comparisons.

Statistical analyses

Data are presented as mean ± SD. Normality was assessed by means of standard distribution measures, visual inspection of *Q*–*Q* plots and box plots, and the Shapiro–Wilk test. Variables with a non-normal distribution were log-transformed (Ln) for analysis (Hopkins et al. 2009). Where normalization was not possible for some variables, non-parametric methods were used. The intergroup differences in incidental PA and training monitoring were evaluated via one-way ANOVA. Also, exact *P* value differences between groups were determined from non-paired *t* tests with Bonferonni's correction. The intergroup differences in dietary intake were evaluated via Kruskal–Wallis test. The effect of training interventions in perceived stress, vertical jump and anaerobic performance was evaluated by a two-way ANOVA with a repeated measures factor of two levels (time) and intersubject factor of three levels (group). If appropriate, post hoc analyses were conducted using paired *t* tests with

Bonferroni's adjustment. As normality assumption was not satisfied for body composition, isoinertial squat test, and incremental endurance test, a non-parametric ANOVA-type statistics (time × group) was conducted using the nparLD R software package (Noguchi et al. 2012). Non-parametric ANOVA-type statistics allows the same analysis as traditional ANOVA (i.e. the effect of each factor and interaction between them) but is based on the use of ranks for calculating the so-called 'relative marginal effects' (Noguchi et al. 2012). When a significant interaction was detected, paired comparison within groups (i.e. after vs. before) was applied using the Wilcoxon signed-rank test and paired comparison between groups using the Mann–Whitney *U* test with Bonferroni's adjustment. For HRV parameters and redox status, a 4 × 4 (time × group) parametric or non-parametric ANOVA were performed when appropriate. Cohen's *d* (for normal variables) and $r = z/\sqrt{N}$ (for non-normal variables) were calculated for ES analyses representing ≤ 0.20 as a small effect, 0.50 as a medium effect, and ≥ 0.80 as a large effect (Cohen 1988). A post hoc power analysis was calculated using the G*Power software (version 3.1.9.2). The statistical power values for an ANOVA within–between interaction for a total sample of 30 subjects, four groups, two measurements (i.e. pre-test vs. post-test), an alpha level of 0.05, and a correlation between repeated measurements of 0.7 were 0.79 and 0.99 for a medium ($f = 0.25$) and a large ($f = 0.40$) effect sizes, respectively. In addition, we calculated the sensitivity of the ANOVA to detect within–between interactions for an alpha level of 0.05, a power of 0.80, a total sample of 30 subjects, four groups, two measurements within groups, and a correlation between repeated measurements of 0.7, and it was obtained that the test was sensitive to detect a medium effect size ($f = 0.252$). The statistics were performed with the software IBM SPSS Statistics for Windows Version 23 (IBM Corporation, Armonk, New York, USA) and the nparLD R software package. All graphics were made with GraphPad Prism 6 (GraphPad Software, San Diego, CA, USA). The alpha level was set at $P < 0.05$.

Results

During the testing sessions, three participants (one from RTG, one from SITG, and one from CTG) dropped out because of a disease and some injuries not related to this study. Thus, 30 participants (15 females, 15 males) aged 19–35 years (25.3 ± 4.5 years) composed the groups that presented similar sex distribution (50%): RTG (26 ± 4.1 years, $n = 8$), SITG (25.3 ± 5.3 years, $n = 8$), CTG (23.6 ± 4.8 years, $n = 8$), and CONG (26.2 ± 3.9 years, $n = 6$). No between-group differences were found at baseline for all parameters analyzed ($P > 0.05$). All these participants completed 100% of the training sessions.

Body composition

For body mass, neither main effects nor time × group interaction was detected ($P > 0.05$). Regarding BMI, a significant effect of group was observed ($P = 0.004$). Post hoc analyses showed lower values for CONG in comparison with the experimental groups. Neither main effect of time nor time × group interaction was observed ($P > 0.05$). There was a main effect of time ($P \leq 0.001$) for body fat (%), with lower values after training whereas neither main effect of group nor time × group interaction was detected ($P > 0.05$) (Table 1).

