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Article

Aerobic adaptions following two iso-effort training programs: an intense continuous and a high-intensity interval

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Abstract

The intensity of the training stimulus and the effort exerted (regarded as an index of internal load) to complete an exercise session are driving forces for physiological processes and long-term training adaptations. This study compared the aerobic adaptations following two iso-effort, ratings of perceived exertion (RPE)-based training programs, an intense continuous (CON) and a high-intensity interval (INT). Young adults were assigned to a CON ($n = 11$) or an INT ($n = 13$) training group to perform 14 training sessions within 6 weeks. The INT group performed running bouts (9.3 ± 4.4 repetitions) at 90% of peak treadmill velocity (PTV) with bout duration equal to 1/4 of time to exhaustion at this speed (134.2 ± 27.9 s). The CONT group ran (1185.0 ± 487.6 s) at a speed corresponding to −2.5% of critical velocity (CV; 80.1% ± 3.0% of PTV). Training-sessions were executed until RPE attained 17 on the Borg scale. VO_2max, PTV, CV, lactate threshold velocity (vLT), and running economy were assessed pre-, mid-, and post-training. Both CONT and INT methods increased ($p < 0.05$) VO_2max (INT: 57.7 ± 8.1–61.41 ± 9.2; CONT: 58.1 ± 7.5–61.1 ± 6.3 mL kg^{-1} min^{-1}), PTV (INT: 14.6 ± 1.8–15.7 ± 2.1; CONT: 15.0 ± 1.7–15.7 ± 1.8 km h^{-1}), CV (INT: 11.8 ± 1.4–12.8 ± 1.8; CONT: 12.2 ± 1.6–12.9 ± 1.7 km h^{-1}), and vLT (INT: 9.77 ± 1.1–10.8 ± 1.4; CONT: 10.4 ± 1.4–11.0 ± 1.8 km h^{-1}) with no differences ($p > 0.05$) between them; running economy remained unchanged. The continuous training method, when matched for effort and executed at relatively high intensity at the upper boundaries of the heavy-intensity domain (∼80% of PTV), confers comparable aerobic adaptations to those attained after a high-intensity interval protocol following a short-term training period.

Key words: HIIT, interval training, continuous exercise, iso-effort, aerobic performance, high intensity

Introduction

High-intensity interval training (HIIT) and continuous training are two effective methods for the improvements in cardiorespiratory (aerobic capacity), muscle metabolic function, and aerobic performance (Daussin et al. 2008; Hottenrott et al. 2012; Milanović et al. 2015). The continuous method is usually performed at the moderate intensity domain (below the lactate threshold—speed/power corresponding to that at 50%–70% VO_2max) and for long-to-very long exercise durations (i.e., 30–120 min) (Jung et al. 2019; Papandreou et al. 2020). On the other hand, the interval training method is applied using exercise intensities at the severe domain (above critical velocity (CV)—speed/power corresponding to that at 85%–140% of VO_2max) with short-to-long exercise bouts (i.e.,15 s–8 min) (Stepto et al. 1999; Smith-Ryan et al. 2015; Ronnestad et al. 2020). Numerous studies showed that low-volume HIIT induces greater or similar improvements in VO_2max and peak treadmill velocity (PTV) accumulating less exercise time when compared with high-volume moderate-intensity continuous training (Helgerud et al. 2007; Jung et al. 2019; Milanovich et al. 2015; Papandreou et al. 2020).

The efficacy of a training program is affected by the combination of the intensity and the duration (determinant of training volume) of the exercise session that determines total training stress (stimulus) (Hofmann and Tschakert 2017). Most studies have used the total work approach to equalize the training stimulus and compare the efficacy of the continuous and the interval training methods (Cunha et al. 2016; Jung et al. 2019). Nevertheless, the amount of total work (training intensity and volume) completed during an exercise session reflects only the external load, while total training stress (stimulus) may be better defined by internal load parameters (Halson 2014; Schwellnus et al. 2016; Soligard et al. 2016). Under total work-matched conditions, the higher intensity of an interval training protocol leads to higher heart rates (HRs), oxygen consumptions, lactate concentrations, and ratings of perceived exertion (RPE) than a low-intensity continuous training protocol (Hottenrott et al. 2012; Nicolò et al. 2014), suggesting a higher internal load and a higher training stimulus (Eston 2012; Halson 2014; Schwellnus et al. 2016; Soligard et al. 2016). Therefore, matching for external load parameters between the two exercise methods does not necessarily ensure a similar internal load and training stimulus during exercise sessions, which is the main driving force for long-term training adaptations (Baar 2009; Egan and Juleen 2013). In fact, in real practice, coaches and exercise specialists do not use solely the external total work approach to design interval and continuous training and to monitor the training stimulus but rather apply indices of internal load as well (Muñoz et al. 2014; Stöggl and Sperlich 2015). The iso-effort approach, by using rate of perceived exertion values, has been widely suggested as a measure of internal load and training stimulus of an exercise session and has been used to monitor the physiological strain during aerobic exercise (Pratt et al. 2013; Sandbakk et al. 2013; Seiler et al. 2013; Nicolò et al. 2014). Previous studies showed comparable central hemodynamic, muscle oxygenation, and metabolomic responses between iso-effort continuous and long-interval high-intensity exercise bouts (Zafeiridis et al. 2015, 2016) pertaining to comparable long-term training aerobic adaptations. Nevertheless, no study, so far, has compared the efficacy of a high-intensity interval and a continuous training program under iso-effort conditions. This is important as the accumulated internal load (training stimulus) during individual exercise sessions may govern long-term training adaptations.

Apart from the above, coaches often apply the continuous training method using high intensity, called "race pace" or "tempo" runs, with the intensity being around the 2nd lactate threshold or CV, which is at the boundaries of the heavy–severe intensity domain. Although the intense continuous training is being used in the training plans of athletes (Bakayev and Bolotin 2020; Casado et al. 2021), research studies have focused on continuous training at the moderate-intensity domain providing a different metabolic stimulus compared with HIIT executed at the severe-intensity domain at higher levels of exertion (Cavar et al. 2019; Papandreou et al. 2020). Furthermore, most studies that compared the continuous and the interval training methods focused on the improvement of VO_2max and PTV (Rognmo et al. 2004; Helgerud et al. 2007; Tanisho and Hirakawa 2009). Aerobic and endurance performance depends on other parameters as well, such as running economy, velocity at the 1st and the 2nd lactate threshold, and CV (Jones 2006; Joyner and Coyle 2008). To the best of our knowledge, no study has compared the efficacy of the two methods on these parameters using the iso-effort approach and the continuous training performed at the heavy-intensity domain preserving exercise time. Such a study would enrich our knowledge regarding the effects of interval and continuous training on important physiological determinants of endurance performance.

