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Metabolic effects of two high-intensity circuit training protocols: Does sequence matter?

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A B S T R A C T

Background/objective: The integration of high-intensity interval training (HIIT) and circuit weight training (CWT) is seamless and practical for meeting recommended exercise guidelines. The purpose of this study was to determine the ideal combination of HIIT and CWT to elicit desired acute cardiorespiratory and metabolic responses in variables such as energy expenditure (EE), oxygen consumption (VO_2), heart rate (HR), blood lactate (BLa^-), excess post-exercise oxygen consumption (EPOC), rating of perceived exertion (RPE), and enjoyment.
Methods: Fourteen trained males (25.7 ± 4.4 yr) completed two exercise protocols matched for volume and recovery periods. On one day, participants performed six HIIT bouts prior to three rounds of a nine exercise CWT protocol (HIC). The second day (separated by ≥ 72 h) consisted of three rounds of three mini-circuits (three exercises per circuit) integrated with three HIIT bouts between the first and second and second and third mini-circuits (TRI). VO_2, HR, and EE were monitored throughout both protocols. EPOC for a 20-min duration, [BLa^-] (five time points), RPE, and enjoyment were measured post-exercise.
Results: Energy expenditure was significantly higher during the HIC compared to the TRI protocol ($p = .012$), as well as EPOC ($p = .034$). [BLa^-] was significantly greater immediate-, 5min-, 10min- and 20min-post-exercise following HIC as compared to TRI. Mean values for HIC and TRI were similar ($p > .05$) for HR and RPE.
Conclusion: Performing HIIT prior to CWT elicits a higher metabolic perturbation compared to the TRI protocol. Although a significant EE difference was detected between the two trials, the practical difference (~20 kcal) between protocols indicates both protocols are similarly effective for caloric expenditure, metabolic and cardiorespiratory response.

Introduction

Exercise programs integrating both resistance exercise (RE) and aerobic training have increased in demand due to their ability to meet exercise guidelines in a time efficient manner.[1] Given that 'lack of time' is the primary reason people do not exercise[2] fitness trainers aspire to develop exercise programs that meet both aerobic and RE goals of a client in a punctual training session, regardless of client fitness level or experience.[1] This, in part, explains the popularity of newer exercise programs (CrossFit, P90X, Insanity) that commonly integrate RE and high-intensity interval training (HIIT) in a progressive overload fashion for continued improvements in exercise performance. HIIT is the performance of short bouts (as little as 6 s to 4 min) of high-intensity exercise alternated with low-intensity bouts during aerobic activity.[3]

Circuit weight training (CWT) is defined as the performance of

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6–12 exercises in a sequential order with little to no break between exercises.[4] With respect to concurrent training, previous research has focused on the sequence of aerobic endurance exercise prior to and following CWT and its effects on strength and power development.[5] Skidmore and colleagues[6] compared the integration of HIIT into CWT to moderate-intensity aerobic training integrated into the same CWT protocol on rating of perceived exertion (RPE), blood lactate concentration [BLa^-] and heart rate (HR). As hypothesized, HIIT integrated into CWT lead to greater RPE, [BLa-], and HR compared to moderate-intensity aerobic training integrated into CWT.

It is known that CWT[7,8] and HIIT[9–11] can simultaneously target muscular strength, endurance and aerobic performance goals. However, no studies have compared the integration of HIIT with CWT (HIIT performed within a CWT protocol) to HIIT performed prior to CWT on the following variables: oxygen consumption (VO_2), energy expenditure (EE), [BLa^-], and excess post-exercise oxygen consumption (EPOC). Furthermore, no studies have determined whether exercisers report greater enjoyment performing one sequence or the other.

Both CWT and HIIT are effective exercise programs which can be seamlessly integrated; however, further research is needed regarding the ideal combination of HIIT and CWT to elicit desired acute cardiorespiratory and metabolic responses as well as perceived exertion and enjoyment. There is a plethora of research on HIIT[12,13] and an equally robust number of studies showing multiple benefits of CWT.[4] There is very little research on the combined effect of HIIT and CWT or integrating HIIT within a CWT format. Thus, the purpose of this study was to examine two concurrent sessions of equal training volume differing only in order; whether performing bouts of HIIT training prior to a CWT protocol can produce similar responses to HIIT bouts within CWT protocols for the following variables: HR, VO_2, EE, [BLa^-], EPOC, RPE, and enjoyment in college-aged recreationally trained men.