Vertical jump

There were no main effects of time and group ($P > 0.05$) for CMJ height. However, a significant interaction was found ($F = 3.653$; $P = 0.025$) for CMJ height. Pairwise comparison showed an increment in RTG ($P = 0.037$; $d = 0.31$) but not in SITG ($P = 0.232$; $d = -0.11$), CTG ($P = 0.100$; $d = 0.18$) or CONG ($P = 0.982$; $d = 0.01$) (Fig. 2). No intergroup differences were found at any time ($P > 0.05$).

Anaerobic performance

There was a main effect of time ($P < 0.001$), but neither main effect of group nor interaction ($P > 0.05$) was observed for PP, TW and RPM_{max} (Table 1).

Isoinertial squat test

There were a significant main effect of time ($P = 0.021$) and time × group interaction ($F_{1.97,\infty} = 4.702$; $P = 0.005$) for MV.

Pairwise comparisons detected higher values after training for RTG ($P = 0.017$; $r = 0.84$) but not for SITG ($P = 0.731$; $r = 0.22$), CTG ($P = 0.123$; $r = 0.54$) or CONG ($P = 0.345$; $r = 0.38$). There were a significant main effect of time ($P = 0.014$) and interaction ($F_{2.81,\infty} = 5.215$; $P = 0.002$) for MP. Post hoc pairwise comparisons detected significant improvements after training for RTG ($P = 0.017$; $r = 0.84$) and CTG ($P = 0.036$; $r = 0.74$), but not for SITG ($P = 0.674$; $r = 0.15$) and CONG ($P = 0.600$; $r = 0.21$). A significant main effect of time ($P < 0.001$) and interaction ($F_{1.97,\infty} = 2.616$; $P = 0.004$) were observed for MF. Higher values after training were detected for RTG ($P = 0.012$; $r = 0.89$) and CTG ($P = 0.012$; $r = 0.89$), but not in SITG ($P = 0.161$; $r = 0.49$) and CONG ($P = 0.345$; $r = 0.38$). No main effect of group was found for any of these variables ($P > 0.05$) (Fig. 3).

Incremental endurance test

Significant main effect of time ($P = 0.016$) and time × group interaction ($F_{2.89,\infty} = 3.075$; $P = 0.030$) were detected for

Table 1 Body composition and cycling performance parameters

Parameter	RTG ($n=8$)		SITG ($n=8$)		CTG ($n=8$)		CONG ($n=6$)	
	Before	After	Before	After	Before	After	Before	After
Body composition								
Body mass (kg)	76.5 ± 18.6	76.6 ± 19.4	74.9 ± 16.3	74.9 ± 16.9	66.9 ± 9	67.5 ± 8.9	60.8 ± 6	60.7 ± 5.9
BMI (kg m^{-2})	25.1 ± 4.1	25.1 ± 4.3	25.9 ± 3.8	25.9 ± 4	23.2 ± 1.8	23.4 ± 1.9	21 ± 1.4	20.9 ± 1.4
Body fat (%)	23.1 ± 5.2	22.4 ± 6	26.1 ± 11	25.4 ± 12.1	22.4 ± 8.8	21.2 ± 8.9	18.9 ± 10.6	17.5 ± 9.6
Incremental test								
VO_{2max} (ml kg^{-1} min^{-1})†	33.6 ± 6.3	35 ± 5.6	35.5 ± 7.5	38.1 ± 8*	35.3 ± 6.4	37.4 ± 6.9*	34.2 ± 5.9	33 ± 5.4
P_{max} (W)	241 ± 61.4	249.7 ± 60.2	237.2 ± 51.1	246 ± 54.5	216 ± 45.3	224.7 ± 50.6	194.3 ± 37.6	199.3 ± 38.8
RER_{max}	1.20 ± 0.12	1.20 ± 0.06	1.19 ± 0.07	1.21 ± 0.09	1.20 ± 0.08	1.22 ± 0.1	1.29 ± 0.16	1.31 ± 0.17
Anaerobic performance								
PP (W)	764 ± 288.8	817.6 ± 303.3	802.6 ± 269.7	865.3 ± 278	725.7 ± 225.6	852.7 ± 269	668.5 ± 209.4	694 ± 173.8
TW (kJ)	3.1 ± 1.1	3.2 ± 1.2	3.3 ± 1	3.6 ± 1.1	3 ± 0.8	3.5 ± 0.9	2.7 ± 0.8	2.8 ± 0.6
RPM_{max}	117.2 ± 17	124.2 ± 22.7	124 ± 17.4	135 ± 19.7	125.7 ± 12.5	136.7 ± 19.4	123.2 ± 21.8	125 ± 17.9