Based on the above, the purpose of this study was to compare the adaptations after a 6-week training period between the intense continuous and the HIIT methods performed under iso-effort conditions (similar RPE values) on maximal (VO_2max and PTV) and submaximal (CV, lactate threshold parameters, and running economy) aerobic performance parameters. We hypothesized that the two training methods would induce comparable aerobic adaptations. We based our hypotheses considering that (*i*) the continuous training will be performed at the boundaries of heavy-to-severe intensity domain (close to the intensity domain of interval training) and (*ii*) the training methods will be matched for overall internal load using the iso-effort approach.

Methods

Subjects

Thirty-one subjects were screened prior to participation in the study. Five subjects were excluded because they refused to discontinue their training program and follow only the one applied in this study. Twenty-four young adults (9 males and 15 females, age: 21 ± 3 years, body mass: 67.4 ± 9.8 kg, VO_2max: 57.7 ± 7.6 mL kg^{-1} min^{-1}) volunteered to participate in this study after signing an informed consent form. All participants were involved in low-intensity continuous training, 1–3 times per week for 30–45 min for at least 3 months. The experimental protocol was approved by the Institutional Research Ethics Committee (23566/129/2020) of Democritus University of Thrace and was conducted in accordance with the ethical standards of the Declaration of Helsinki.

Experimental design and training programs

A parallel group research design was used in this study. Initially, 26 participants (10 males and 16 females), using stratified randomization (gender was the variable of stratification) were randomly assigned (1:1), according to a random number table, either to an intense continuous training group (CON) or to a HIIT group (INT). During the second week, two participants (one male and one female) from the CON group withdrew from the study due to personal reasons, not related to the experiment. So, the study was completed, and the collected data were analyzed for 11 participants (4 males and 7 females) in the CONT group and 13 participants (5 males and 8 females) in the INT group (Fig. 1).

The training program consisted of 14 training sessions performed over a 6-week period. Three training sessions were executed in the 1st, the 2nd, the 4th, and the 5th week and one training session in the 3rd and the 6th week. The sessions were separated by a 48–72 h rest period. During the experiment, participants did not perform any other form of training besides of that applied in this study. VO_2max, PTV, oxygen consumptions, HRs and the velocities corresponding to the 1st and the 2nd lactate thresholds (LT_1 and LT_2), the velocity at 4 mmol L^{-1} of blood lactate concentration (v4 mmol), running economy, and CV were measured before, after seven training sessions (3rd week, 2 days after the 7th training session), and after the completion of training program (Fig. 2).

The INT group trained using the interval method. During the exercise sessions, the participants ran each bout at an intensity corresponding to 90% of PTV. PTV was used to prescribe the exercise intensity at the INT group as this method has been used in previous studies (Cavar et al. 2019). The duration of the running bouts was equal to 1/4 of the individual time to exhaustion at 90% of PTV (determined

Fig. 1. Flow chart of the study (INT = interval training group, CONT = continuous training group).

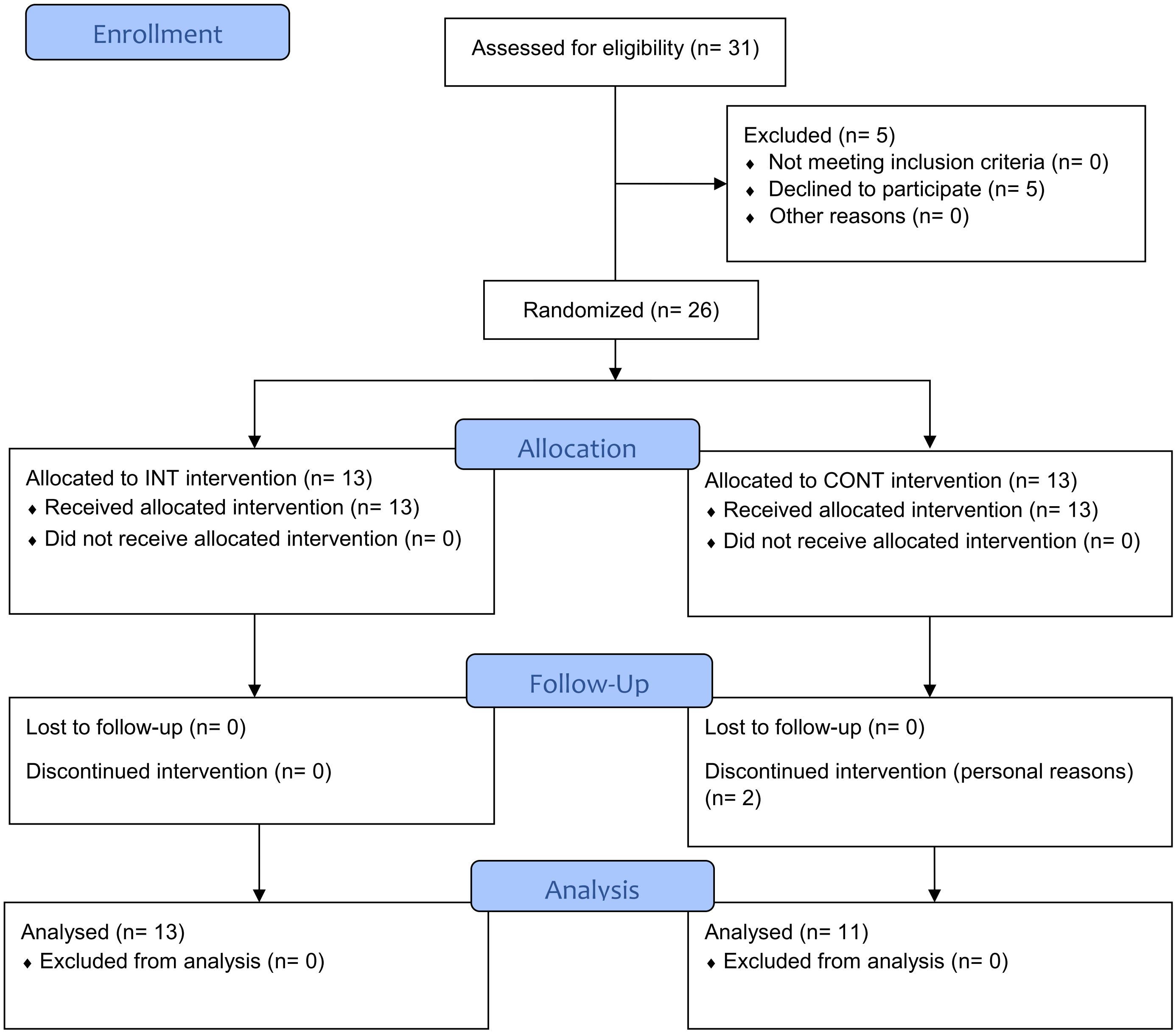
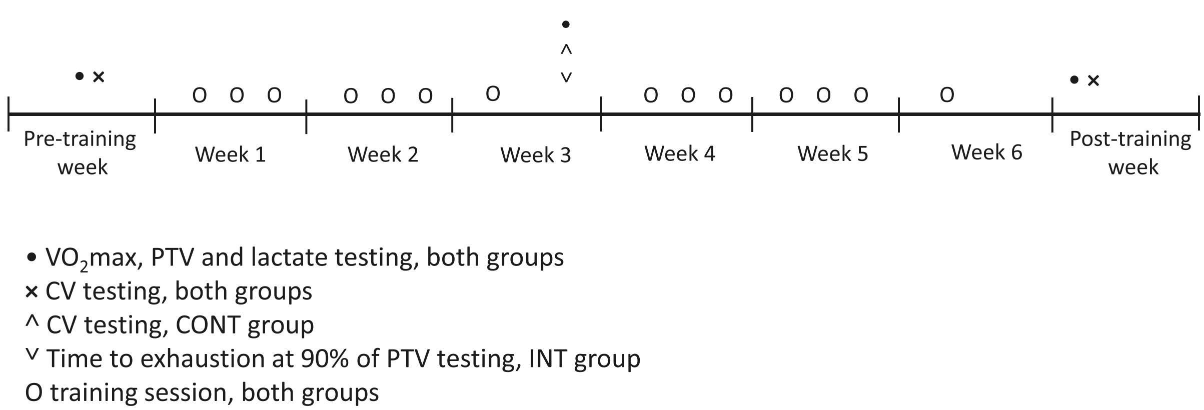