Materials and methods

Study design

Fourteen healthy male volunteers served as their own control in a repeated-measure, counterbalanced crossover design, in which subjects performed both HIIT before CWT (HIC) and a trial integrating HIIT with mini-CWT (TRI), separated by at least 72 h. Trials were precisely equated for total work (all externally loaded circuit exercises were performed for 10 repetitions for a duration of 30 s of time under tension) and recovery period durations for all participants. Both protocols were comprised of six bouts of HIIT in a 1:3 format (30-sec work and 90-sec recovery), while CWT was a 1:1 format (30-sec work [10 or 15 repetitions; 3 s per repetition] and 30-sec recovery). Before the trials, participants completed treadmill maximal oxygen consumption (VO_{2max}) and one-repetition maximum (1-RM) testing following established guidelines at the same time of day as the exercise protocols with the same research technician running all tests and trials. Testing was performed in the following order: (1) VO_{2max} test, (2) 1-RM tests, (3) familiarization, (4) protocol trials were counterbalanced with (5) being the opposite protocol from trial 4. See Fig. 1 for a detailed outline of the study design, including duration between exercise testing days.

Participants

All participants (age = 25.7 ± 4.4 yr) were informed of the study protocol approved by the university Institutional Review Board and signed a written informed consent prior to participation. Training status was self-reported and individuals who lacked resistance training at least two days per week and aerobic training at least three days per week for at least 6 months were excluded (see Table 1). A homogenous population of healthy, active participants was chosen to better understand the efficacy of these high-intensity training protocols for this fitness level. Prior to beginning the study, all participants completed a standardized health history/exercise questionnaire to ensure they had no physical limitations and met the minimum requirements for study participation. None of the participants had a history of musculoskeletal injuries, cardiovascular or pulmonary disease, or were on medications during the study. Participants were instructed to consume the same meal at the same time interval prior to both trials.

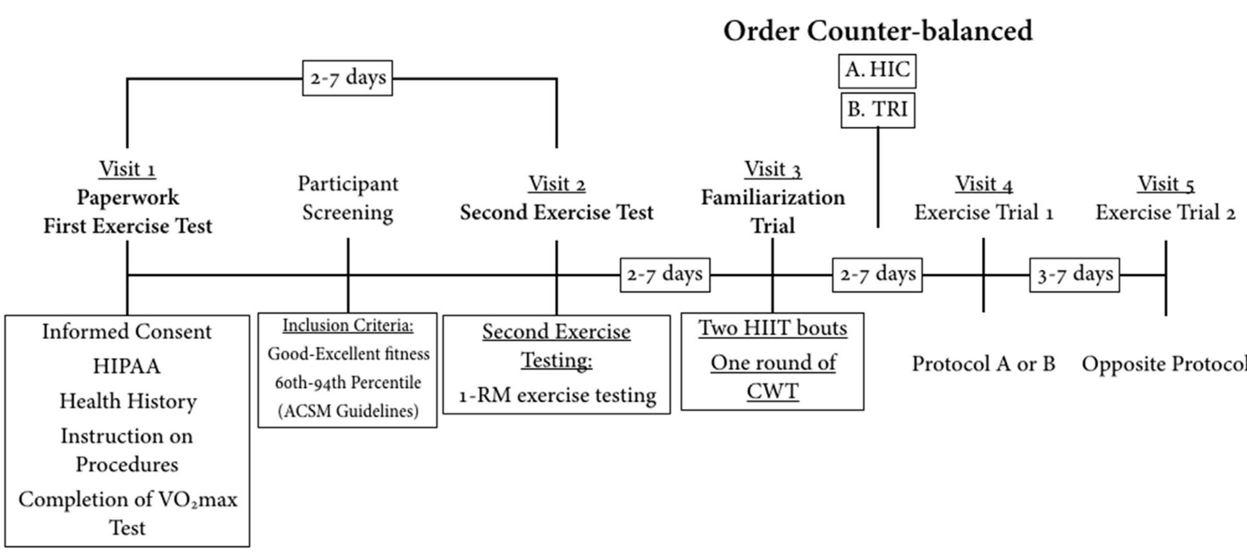

Fig. 1. Research study design. 1-RM = one-repetition maximum; ACSM = American College of Sports Medicine; CWT = circuit weight training; HIIT = high-intensity interval training; HIPAA = Health Insurance Portability and Accountability Act; HIC = high-intensity interval exercise prior to circuit weight training; TRI = mini-circuit weight training (three exercise circuits) with integrated high-intensity exercise.