Data are mean ± SD

RTG resistance training group, *SITG* sprint interval training group, *CTG* concurrent training group, *CONG* control group, VO_{2max} maximum oxygen consumption, P_{max} maximum power, RER_{max} maximum respiratory exchange ratio, *PP* peak power, *TW* total work, RPM_{max} maximal pedaling rate

$^{\dagger}P<0.05$ main effect of interaction; $^{*}P<0.05$ before vs. after intragroup differences

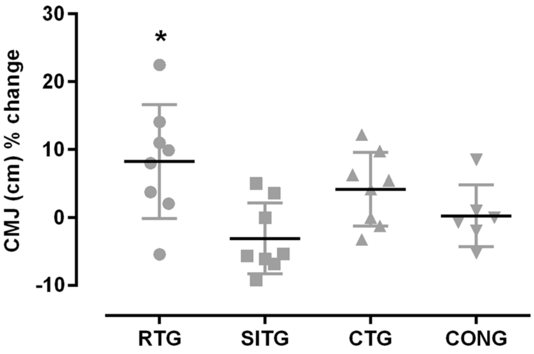


Fig. 2 Percentage (%) change before vs. after in countermovement jump (CMJ) for all groups. *RTG* resistance group, *SITG* sprint interval training group, *CTG* concurrent group, *CONG* control group. $^{*}P<0.05$ before vs. after intragroup differences

VO_{2max}. Significant improvements were observed in SITG ($P=0.012$; $r=0.89$) and CTG ($P=0.042$; $r=0.72$), but not in RTG ($P=0.093$; $r=0.59$) and CONG ($P=0.345$; r=-0.38) (Fig. 4). No main effect of group was found ($P>0.05$). Regarding P_{max}, only a main effect of time ($P<0.001$) was obtained, whereas neither group nor time × group interaction was observed ($P>0.05$). No significant effect was detected for RER_{max} ($P>0.05$) (Table 1).

Training monitoring

No significant differences were observed between groups in TW during the training period (RTG: 25.2 ± 9.2; SITG: 26.4 ± 8.8; CTG: 24.4 ± 6.5 kJ; $P>0.05$). Significant differences were found in HR_{mean} (RTG: 123 ± 15; SITG: 142 ± 13; CTG: 137 ± 10 b·min^{-1}; $P=0.013$) for RTG vs. SITG ($P=0.013$; $d=-1.35$) and RTG vs. CTG ($P=0.033$; $d=-1.10$). In addition, significant differences were observed in *CR-10 RPE* (RTG: 3.9 ± 1; SITG: 7 ± 1.4; CTG: 4.2 ± 1.2; $P<0.001$) for RTG vs. SITG ($P<0.001$; $d=-2.55$) and CTG vs. SITG ($P<0.001$; $d=-2.14$).

Perceived stress

There was a main effect of time ($P=0.002$), but neither main effect of group nor time × group interaction ($P>0.05$) was found for *BPSS-10*.

Incidental PA

A significant difference was observed in the % time spent at moderate intensity ($P=0.024$). A difference was observed between SITG and CTG ($P=0.004$; $d=-1.66$) (Table 2).

Dietary intake

There were no significant differences in dietary intake between groups during the training period ($P>0.05$) (Table 2).