Fig. 2. Experimental design of the study.



during the CV testing) followed by passive rest equal to 2/3 of exercise duration. The duration of the exercise bouts was individualized based on the time to exhaustion at 90% of PTV to reduce between subject's variability. The participants terminated each exercise session when an RPE value of 17 was reached. Running bout duration and intensity were adjusted after seven training sessions (during the 3rd week) following a reassessment of the time to exhaustion at 90% of the "new" PTV achieved during mid-testing as a result of training.

The CONT group trained using the continuous method. During the training sessions the participants ran with an intensity corresponding to −2,5% of CV until they reported a rating of 17 at the 6–20 Borg's scale. Running velocity was adjusted after seven training sessions (during the 3rd week) after reassessment of CV. CV was used to determine the exercise intensity in the CONT group to ensure that all individuals would ran at the heavy-intensity domain and be able to complete at least 15 min of continuous running, and to minimize the high inter-individual variations in endurance time at intensities near the upper limit of the heavy-intensity domain (Brickley et al. 2002). Using PTV to determine the intensity in the CONT group would increase the possibility for trainees to exercise at different exercise intensity domains.

As mentioned above, all participants performed each exercise session until attaining an RPE value of 17. This approach was used to prescribe exercise intensity between different protocols to ensure similar effort. The use of RPE is practical, valid, reliable and direct tool for coaches in prescribing and monitoring an aerobic exercise program without expensive equipment (Halson 2014). In addition, RPE scores are being consistently used as measures of internal training load (Foster et al. 2001; Eston 2012; Halson 2014; Schwellnus et al. 2016; Soligard et al. 2016), No feedback on performance and no encouragement during a training session was given to participants to minimize external factors influence (Currell and Jeukendrup 2008). The training sessions of both groups started with an 8-min warm-up (5 min at 60% and 3 min at 80% of PTV) followed by 5 min of passive and dynamic stretching of the lower limbs.

Testing procedures

Maximal incremental test

All participants performed a maximal incremental test on a treadmill (h/p cosmos pulsar 3p, Nussdorf, Traustin, Germany) for the assessment of VO_2max, PTV, HRmax, and the relationship between blood lactate concentrations and running velocity for the assessment of LT_1 and LT_2 and v4 mmol. The protocol started at 8 km h^{-1} and was increased by 1.5 km h^{-1} every 3 min until volitional exhaustion. Treadmill grade was set at 1% throughout the protocol. Oxygen consumption was measured breath by breath (Vmax Encore 229, Sensor Medics, USA) throughout the maximal incremental test. The data were calculated in 30 s intervals and the highest 30 s VO_2 value recorded was considered as VO_2max. HR was continuously measured telemetrically (Polar H10), and the highest 10 s value was regarded as HRmax. The test was considered as maximal when at least three of the following criteria were achieved: (*i*) exhaustion of the participants, (*ii*) a plateau in oxygen consumption (increase of <2 mL kg^{-1} min^{-1}) despite an increase in running velocity, (*iii*) maximal HR higher than 90% of the predicted maximum (220-age), and (*iv*) maximum respiratory exchange ratio >1.1 (Rivera-Brown et al. 1994). PTV was calculated using the following formula

$$\text{PTV (km/h)} = \text{Velocity of the last completed stage} + (\text{seconds run at last stage}/180)$$

Running economy

Running economy was determined by measuring the oxygen consumption while running for 10 min at the same absolute velocity (corresponding to 70% of the pre-training PTV) pre- and post-training. Gas exchange was measured continuously and the average values of O_2 consumption from the 7th to the 9th min of running were used for the determination of running economy (Fletcher et al. 2009).

Lactate thresholds and v4 mmol determination

During the maximal incremental test, at the end of each 3 min stage, whole blood samples (0.3 μL) were collected from the fingertip and were immediately analyzed for blood lactate concentrations with a portable analyzer (Lactate pro, Arkray, Japan).

The individual relationship between lactate concentrations and running velocities was determined using a nonlinear regression model $y = b \times \exp(x/c) + a$, where y = lactate concentration, x = running velocity, and a, b, and c are constants. Using this model, the LT_1 and LT_2 were identified as the velocities at which blood lactate concentrations were increased by 0.3 and 1.5 mmol L^{-1} from baseline values, respectively; the velocities at the fixed blood lactate value of 4 mmol L^{-1} were calculated, as well. Velocities at LT_1 and LT_2 were also expressed relative to PTV (%PTV) and based on the linear relationship between VO_2 and HR with running velocity in absolute (mL kg^{-1} min^{-1}, b min^{-1}) and relative (%VO_2max, %HRmax) to VO_2max and HRmax values.