Table 1
Subject characteristics ($n = 14$).

Characteristic	Mean ± SD
Height (cm)	173.8 ± 5.1
Mass (kg)	77.6 ± 5.8
Age (yr)	25.7 ± 4.4
Body fat (%)	10.6 ± 3.7
VO_{2max}[d] ($ml \cdot kg^{-1} \cdot min^{-1}$)	47.6 ± 4.3
V_{max}[e] ($m \cdot min^{-1}$)	235.1 ± 20.3
HR_{max}[f] (bpm)	190.7 ± 9.0
Squat 1-RM[a] (kg)	133.9 ± 18.5
BB[b] Bent Over Row 1-RM (kg)	83.7 ± 13.7
DB[c] Shoulder Press 1-RM (kg)	29.2 ± 5.6
Trap Bar Dead Lift 1-RM (kg)	157.4 ± 22.7
Lat Pull Down 1-RM (kg)	123.3 ± 21.4

[a] 1-RM = one-repetition maximum.
[b] BB = barbell.
[c] DB = dumbbell.
[d] VO_{2max} = rate of maximal oxygen consumption.
[e] V_{max} = maximal velocity obtained during VO_{2max} test.
[f] HRmax = maximal heart rate obtained during maximal exercise test.

Exercise testing and screening

Prior to the exercise protocol trials, all participants performed a VO_{2max} test on a treadmill ergometer (C966i, Precor Inc., Woodinville, WA, USA) on the participant's initial visit (Visit 1; see figure below). Oxygen consumption was measured using a calibrated portable metabolic analyzer (as described above). All VO_{2max} testing was performed in a ramp fashion, previously described by Beltz et al.[14]. At the start of the exercise test, treadmill was set to an incline of 3.0% and a starting speed of 'light' according to the participant. Speed was increased 0.1 mph every 15 s to the point when the participant could no longer continue. Maximal oxygen consumption was confirmed when an individual subject attained at least two of the following criteria: heart rate within 10 beats of age predicted max, respiratory exchange ratio equal to or greater than 1.15, and/or rating of perceived exertion ($RPE_{6\text{-}20}$)[15] greater than 17. All participants met the criteria for VO_{2max} attainment. The results of the VO_{2max} test determined if the participant was eligible for inclusion in the study (see Table 1). If the VO_{2max} results determined that the participant was not eligible for the study (e.g., less than 'Good' cardiorespiratory fitness according to the ACSM guidelines based on the participant's age), the participant was excluded from any further trials. Max velocity (V_{max}) reached during the VO_{2max} test was used to determine the running speeds for the HIIT bouts. Maximal heart rate attained during the VO_{2max} test was used as the HRmax during statistical analysis.

After a minimum of 48 h following the VO_{2max} test, participants returned to the exercise laboratory for one-repetition maximum testing (1-RM testing) (Visit 2). To determine load during exercise protocol, all 1-RM exercises were completed in the following order: Smith machine back squat, bent over barbell row, trapezoid bar deadlift, dumbbell shoulder press, and latissimus pull down (see Table 1). All 1-RM testing followed standardized guidelines previously described by Haff & Triplett.[16] Exercise technique, range of motion and repetition duration (3-sec per repetition) were explained and monitored by the same researcher (NSCA Certified Personal Trainer) on all exercises for all participants. Repetition duration was cued using a metronome (SQ 50V, Seiko Instruments Inc., Shizuoka, JPN).

Between two and seven days following 1-RM testing, participants returned for a familiarization trial (Visit 3). Two bouts of high-intensity interval training were performed, followed by a round of the CWT protocol. The familiarization was done to ensure volunteers understood the sequence of the CWT protocol and proper form/technique could be executed for each exercise. Upon completion of the familiarization trial, participants were counterbalanced to one of the two exercise protocols: HIIT before conventional CWT (HIC) or integration of HIIT exercise with mini-CWT (TRI). The familiarization and exercise trials were separated by three to seven days.