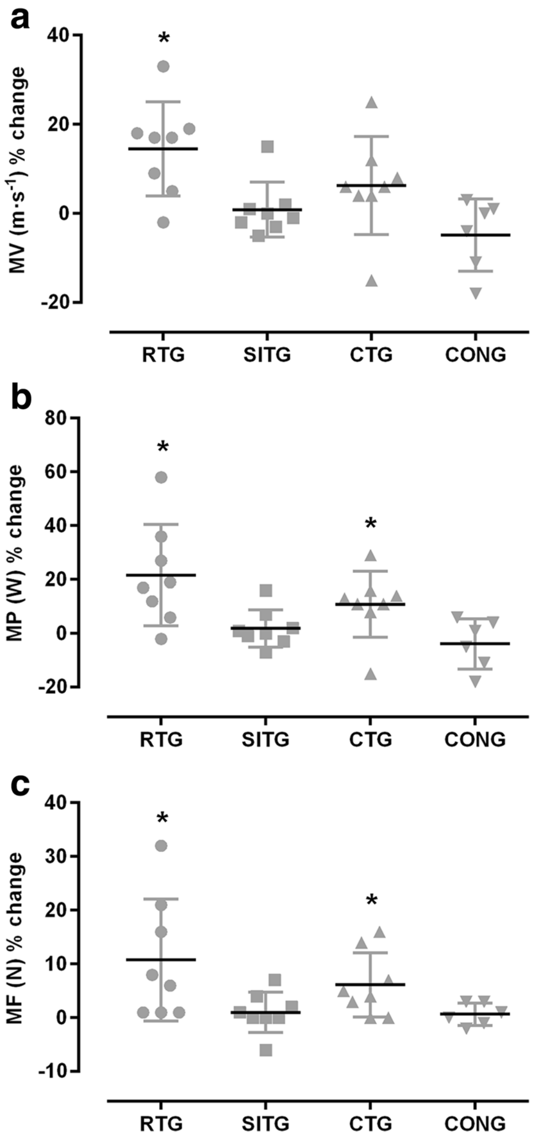


Fig. 3 Percentage (%) change before vs. after in mean velocity (MV) (**a**), mean power (MP) (**b**), and mean force (MF) (**c**) in isoinertial squat test for all groups. *RTG* resistance training group, *SITG* sprint interval training group, *CTG* concurrent training group, *CONG* control group. *$p < 0.05$ before vs. after intragroup differences

HRV measures

There was a main effect of time ($P \le 0.001$) in all the variables (i.e. R–R, SDNN, RMSSD and $\alpha 1$), but neither main effect of group nor interaction was detected ($P > 0.05$).

Redox status

Data from two participants for each experimental group were lost. There were significant main effects of time ($P < 0.001$) and group ($P = 0.029$), and a time × group interaction ($F_{4.31,\infty} = 14.883$; $P < 0.001$) for CAT. Post hoc pairwise comparisons detected significant increments in all the experimental groups for CAT before and after training at pre- and post-incremental tests ($P < 0.001$; $d \ge 2.30$). For GSH, significant main effects of time and group, and a time × group interaction ($F_{9,78} = 37.033$; $P < 0.001$) were found. Post hoc analysis detected a significant increase in all the experimental groups for GSH before and after training at pre- and post-incremental tests ($P < 0.05$; $d \ge 2.02$). For SOD, a significant main effects of time and a time × group interaction ($F_{9,78} = 7.418$; $P < 0.001$) were observed, without main effect of group ($P = 0.361$). Post hoc intragroup comparisons revealed a significant increment in all the experimental groups for SOD before and after training at pre- and post- incremental tests ($P < 0.05$; $d \ge 1.74$) (Fig. 5). For UA, significant main effects of time, group and a time × group interaction ($F_{9,78} = 11.513$; $P < 0.001$) were detected. Subsequent post hoc analysis showed that there were no intragroup differences ($P > 0.05$). Finally, for TBARS, no significant effects were observed ($P > 0.05$).

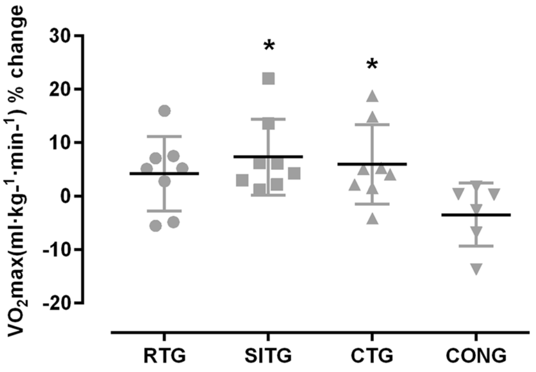


Fig. 4 Percentage (%) change before vs. after in maximum oxygen consumption (VO_{2max}) for all groups. *RTG* resistance group, *SITG* sprint interval training group, *CTG* concurrent group, *CONG* control group. *$P < 0.05$ before vs. after intragroup differences