Critical velocity

To calculate CV, participants ran until exhaustion, in random order, at velocities corresponding to 90%, 100%, and 110% of PTV at three separate days (Housh et al. 2001). Strong verbal encouragement was provided during each test, and the time to exhaustion was recorded to the nearest second. Afterwards, using linear regression analyses, the relationship between the distance covered at each run and the time to exhaustion was calculated. The slope of the linear regression line was the CV.

All running protocols were performed on a treadmill (h/p cosmos pulsar 3p, Nussdorf, Traustin, Germany) in the laboratory with a room temperature of 20–21 °C and approximately at the same time of day (±1 h).

Statistical analysis

Data are reported as means ± standard deviations. Normal distribution of the data was examined with the Shapiro–Wilks test, and skewness and kurtosis measures. A two-way Analysis of variance (ANOVA) (training group × time) with repeated measures on the "time" factor was used to examine the differences among the two training groups across time points in the measured parameters. The design and analysis were sensitive to detect a moderate effect size ($\eta^2 = 0.06/f = 0.25$) for the interaction among the within and the between subjects' factors, with a power of 0.8 given to our sample size, an alpha level of 0.05, and assuming a correlation of 0.6 among the repeated measures (Gpower 3) (Faul et al. 2007). Significant differences between means were located with the Newman–Keuls post-hoc procedure. The significance level was set at $p < 0.05$. The effect size (ES) d of each treatment (pre to 6 weeks) and of the differences in the improvements between groups was determined as suggested by Cummings (2012). Effect sizes >0.2, >0.5, and >0.8 were interpreted as small, moderate, and large, respectively.

Results

Training data

All subjects from both training groups completed the assigned number of the 14 training sessions within the 6-week training period. The participants of the CONT group exercised at each session for 1185.0 ± 487.6 s (19.8 ± 8.1 min) at −2,5% of CV that corresponded to 80.1% ± 3.0% of PTV. The subjects of the INT group completed each session at 9.3 ± 4.4 bouts of 134.2 ± 27.9 s (2.2 ± 0.5 min) duration with 89.9 ± 18.7 sec (1.5 ± 0.3 min) of rest. The average net exercise time duration (excluding rest duration) was 1249.7 ± 123.0 s (20.8 ± 2.1 min) and was not different compared with that in CONT ($p = 0.65$); the exercise session duration in INT group, including rest duration, was 2020.4 ± 283.3 s (33.7 ± 4.7 min). Training running velocity increased from 11.9 + 1.5 km h^{-1} during the first seven sessions to 12.6 + 1.5 km h^{-1} during the last seven training sessions for the CONT group, and from 13.1 + 1.6 km h^{-1} to 13.8 + 1.8 km h^{-1} for the INT groups, respectively. Net exercise duration of each session for both training programs and the number of repetitions performed at each INT session are presented in Fig. 3.

No significant changes ($p > 0.05$) were found in body mass after training for the INT (pre-training: 67.2 ± 10.5 kg, 3 weeks: 67.3 ± 9.9 kg, 6 weeks: 67.3 ± 9.7 kg) and the CONT groups (pre-training: 67.8 ± 9.8 kg, 3 weeks: 68.2 ± 9.7 kg, 6 weeks: 67.9 ± 9.3 kg), and the body mass was not different ($p > 0.05$) between groups at any time point.

Vo_2max

VO_2max in absolute values (L min^{-1}) was higher for the INT (ES: 0.24) and the CONT (ES: 0.20) groups after 6 weeks of training compared with the pre-training values (Fig. 4A). Nevertheless, at mid-point of the training program VO_2max (L min^{-1}) increased only in the CONT group ($p < 0.05$). No significant differences were found between CONT and INT groups in their improvement of absolute VO_2max (ES: 0.07; $p > 0.05$).

Similarly, VO_2max in relative units (mL kg^{-1} min^{-1}) was higher for both the INT (ES: 0.41) and the CONT (ES: 0.39) groups after 6 weeks of training compared with the pre-training values (Fig. 4B). VO_2max increased after 3 weeks of training compared with pre-training only in the CONT group ($p < 0.05$) with no further significant improvements until the end of the program. No significant differences were found between CONT and INT groups in VO_2max groups in their improvement of VO_2max in relative values (ES: 0.10; $p > 0.05$).

Peak treadmill velocity

PTV was higher ($p < 0.05$) after 3 and 6 weeks of training compared with pre-training values in both groups (INT ES: 0.54; CONT ES: 0.37). After 6 weeks of training, PTV was higher ($p < 0.05$) compared with the respective 3-week value only in INT group (Fig. 4C). PTV improved similarly in the CONT and the INT groups (ES: 0.22; $p > 0.05$).

Maximum heart rate

Maximum HR did not change ($p > 0.05$) with training in both groups (INT ES: 0.22; CONT ES: 0.13) and no differences were found between groups (ES: 0.11; $p > 0.05$) (Fig. 4D).

Critical velocity

CV, expressed in absolute values (km h^{-1}), significantly increased ($p < 0.05$), following 6 weeks of training in both protocols (INT ES: 0.55; CONT ES: 0.38) with no differences observed between them (ES: 0.18; $p > 0.05$; Fig. 5E). However, there were no effects of either protocol on CV values when expressed as a percent of PTV (INT ES: 0.07; CONT pre-6 weeks 0.15; Fig. 5F) or any differences between them (ES: 0.08; $p > 0.05$).