Anthropometrics and body composition

Each session took place in the same location under similar environmental conditions and at the same time of day (±2 h). Height (nearest 0.1 cm) and body mass (nearest 0.1 kg) was measured at the beginning of each session wearing lightweight clothing. Upon arrival for the first exercise testing trial, body density was estimated using a standardized three-site (e.g., chest, abdomen, thigh) skinfold (Lange, Beta Technology, Ann Arbor, MI, USA) measured in duplicate and averaged.[17] The same technician performed the skinfold measurements for all participants. Body fat was calculated using the appropriate body density equation.[18]

Blood lactate

Blood lactate measurements (Lactate Plus, Nova Biomedical, Waltham, WA, USA) were collected pre-, immediate post- (IP), 5-min post-, 10-min post- and 20-min post-exercise. All [BLa^-] samples throughout the study were collected using a lancing device at the ear lobe, obtained in duplicate and averaged for analysis.

Metabolic gas and heart rate

Oxygen consumption and carbon dioxide production were continuously measured using breath-by-breath sampling ($K4b^2$, COSMED, Chicago, IL, USA) to obtain metabolic variables (i.e., VO_2, EPOC) for the following exercise trials: VO_{2max}, HIC and TRI. Average VO_2 was calculated as a running average for the breath-by-breath data (taken from minute 0 to the end of exercise), which was shown during testing to be equal to an average calculated with 15-sec averaged VO_2 data. The metabolic gas analyzer was calibrated prior to each exercise session in accordance with manufacturer guidelines. Heart rate was monitored continuously using a Polar™ heart rate monitor (V800, Polar Electro Inc., Woodbury, NY, USA), which was integrated with the $K4b^2$ device. These HR and metabolic data were downloaded following the exercise trials. EE provided by the $K4b^2$ device was utilized for statistical analysis.

Ratings of perceived exertion and enjoyment

To ensure the most consistent responses, subjects provided $RPE_{6\text{-}20}$ and enjoyment ratings using a Physical Activity Enjoyment seven-point bipolar Scale (PAES)[19,20] for the entirety of each exercise protocol at 20-min post-exercise.[21] The PAES is a validated questionnaire that allows for quantitative ratings of perceived enjoyment.[19] Responses for PAES are on a bipolar scale from 1 to 7. For example, *I enjoy it* is a score of "1", while *I hate it* is a score of "7". Other dichotomized responses on the PAES are *I feel bored* and *I feel interested*, *I find it energizing* and *I find it tiring*, and *It's very gratifying* and *It's not at all gratifying*. A response of "4" would be considered neutral for the participant.

Exercise protocols

Upon arrival for both HIC and TRI exercise sessions, participants were fitted with the portable metabolic cart (K4b^2) and HR monitor and one-minute of resting data were collected. The sequence the exercise trials are illustrated in Fig. 2. Both HIC and TRI protocols were matched for volume-load and time (43.25 min) and monitored by the same researcher to ensure form/technique and safety. While no review specifies the suggested work to rest ratios that are best for HIIT[12,13] and CWT[4], we selected 1:3 (work:rest) for HIIT and 1:1 for CWT based on pilot data. Excess post-exercise oxygen consumption (EPOC) was collected for 20 min immediately following the completion of the exercise protocol while the participant was sitting quietly.

Analyses of data

Data are presented as mean ± standard deviation. Paired student t-tests were performed to determine differences for average VO_2 and HR between the two protocols. Area under the curve (AUC) was calculated using 11-breath averaging[22] for VO_2 data during EPOC for both protocols and plotted against time using the statistical software Prism (GraphPad Software, Inc., La Jolla, CA, USA). Energy expenditure was obtained from the K4b^2. A two-way analysis of variance (ANOVA) with repeated measures was used to determine differences for [BLa$^-$] (2 × 5) between the two protocols for all time points. A Wilcoxon signed ranks test was used to determine differences for RPE and PAES between the protocols. Alpha-level was set to $p \leq 0.05$ for all statistical analyses. These data were analyzed using the statistical package SPSS (Version 21.0, Chicago, IL, USA). According to a statistical power analysis with an α-level = 0.05 and 1-β = 0.80, the number of subjects required per group for a valid analysis was $n = 12$.