Discussion

This is the first study that compared time-matched high-intensity programs utilizing very short "all out" efforts during single vs. concurrent exercise modes on physical and physiological parameters. The main finding was that CTG improved similarly to the other exercise groups (RTG and SITG), lower body strength, aerobic capacity and redox status. Furthermore, this work is the first to control confounding variables such as dietary intake, incidental PA, and perceived psychological stress that could interfere with physiological adaptations.

The chronic interference hypothesis postulates that high volume or intensity of training could promote overreaching or overtraining, thus inducing competing responses when

Table 2 Incidental physical activity and dietary intake

	RTG ($n=8$)	SITG ($n=8$)	CTG ($n=8$)	CONG ($n=6$)
Incidental physical activity				
kcal day^{-1}	333.7 ± 185	403.9 ± 241.1	386.3 ± 214.1	219.9 ± 59.7
% in sedentary domain	83 ± 8.3	86.6 ± 4.3	82 ± 5.7	85.1 ± 6
% in light domain	13.7 ± 7.9	11.2 ± 4.1	13.7 ± 4.7	11.6 ± 4.4
% in moderate domain†	3 ± 1.5	1.9 ± 0.8	4 ± 1.6*	3.1 ± 1.5
% in vigorous domain	0.2 ± 0.2	0.3 ± 0.7	0.3 ± 0.3	0.2 ± 0.3
Dietary intake				
kcal day^{-1}	1505.3 ± 300.2	1858.6 ± 771.9	1764.1 ± 870.7	1584.1 ± 449.9
g day^{-1} of protein	71.8 ± 26.3	85.9 ± 30.4	76.2 ± 34.9	71.5 ± 20.3
g day^{-1} of carbohydrate	180 ± 45.2	213.3 ± 96.1	234 ± 114.6	209.7 ± 55
g day^{-1} of fat	55.8 ± 14.5	74.2 ± 34.9	58.8 ± 32.4	51.8 ± 20.7
mg of vitamin C	71.5 ± 54.8	76.6 ± 42.2	124.4 ± 93.4	140.8 ± 61.2
mg of vitamin E	7.1 ± 4.6	5.3 ± 2.2	7.1 ± 6.6	5.4 ± 3.4
µg of vitamin A	144.6 ± 103.9	159 ± 99.5	210.2 ± 106.5	126.4 ± 123.3

Data are $M \pm$ SD

RTG resistance group, *SITG* sprint interval training group, *CTG* concurrent group, *CONG* control group

$^{\dagger}P < 0.05$ intergroup differences; $^{*}P < 0.05$ differences from SITG

strength and endurance training are performed concomitantly (Wilson et al. 2012; Doma et al. 2017). Recently, a meta-analysis concluded that integrating HIIT in concurrent regimes could impede the development of lower body strength, with a trend for more negative effects detected when performing cycling HIIT (Sabag et al. 2018). Similarly, Doma et al. (2017) have suggested that RT-induced fatigue may impair the quality of endurance training sessions, thereby limiting the optimization of endurance development. In this regard, concomitantly training very short duration sprinting and resistance exercise bouts might promote a lower interference effect as they produce similar neuromuscular demands (Wilson et al. 2012). For instance, two previous studies reported that modified SIT of 20 s did not impair the gains in maximum strength of upper and lower limbs (Cantrell et al. 2014; Laird et al. 2016). The current findings are in line with these previous studies (Cantrell et al. 2014; Laird et al. 2016), as CTG improved power and force in the squat exercise to a similar extent than RESG. Furthermore, the present study demonstrated that performing cycling training prior to strength training did not impede on lower body strength development as previously reported (Eddens et al. 2017; Sabag et al. 2018). It is probable that the lower level of endurance training volume employed in the current study, compared to that of previous studies (Coffey and Hawley 2017; Eddens et al. 2017; Sabag et al. 2018), mitigated potential interference on strength development (Doma et al. 2017). This training sequence (i.e. endurance prior to strength training) has also been confirmed to minimize carry-over effects of fatigue between training modes, given that muscular contractility is better preserved by incorporating endurance training prior to strength training performed on the same day (Doma and Deakin 2013).