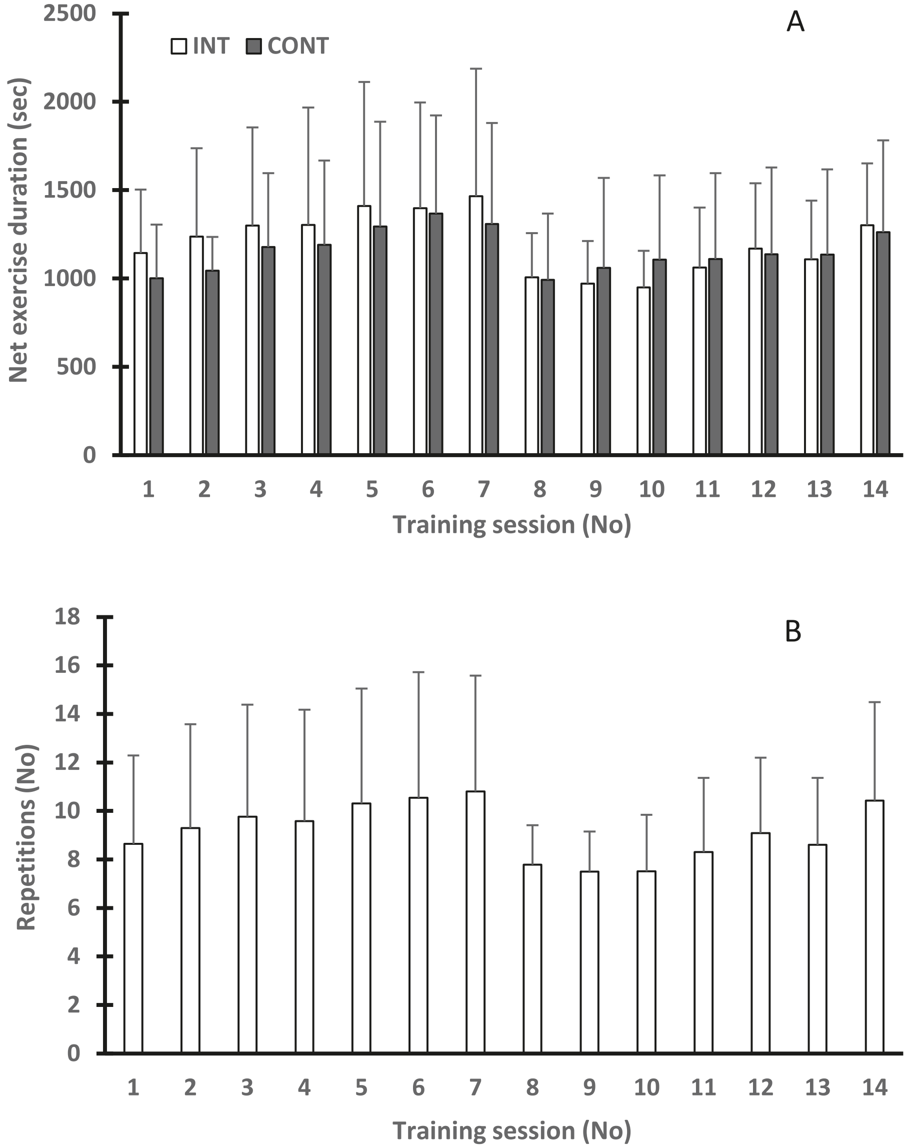
Velocities at lactate thresholds

Velocities at both LT_1 and LT_2 were higher ($p < 0.05$) following 3 and 6 weeks of training compared with pre-training values in both the INT (ES LT_1: 0.78; ES LT_2: 0.64) and the CONT (ES LT_1: 0.36; ES LT_2: 0.31) groups with no differences between the 3rd and the 6th week of training ($p > 0.05$). Comparisons between groups revealed no differences in the velocities at LT_1 and LT_2 between the two training groups at any time point (ES LT_1: 0.31; ES LT_2: 0.26; $p > 0.05$; Figs. 5A and 5C). When the velocities at LT_1 were expressed as a percentage of PTV, LT_1 velocity was higher ($p < 0.05$) only in the INT group after 3 weeks of training with no further changes until the 6th week (INT ES: 0.31; CONT ES: 0.10) with no differences observed between groups (ES: 0.24; $p > 0.05$). LT_2 velocity, expressed as a percentage of PTV, did not change ($p > 0.05$) with both training interventions (INT ES: 0.15; CONT ES: 0.00) and no differences were found among them (ES: 0.17; $p > 0.05$; Figs. 5B and 5D).

VO_2 at lactate thresholds

Oxygen uptakes at the velocities of LT_1 (INT ES: 0.76; CONT ES: 0.49) and LT_2 (INT ES: 0.50; CONT ES: 0.34) were significantly higher ($p < 0.05$) after 6 weeks of training compared

Fig. 3. (A) Net exercise duration at each training session for the interval (INT) and the continuous (CONT) training groups and (B) number of repetitions performed by the participants of the interval group at each session.



with pre-training values in both groups, with no differences in their changes between groups (LT_1 ES: 0.11; LT_2 ES: 0.11; Table 1). VO_2 at LT_1, expressed as a percentage of VO_2max, did not change ($p > 0.05$) following either training interventions (INT ES: 0.22; CONT ES: 0.28) and LT_2 (INT ES: 0.03, CONT ES: −0.05) and was not different between groups at any time point examined (LT_1 ES: 0.02; LT_2 ES: 0.08; Table 1).