Results

[BLa$^-$]

The repeated measures (2 × 5) ANOVA yielded a significant difference between HIC and TRI for [BLa$^-$] time, $F(4, 65) = 4.619$, $p = .002$. Post hoc t-test with Bonferroni adjustment determined HIC elicited significantly higher [BLa$^-$] compared to TRI measurements for IP (10.7 ± 3.8 vs. 8.5 ± 3.4 mg dL^{-1}), $p < .001$, 95% CI [8.3, 11.0], 5-min (10.1 ± 3.1 vs. 8.0 ± 3.4 mg dL^{-1}), $p < .001$, 95% CI [7.8, 10.3], 10-min (8.9 ± 3.0 vs. 6.6 ± 3.1 mg dL^{-1}), $p < .001$, 95% CI [6.6, 9.0] and 20-min (6.6 ± 2.7 vs. 4.9 ± 2.4 mg dL^{-1}), $p = .001$, 95% CI [4.8, 6.7] post-exercise time points (see Fig. 3).

VO_2 and HR

Average VO_2 (VO_{2ave}) was significantly greater during HIC compared to TRI (mean = 1.99 ± 0.22 L min^{-1} vs. 1.92 ± 0.23 L min^{-1}, respectively); $t(13) = 2.561$, $p = .024$, 95% CI [1.87, 2.04]. Fig. 4 illustrates VO_2 tendencies during the two protocols. In order to determine percent-VO_2 reserve (%VO_2R) for practical application, VO_2 reserve for each participant was calculated as: VO_{2max} − 3.5 ml kg^{-1}·min^{-1}. VO_{2ave} (in ml·kg^{-1}·min^{-1}) was divided by VO_2R to calculate %VO_2R.[23] There was no difference for %VO_2R between HIC and TRI protocols (57.4 ± 4.6% vs.