Previously, it has been suggested that the combination of short sprints with high-intensity resistance exercise can be effective for promoting enhancements in running sprint velocity and maximum strength (Ross et al. 2009). In fact, this combination could be even better since shorter sprints promote lesser homeostatic disturbances and residual fatigue than SIT with longer bouts (Balsom et al. 1992a; Benitez-Flores et al. 2018). Further, it may be suggested that the current RT protocol performed with a low external load could minimize RT-induced fatigue, compared to traditional RT methods with heavy loads, therefore, optimizing the quality of SIT sessions and lower interference of endurance adaptations (Doma et al. 2017). This point is relevant, as muscle power is the parameter most negatively affected by CT (Wilson et al. 2012). Moreover, the CTG improved $VO_{2\max}$ to a similar extent as the SITG, therefore, demonstrating a similar adaptation with no interference effect observed for both anaerobic and aerobic performances. It has recently been shown that limiting velocity loss during training sets generates positive changes in the force–velocity curve and preserves the percentage of myosin heavy chain IIx (Pareja-Blanco et al. 2017). Therefore, considering that both RT and SIT were performed with very short efforts in the current study, this could be a key factor for CTG inducing both neuromuscular and aerobic adaptations to similar levels as SITG and RTG.

RTG was the only group that showed a significant increase in CMJ height after training (~ 8%). This is in agreement with other works that compared concurrent HIIT and RT (Chtara et al. 2008; Fyfe et al. 2016). These

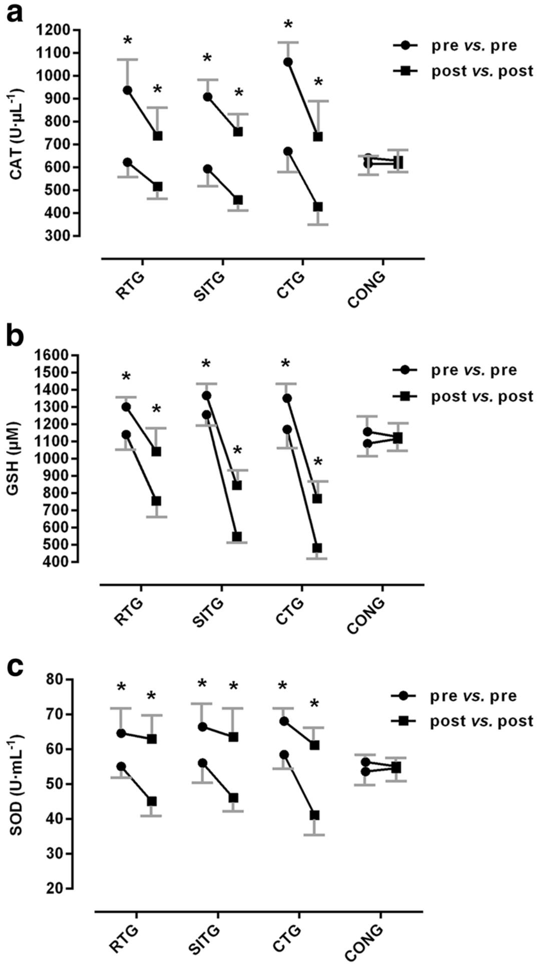


Fig. 5 Catalase (CAT) (**a**), glutathione peroxidase (GSH) (**b**), and superoxide dismutase (SOD) (**c**) response before and after training (pre- vs. pre- and post- vs. post-incremental test) for all groups. *RTG* resistance group, *SITG* sprint interval training group, *CTG* concurrent group, *CONG* control group. *$P < 0.05$ before vs. after intragroup differences