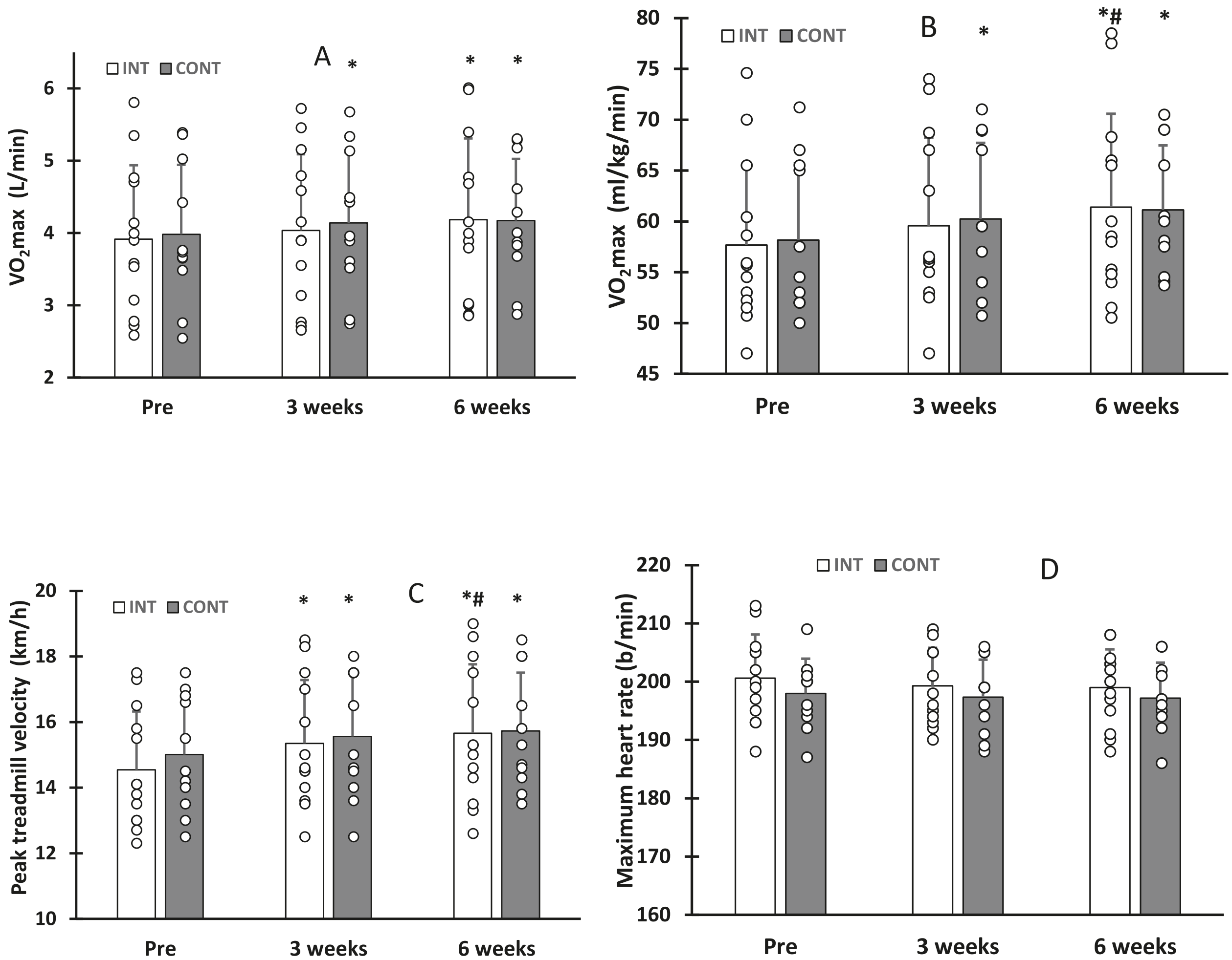
Heart rate at lactate thresholds

No significant differences were found for the HRs corresponding to LT_1, in absolute units (b min^{-1}), after 6 weeks of training compared with pre-training values in both groups (INT ES: −0.24; CONT ES: 0.00) and no differences were observed between groups (ES: 0.22; $p > 0.05$; Table 1). Also, no changes were observed for the HRs corresponding to LT_1, expressed in relative units (%HRmax) (INT ES: −0.11; CONT ES: 0.10) with no differences between groups (ES: 0.19; $p > 0.05$; Table 1). No significant changes were found for the HRs corresponding to LT_2, in absolute units (b min^{-1}), after 6 weeks of training in both groups (INT ES: −0.32; CONT ES: −0.10) with no differences between the two groups (ES: 0.21; $p > 0.05$). Similarly, no changes were observed at the HRs corresponding to LT_2 when expressed in relative units (%HRmax) (INT ES: −0.16; CONT ES: −0.02) and no differences were observed between groups (ES: 0.15; $p > 0.05$; Table 1).

Velocity at 4 mmol L^{-1} lactate concentration

Velocities at the fixed blood lactate concentration of 4 mmol L^{-1} were higher following 3 and 6 weeks of training compared with pre-training values in both the INT (ES: 0.69) and the CONT (ES: 0.44) groups ($p < 0.05$) with no improvements observed from the 3rd to the 6th week of training ($p > 0.05$). Comparisons between groups revealed no differences between groups in the improvement of velocities at 4 mmol L^{-1} (ES: 0.17; $p > 0.05$; Fig. 6A).

Fig. 4. (A) Maximum oxygen consumption in absolute and (B) relative units, and (C) peak treadmill velocity and (D) maximum heart rate for the interval (INT) and the continuous (CONT) training groups during the 6-week training period. $^{*}p < 0.05$ from pre-training, $^{\#}p < 0.05$ from 3 weeks of training.



Running economy

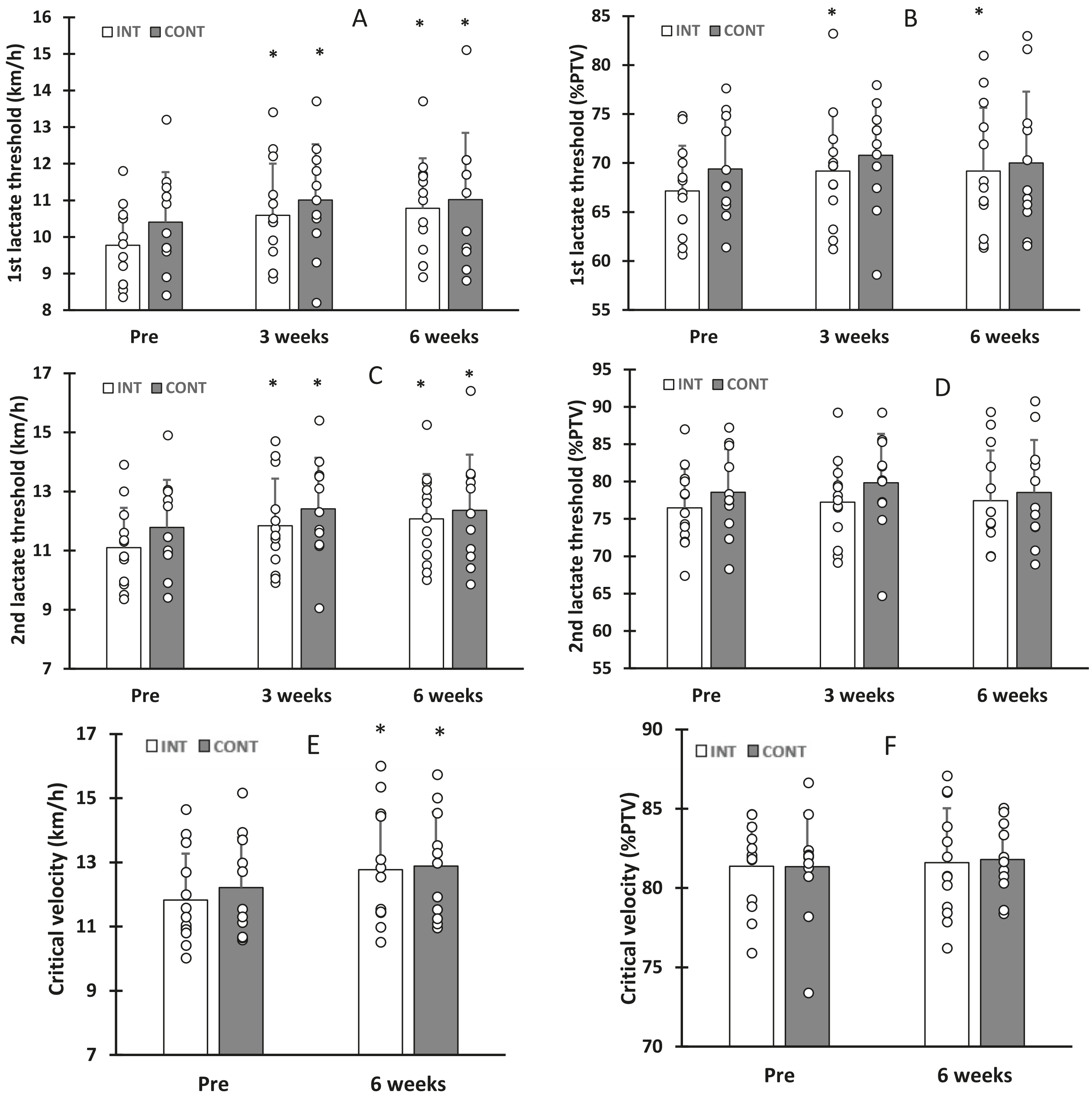
Oxygen cost of running when running at 70% of pre-training PTV before and after the interventions did not change significantly ($p > 0.05$) following either training program (INT ES: −0.11; CONT ES: −0.11; Fig. 6B) and did not differ between groups (ES: 0.03; $p > 0.05$).