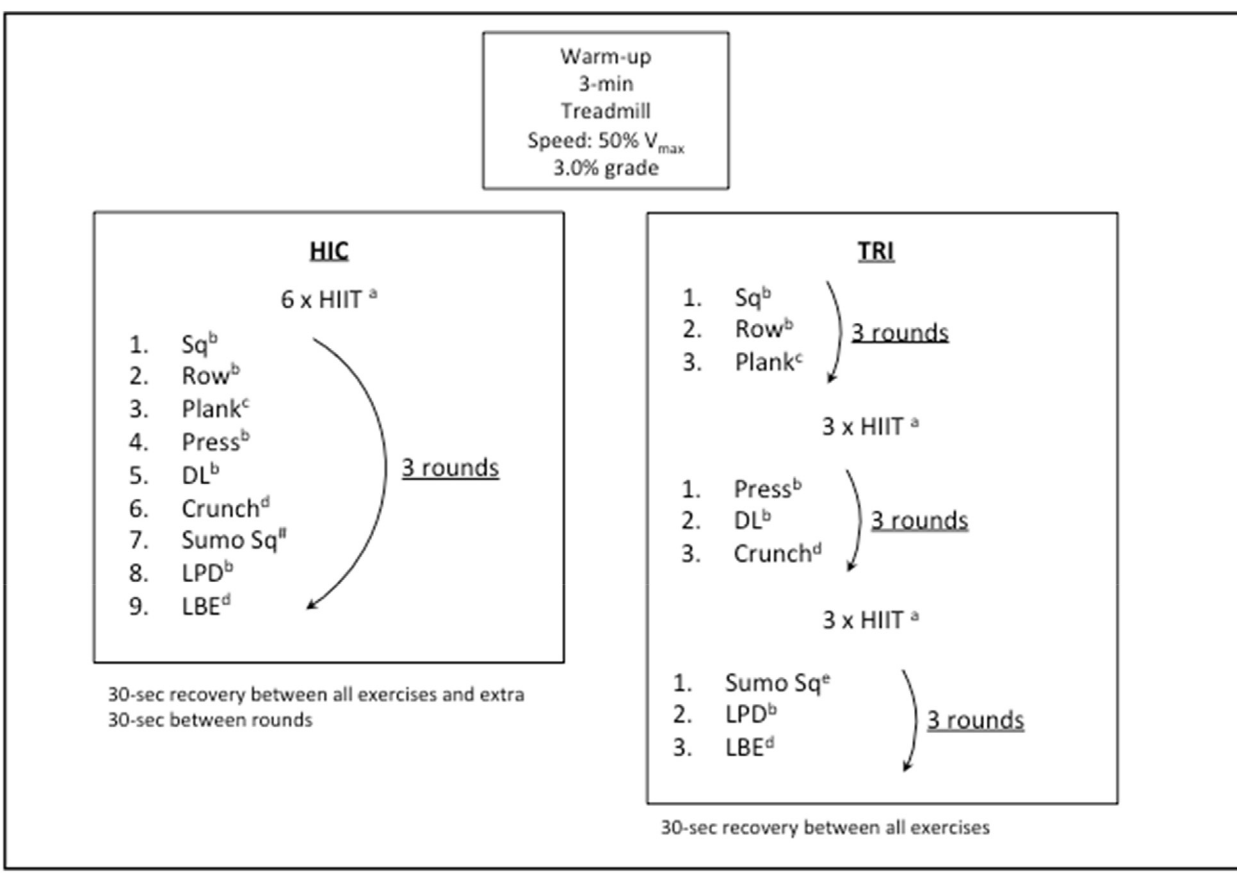

Fig. 2. Exercise protocol design for HIC and TRI. *DL – trapezoid bar deadlift; LBE – low back extension; LPD – latissimus pull down; Press – dumbbell shoulder press; Row – bent over barbell back row; Sq – Smith machine back squat; Sumo Sq – kettlebell sumo squat. [a] - 30sec @ 105% Vmax, 90sec @ 3mph 3% grade. [b] - 10 repetitions @ 50% 1-RM. [c] - 30sec duration. [d] - 15 total repetitions @ body weight. [e] - 10 repetitions using 16 kg kettlebell.

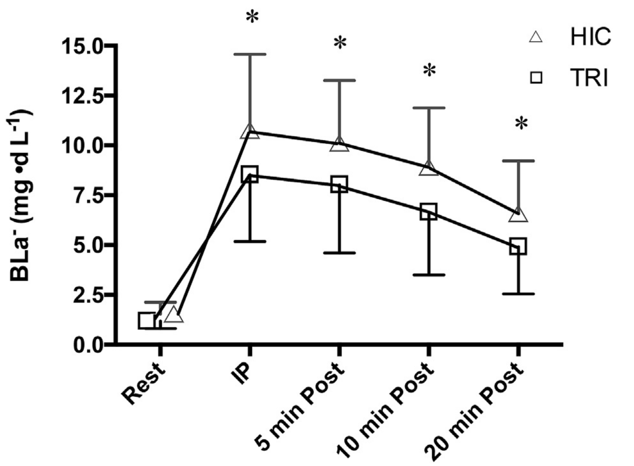

Fig. 3. Blood lactate response between HIC and TRI. [a]HIC = high-intensity interval exercise prior to circuit weight training; [b]TRI = mini-circuit weight training (three exercise circuits) with integrated high-intensity exercise; Blood lactate ($[BLa^-]$); immediate post-exercise (IP); 5 min post-exercise (5 min Post); 10 min post-exercise (10 min Post); 20 min post-exercise (20 min Post); *indicates significance between protocol time-points.

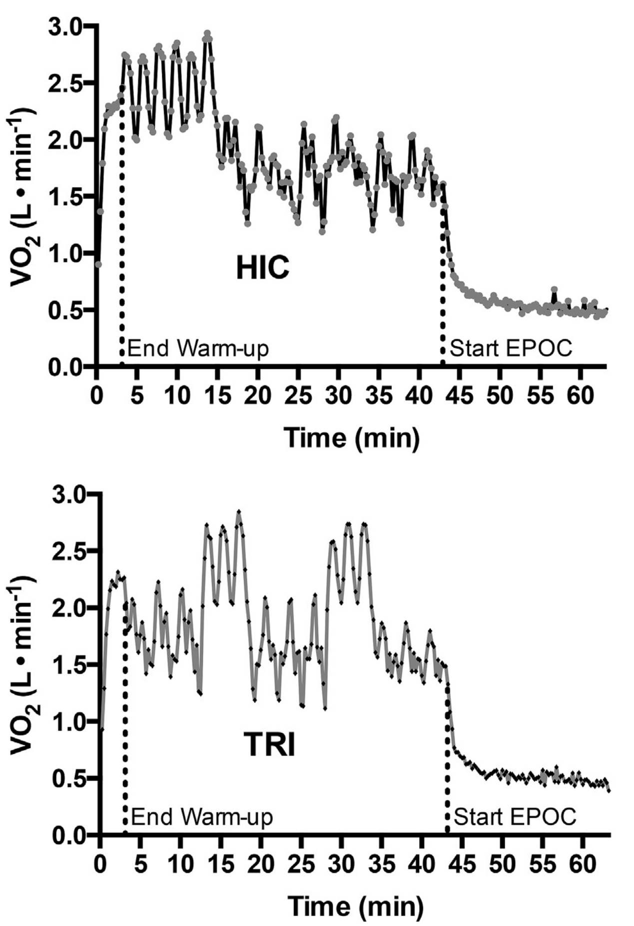

Fig. 4. Oxygen consumption response for HIC and TRI. *Excess post-exercise oxygen consumption (EPOC); HIC = high-intensity interval exercise prior to circuit weight training; TRI = mini-circuit weight training (three exercise circuits) with integrated high-intensity exercise; rate of oxygen consumption (VO_2).