results suggest that the particular training stimuli and volume could be important to potentiate some neuromuscular adaptations. The principle of training specificity indicates that performance enhancements are related to the modality used, depending on the muscular actions involved, speed of movement, range of motion, energy systems and loading patterns (Kraemer and Ratamess 2004). Despite that both cycling and squatting exercises having biomechanical similarities (Bloomer et al. 2006; Wilson et al. 2012) and were completed at high power levels, we speculate that the force-vector application and specific volume might have a role in transference adaptations and CMJ performance changes (Gonzalo-Skok et al. 2016). In contrast to previous literature on SIT (Sloth et al. 2013), we did not find any improvement in anaerobic performance during a supramaximal effort. Previously, it was reported that modified SIT can increase power output in the short term (Hazell et al. 2010; Zelt et al. 2014; Kavaliauskas et al. 2015; Yamagishi and Babraj 2017; Olek et al. 2018) which has not been confirmed in our data. While we do not know the exact reason for this discrepancy with previous literature, it could be speculated that lower TW (~25 kJ vs. 38–59 kJ) (Hazell et al. 2010; Yamagishi and Babraj 2017) and work-to-rest ratio (1:5 vs. 1:8) (Kavaliauskas et al. 2015) performed in the current study when compared to previous ones could be the reason behind this absence of significant improvements. Further studies should verify this issue while controlling other methodological aspects as exercise order during evaluations, and other factors affecting fatigue and recovery.

Another relevant component of our study is that a modified, short version of a HIIT protocol (~13 min) was sufficient to improve VO_{2max} in both SITG and CTG. This training method has a practical significance, since Vollaard and Metcalfe (2017) suggested that shorter sessions could remove many of the common barriers for adhering to regular exercise. Thus, the current study demonstrates the importance of identifying the smallest dose of sprint training required to optimize health benefits (Carrasco 2017). In fact, the TW (~25 kJ) in our proposal was lower to those completed in previous studies using modified SIT (Gillen et al. 2016) and classical SIT (Burgomaster et al. 2008). In addition, both groups maintained a higher HR_{mean} during sessions, representing ~80% of maximum HR. This is in line with previous research with very short sprints in which participants spent several minutes per session near the "red zone" (i.e. ~ 90% VO_{2max}) (Benitez-Flores et al. 2018), allowing sufficient training stimuli to the cardiopulmonary system (Buchheit and Laursen 2013). Enhancements of cardiorespiratory fitness has already been established utilizing a low volume of adapted SIT (Metcalfe et al. 2012, 2016; Gillen et al. 2016). However, this is the first report with similar increments combining both SIT and RT. Thus, the modifications observed in VO_{2max} (~7%) in the current study are comparable to those found after the same period of time using classical SIT (Whyte et al. 2010; Astorino et al. 2011), and HIIT (Lanzi et al. 2015), and can be explained by several central (Matsuo et al. 2014) and peripheral adaptations (Sloth et al. 2013). Our observations also have substantial clinical relevance, because a ~3.5 ml kg^{-1} min^{-1} increase in VO_{2max} is associated with a 13% and 15% lower risk of all-cause mortality and cardiovascular events, respectively (Kodama et al. 2009). Therefore, according to the present findings and the information provided by others (Vollaard and Metcalfe 2017), it could be suggested that both SIT and CT performed with very short efforts are adequate methods to induce cardiorespiratory adaptations after only six sessions.

Exercise-induced reactive oxygen species production is fundamental to oxidative metabolism and redox homeostasis, having important clinical implications, as they regulate the pathophysiology of cardiometabolic diseases (Radak et al. 2013). High-intensity exercise could potentiate the antioxidant response when compared to low-intensity exercise. For instance, Parker et al. (2018) recently showed that SIT promoted superior acute alterations in biomarkers of redox homeostasis compared to extensive HIIT and moderate-intensity continuous training. Bogdanis et al. (2013) reported that nine sessions of classical SIT attenuated oxidative stress and up-regulated antioxidant activity, similar to what was previously observed by Fisher et al. (2011) with HIIT. The current results align with this benefit of high-intensity exercise on redox status, since the three training groups significantly improved endogenous antioxidant defense after the training period. These findings provide novel support for the use of very short, "all out" bouts with different exercise modes, as a valid option for promoting protection against cardiometabolic diseases associated with oxidative stress. Furthermore, to the best of our knowledge, this is the first study to exhibit enhancements in the antioxidant profile after only 2 weeks of training, which demonstrates a very time-efficient training approach (~36 min/week) for improving health outcomes.