Discussion

This study is the first to compare the effects of two iso-effort, based on RPE, aerobic training programs, an intense continuous and a high-intensity interval program, on maximal and submaximal aerobic performance parameters after 14 training sessions within a 6-week training period. We hypothesized that key parameters for aerobic adaptations would be the training stimulus that occurs with an accumulated individual training session, and not the training method per se. So, the continuous training method can be as efficacious as the interval training method if the intensity of exercise is in the heavy-intensity domain and the internal load (training stimulus) is similar between the two training methods. The main findings of the study are that (i) both training methods improve maximal (VO_2max, PTV) and submaximal (CV, lactate thresholds, and v4 mmol) indices of aerobic performance, with the exception of running economy that did not change and (ii) there were no differences in maximal and submaximal indices of aerobic adaptations between the continuous and the high-intensity interval method when matched for overall effort (index of internal load) of training sessions and the continuous method is executed at the upper boundaries of the heavy-intensity domain close to CV.

A major finding of this study is the similar improvements of VO_2max and PTV with the interval and the continuous methods when performed under iso-effort conditions. After 6 weeks of training, the interval and the continuous programs improved significantly VO_2max by 6.5% and 5.2% and PTV by 7.6% and 4.8%, respectively. These findings are in contrast with the results of a meta-analysis in healthy individuals that showed a small superiority of HIIT for improvements of VO_2max over the traditional continuous training of low-to-moderate intensity (Milanović et al. 2015). In previous studies

Fig. 5. (A, C, and E) Lactate threshold 1 and 2 and critical velocity in absolute (km h^{-1}) and (B, D, and F) relative to peak treadmill velocity units (%) for the interval (INT) and the continuous (CONT) training groups during the 6-week training period. $^{*}p < 0.05$ from pre-training, $^{\#}p < 0.05$ from 3 weeks of training.



that compared the two training methods, the internal load of high-intensity interval protocols was greater than in the continuous protocols, at least as suggested by the RPE values, the HRs attained, and the blood lactate concentrations (Zafeiridis et al. 2010; Falz et al. 2019). A unique aspect of this study was the application of the iso-effort approach to equalize the internal load (training stimulus) of the two training methods. Previous studies have used the iso-caloric or iso-total work approach (Bartlett et al. 2012; Peake et al. 2014; Combes et al. 2018). This, however, places the continuous training method in a disadvantage because when total (external) work in two training methods is equal, the method executed at a higher intensity (i.e., interval training) places a greater internal load/physiological stress (RPE, HR, lactate concentrations) and may conceivably lead to greater aerobic adaptations and improvements. To overcome this, other studies have used the iso-effort approach, which seems to be most appropriate to compare the two methods (Nicolò et al. 2014; Zafeiridis et al. 2015), but the trainees had to exercise until or near exhaustion, which is likely unpractical, and its long-term use may lead to overtraining/injury syndromes. In this study, we used the iso-effort approach and the exercise sessions were terminated at submaximal level of fatigue when the trainees indicated an RPE score of 17/20 at

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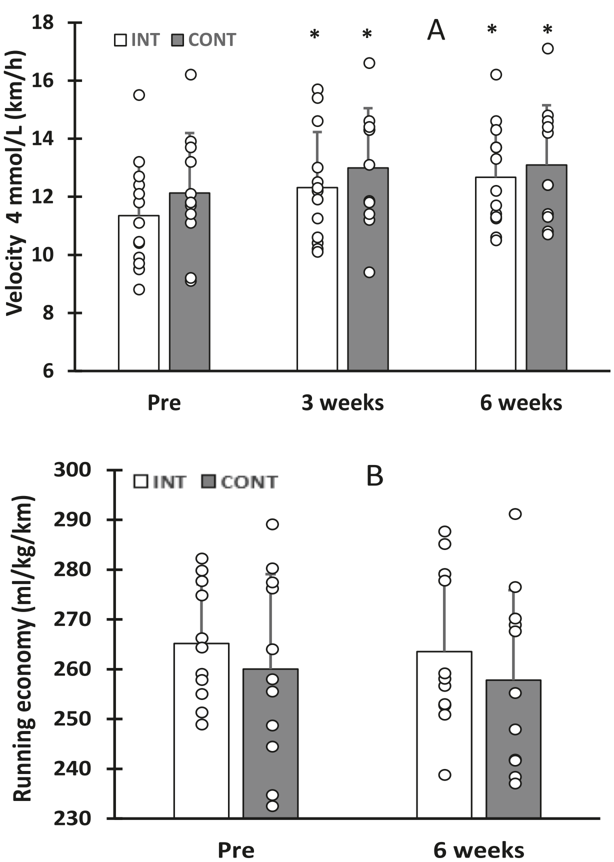
Table 1. Lactate threshold parameters (mean ± SD) during the 6-week training program.