56.7 ± 5.6%, respectively). There was no difference for average HR (HR_{ave}) or percent-HR_{max} (%HR_{max}) between HIC and TRI protocols (149.8 ± 12.5 beats·min^{-1} vs. 149.6 ± 16.3 beats·min^{-1}; 78.5 ± 4.8% vs. 78.4 ± 7.0%, respectively).

EE and EPOC

EE was significantly greater during HIC compared to TRI (mean = 434.6 ± 48.7 vs. 419.9 ± 49.0 kcal, respectively); $t(13) = 2.535$, $p = .025$, 95% CI [409.3, 445.3]. EPOC was significantly greater following HIC compared to TRI (mean = 61.9 ± 7.8 vs. 56.7 ± 6.2 kcal, respectively); $t(13) = 2.900$, $p = .012$, 95% CI [56.5, 62.0].

RPE and PAES

No difference was found for $RPE_{(6\text{-}20)}$ between protocols (HIC: 15.7 ± 1.5; TRI: 16.1 ± 1.4). According to the PAES responses, subjects found the HIC protocol to be more "interesting" compared to the TRI protocol (mean = 6.43 ± 0.76 vs. mean = 6.00 ± 0.88); $Z = -2.121$, $p = .034$. There were no differences between protocols for any other PAES responses.

Discussion

The main findings from the present study were that $[BLa^-]$, exercise EE and EPOC were higher for the HIC protocol compared to the TRI protocol with both protocols being equated for load and time. Combining exercise EE and EPOC resulted in a 20-kcal difference between the protocols, which may not be practically significant for exercisers. The blood lactate results from the current study indicate that performing HIIT prior to CWT poses a more substantial challenge within the exercise muscle milieu compared to integrating HIIT into a clustered mini-CWT (or Tri-set) protocol. Furthermore, performing HIIT prior to CWT elicits greater total energy expenditure compared to HIIT within mini-CWT bouts.

Blood lactate is primarily used as a marker of exercise intensity.[24] Since exercise intensity, duration of rest, and HIIT bouts and duration were equal between protocols, we hypothesized that BLa^- would not differ between protocols; however, this was not the case. Blood lactate concentration was significantly higher for all post-exercise time points following the HIC protocol as compared to TRI program. This may have occurred due to an improved clearance of BLa^- during the integrated HIIT performed in the TRI protocol. During the TRI protocol, CWT was separated by HIIT, which allowed for active recovery periods (90 s walking at 3.0% incline) during the workout. These active recovery periods may have led to a greater BLa^- clearance rate during the TRI protocol. Previous research has shown that active recovery following high-intensity exercise improves BLa^- clearance compared to passive recovery.[25,26] Unlike the TRI protocol, the HIC protocol consisted of CWT performed for 3 consecutive nine-exercise circuits with an additional 30 s of passive recovery between circuits; potentially explaining the greater $[BLa^-]$ accumulation and metabolic perturbation.

During the HIC and TRI protocols, the %VO_2R was 57.4% and 56.7%, respectively, while %HR_{max} was 78.5% and 78.4%, respectively. These %VO_2R and %HR_{max} values are similar to those found in previous research evaluating CWT.[27,28] Interestingly, despite differences in $[BLa^-]$, exercise EE, and EPOC, there was no significant difference in %VO_2R or %HR_{max} between the two protocols. Although both protocols were predominately anaerobic, the VO_2 and HR responses are indicative of a large cardiorespiratory response. These results suggest that both protocols are suitable exercise modalities for eliciting both an anaerobic and aerobic stimulus.