Surprisingly, there were no improvements in autonomic control of HR in any group after training. Our results differ with previous literature showing improvements in HRV indices after the application of supramaximal bouts during 2 weeks (Kiviniemi et al. 2014; de Sousa et al. 2018), which have been associated with changes in the aerobic capacity (Kiviniemi et al. 2015). In contrast, we found improvement in $VO_{2\max}$ without significant alterations in HRV indices. While these results are difficult to explain as a number of methodological aspects could be involved (e.g. posture, HRV indices selected, workload, etc.), it could be speculated that the lower metaboreflex stimulation in present training protocols primarily contributed to these trends. Since our protocols are expected to promote lower glycolytic activation and, therefore, lower lactate production (Benítez-Flores et al. 2018), a lower metaboreflex stimulation could have occurred during sessions when compared to previous studies (Kiviniemi et al. 2014; de Sousa et al. 2018), thereby limiting autonomic adaptations after only six sessions (Stanley et al. 2013). Further studies with different glycolytic activity levels should be performed for appropriately testing this hypothesis.

The present study demonstrates several strengths that should be highlighted. First, all participants from the experimental groups completed each session that were time matched for volume of training, reaching a similar total external workload as confirmed by the non-significant differences between groups in TW. This issue is very important because the lack of criteria when comparing divergent training proposals has been suggested to be an important flaw in CT studies (Leveritt et al. 1999; Fyfe et al. 2014; Coffey and Hawley 2017). In this regard, the differences observed in *CR-10 RPE* and HR_{mean} between groups allow appropriate comparisons of both external and internal workloads between groups, thereby highlighting greater efficiency of the CTG. Furthermore, our results demonstrate greater validity since three potentially confounding factors, including incidental PA, diet, and psychological subjective stress perceived by participants during the experimentation period, were objectively controlled with comparable measures between groups. The percentage of time at moderate intensity of incidental PA was the only measure reported to be different between SITG and CTG, which does not likely affect the conclusions.

There are also some limitations in the current study that should be mentioned. First, the number of participants in each group was reduced during the trial, and some samples were lost in the case of redox status. Further studies should verify if the current findings could be confirmed with greater samples. Second, the training period was shorter than most training studies and, therefore, it is not possible to make inferences about what would happen if these interventions would be prolonged. Third, we only recorded HRV on a single day during submaximal exercise; therefore, further studies should determine if autonomic adaptations may be detected in resting and ambulatory conditions over various days (Tonello et al. 2016). Finally, the participants in these studies were young, physically active and healthy. Therefore, the current results could not be extrapolated to other populations (e.g. older populations and/or those with clinical conditions). Further studies with other populations should be conducted over more weeks to determine the efficacy of the current exercise intervention.

Conclusion

In summary, we have examined, for the first time, the benefit of applying high-intensity, very short "all out" efforts on physical and physiological adaptations, using various exercise modes with equivalent workload. The results of this study suggest that the concurrent protocol promotes benefits in neuromuscular performance (i.e. lower body strength) and cardiometabolic health (i.e. aerobic capacity and the redox status) with a lower perceived demand (i.e. *CR-10 RPE*). Interestingly, we did not observe any dropout and adverse events during the intervention period. For this reason, this type of high-intensity protocols could be very important for public health policies with the aim to improve adherence to exercise. Future studies should explore the likely positive effect of programs with very short bouts over longer periods; and to examine these changes in sedentary and clinical populations, especially those with cardiometabolic disorders, in contexts where sophisticated exercise equipment is not necessary. Given that the 'Paleo hypothesis' (Boullosa et al. 2013) states that the polarized intensity distribution of combined PA and exercise would result in greater physiological adaptations and subsequent performances in the long term, furthers studies should elaborate on the chronic effects of these type of SIT protocols when combined or not with other exercises and PA patterns for appropriately testing this hypothesis.

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Author contributions SB-F, DAB, and TSR conceived the study design. SB-F, ARM, and TSR conducted the experiments. SB-F and EI-S conducted the statistical analyses. SB-F, EI-S, TSR, KD and DAB interpreted the results. SB-F, FAV, EI-S, TSR, ARM, KD and DAB: wrote the manuscript. All authors read and approved the final manuscript version.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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