Exercise EE was significantly greater during HIC (442 ± 51.5 kcal) compared to TRI (421 ± 41.2 kcal). Average energy expenditure was greater during both HIC and TRI protocols (10.1 and 9.7 kcal min^{-1}, respectively) compared to results from previous resistance training studies.[29,30] EPOC is used as a marker of metabolic disturbance following anaerobic exercise[31,32] due to returning the body to a homeostatic state (e.g., repletion of muscular substrate, decreases in body temperature, and ventilation rate), which includes the oxidation of BLa-[31–33] Since HIC lead to higher post-exercise [BLa^-] it could be hypothesized that this would also lead to greater EPOC.[6] This was the case in the current study, as the HIC protocol had a higher [BLa^-] and EPOC response compared to the TRI protocol. Although there is no previous research to characterize why this occurred, we hypothesize that the build-up of anaerobic by-products (i.e., blood lactate, hydrogen ions, etc.) following the HIC protocol may have contributed to a greater EPOC response. Since TRI dispersed resistance exercise with HIIT, the low-intensity recovery period during HIIT may have led to improved clearance of the anaerobic by product created during the mini-CWT.

Research has determined that RPE is a suitable measure of intensity during and following both resistance and aerobic exercise.[34,35] Participants in the current study reported the HIC and TRI protocols to be similar in RPE (15.7 ± 1.5 and 16.1 ± 1.4, respectively), despite having significantly higher [BLa-], EPOC, and EE during the HIC protocol. The similarity in RPE between protocols may have been due to both being equated for time and intensity. Both protocols were perceived to be in the 'hard' to 'very hard' range. According to Row and colleagues[35], approximate loads of 50% 1-RM should elicit RPE responses in the 'fairly light' category, while Day et al.[34] reported RPE responses in the 'moderate' to 'somewhat hard' category for similar % 1-RM intensities. However, both studies used single set lifts, unlike the multiple set circuit format used in the current study. Our findings are in agreement with those of Skidmore and colleagues[6], who reported RPE responses in the 'very hard' to 'maximal' range following 3 sets of integrated HIIT with mini-CWT (three exercises per circuit) for 13 repetitions at 90% of a 13-RM with 15-sec of rest between exercises. Limited recovery periods mixed with bouts of HIIT may have led participants to rate the protocol as harder compared to protocols containing only single-set exercises.

We quantified the exercise enjoyment using the PAES and observed that subjects perceived the HIC protocol to be more 'interesting' than the TRI protocol. It is also important to note that both protocols were rated 'enjoyable' and 'gratifying' according to the PAES. Furthermore, we must acknowledge that the sample for the current study was an active population who had been taking part in both resistance and aerobic training. Bartlett and colleagues[19] found similar results when comparing HIIT to moderate-intensity continuous running, where individuals taking part in the HIIT rated it more 'enjoyable' compared to the moderate-intensity continuous running. This was also a physically active sample and may have led to this difference in rating of enjoyment. Since individuals are more likely to adhere to an exercise program they find 'enjoyable'[36], this may be a suitable exercise protocol to increase feelings of enjoyment.

Future research should determine if the integration of HIIT with CWT leads to a different training effect compared to performing HIIT prior to CWT. Specifically, whether the responses of VO_2 and HR for both protocols lead to improvements in aerobic performance, as well as how both protocols would affect muscular endurance and strength. Furthermore, although a 20 kcal difference may lack practical significance in an acute bout of exercise, further research should determine whether this could result in a difference in training adaptation between these two exercise protocols. Lastly, future research ought to determine if individuals who are not physically active would rate these types of protocols as 'enjoyable' and 'gratifying', as well as the long-term adherence to such protocols.

In conclusion, performing HIIT prior to CWT leads to significantly greater [BLa^-], EPOC and EE compared to integrated HIIT with mini-CWT clusters. We also conclude that physically active individuals enjoy HIIT within mini-CWT and performing HIIT prior to CWT equally. From a practical application viewpoint, performing HIIT prior to CWT leads to a larger metabolic disruption during training and thus may not be best indicated for the entry-level fitness participant. For this sample, integrating HIIT into a clustered mini-CWT may be a preferable start with this combination of programs. The data from this study show that HIIT before CWT (HIC) and integrating HIIT with mini-CWT (TRI) elicit several favorable metabolic and cardiorespiratory responses, which may be beneficial for persons desiring to improve muscular fitness and cardiorespiratory endurance in time-efficient protocols.

Declaration of interest statement

The authors declare that they have no conflict of interest related to the present study.

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All authors approved the final version of the manuscript. We would like to acknowledge the participants of the study for dedicating their time.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jesf.2019.08.001.

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