		Pre-training	After 3 weeks of training	After 6 weeks of training
HR LT_1 (b min^{-1})	Interval	170.46 ± 11.21	166.92 ± 7.57	168 ± 8.22
	Continuous	164.55 ± 9.97	164.45 ± 12.35	164.55 ± 6.98
HR LT_2 (b min^{-1})	Interval	180.23 ± 7.57	175.38 ± 6.81	177.62 ± 7.69
	Continuous	175.27 ± 8.26	176 ± 10.03	174.36 ± 7.92
HR LT_1 (%HRmax)	Interval	85.01 ± 4.87	83.78 ± 3.44	84.55 ± 3.92
	Continuous	83.09 ± 4.08	83.29 ± 5.05	83.47 ± 3.16
HR LT_2 (%HRmax)	Interval	89.87 ± 3.14	88.03 ± 3.12	89.30 ± 3.75
	Continuous	88.53 ± 3.42	89.18 ± 4.26	88.46 ± 3.89
VO_2 LT_1 (mL kg^{-1} min^{-1})	Interval	42.04 ± 3.79	43.77 ± 6.28	45.97 ± 5.6*
	Continuous	44.07 ± 5.81	45.66 ± 5.13	47.61 ± 6.42*
VO_2 LT_2 (mL kg^{-1} min^{-1})	Interval	47.22 ± 5.95	48.23 ± 7.53	50.41 ± 6.54*
	Continuous	49.31 ± 7.02	50.89 ± 6.08	52.01 ± 6.89*
VO_2 LT_1 (%VO_2 max)	Interval	73.19 ± 5.81	74,75 ± 5.00	75.11 ± 5.82
	Continuous	76.21 ± 3.36	76,18 ± 5.37	77.64 ± 5.27
VO_2 LT_2 (%VO_2 max)	Interval	81.89 ± 5.39	82,24 ± 4.60	82.27 ± 5.85
	Continuous	85.12 ± 3.53	84,82 ± 6.38	84.94 ± 5.49

Note: HR LT_1: heart rate at the 1st lactate threshold, HR LT_2: heart rate at the 2nd lactate threshold, VO_2 LT_1: oxygen consumption at the 1st lactate threshold, VO_2 LT_2: oxygen consumption at the 2nd lactate threshold.
*$p < 0.05$ from pre-training.

Fig. 6. (A) Velocity at blood lactate concentration of 4mmol L^{-1} and (B) running economy for the interval (INT) and the continuous (CONT) training groups during the 6-week training period. *$p < 0.05$ from pre-training.



the Borg's scale. Thus, the two protocols had comparable submaximal internal loads as suggested by the RPE. This RPE value is close to how the athletes typically perform high-intensity aerobic training in real training settings and has been used by researchers to prescribe the level of fatigue during aerobic training (Seiler and Sjursen 2004) and for matching the effort between different training programs (Rønnestad et al. 2020). Therefore, the similar internal load, as estimated using RPE values, might be a reason for the comparable improvements in VO_2max, PTV, and the submaximal indices of aerobic capacity with the two aerobic training programs.

In this study, the continuous method was performed at the heavy-intensity domain and not at the moderate-intensity domain, as in previous studies. Coaches, however, have been using for many years the continuous method at high intensities (>85% of HRmax or >80% of PTV, heavy-intensity domain), called tempo training, especially when preparing for long-distance running events (Bakayev and Bolotin 2020; Casado et al. 2021). During exercise bouts at the upper boundary of the heavy-intensity domain (slightly below CV), VO_2 demonstrates a slow component delaying the achievement of a steady state even though running velocity is kept stable (Jones et al. 2011). So, the combination of the high intensity (−2.5% of CV corresponding to an average of ∼80% of PTV) and the moderate duration (an average of 20 min) of the continuous training program in this study probably placed a significant stress on the oxygen delivery and utilization systems, comparable to that placed by the HIIT program executed at higher intensity (90% of PTV). This may explain the similar improvements observed in VO_2max with both training methods. In support, previous studies that compared the physiological responses to a single session of an intense continuous exercise (∼80% of PTV for 20 min) to a long-interval high-intensity exercise, similar to those used in our study, have reported comparable acute systemic hemodynamic, muscle oxygenation, and metabolomic responses between the two training sessions (Zafeiridis et al. 2015, 2016).

Apart from the maximal parameters of aerobic performance in this study, a comparison of the efficacy of the interval and the continuous training methods in the improvement of various submaximal aerobic parameters that have a unique physiological role in the assessment of aerobic/endurance performance. This is important as the submaximal indices, such as the velocities at LTs and running economy, have unique physiological role in the assessment of endurance performance. CV and the velocities corresponding to lactate thresholds and the velocity at a fixed blood lactate concentration ($4\,\mathrm{mmol\,L^{-1}}$) were improved after 6 weeks of training with both training programs.

An interesting finding was that VO_2max and PTV improved gradually until the 6th week of training with both training methods, whereas the submaximal aerobic parameters (LT_1, LT_2) improved only during the first 3 weeks of training. Probably, VO_2max improvements affect up to a point submaximal aerobic parameters. Thereafter, training with a lower intensity and a higher volume than those used in this study might be needed to improve the rate of muscle glycogen and fat oxidation to further enhance lactate threshold velocities and oxygen fractional utilization at these intensities.

Some limitations of this study should be acknowledged. The duration of the training period was 6 weeks and caused small-to-moderate increases in measured parameters. A longer training period would most likely result in larger improvements in aerobic performance and might have possibly revealed differences between the two training methods. In addition, in this study, the terminal RPE was used as an internal load measure to equalize the training stress of the two methods (Halson 2014; Soligard et al. 2016; Schwellnus et al. 2016). Session RPE is another internal load index, frequently used to determine the stress of a training session and it could have been applied to match the load of the two training programs. However, it may be not feasible to use it a priori to equalize the two training programs for internal load since its value is individualized and recorded well after the end of a session and cannot be used in advance for programming an iso-effort design (desired exercise effort to terminate exercise). Previous studies that examined the iso-effort design to compare acute or chronic adaptations of aerobic training methods have used a similar approach as ours (Zafeiridis et al. 2016; Ronnestad et al. 2020). Finally, to compare the efficacy of the two training methods on aerobic adaptations, each group performed only one type of training method. I applied setting, however, athletes usually train using both methods at the same time period; this may challenge the ecological validity of our and all previous studies comparing the “continuous” and “high-intensity interval” endurance training protocols. Nevertheless, for non-athletic populations that engage in aerobic/endurance training, our study adds the knowledge that the internal load may be a more crucial parameter than the endurance method per se in eliciting training adaptations.

In conclusion, 6 weeks (14 training sessions) of either continuous or interval training, matched for overall effort based on RPE and both executed at least in the heavy-intensity domain, produce similar adaptations in maximal and submaximal parameters of aerobic performance. Maximal aerobic performance parameters improve mostly after 6 weeks of training, while submaximal aerobic performance parameters begin to improve after only the 3 weeks with no further improvements thereafter, irrespective of the training method used. An intense continuous method (i.e., ~80% of PTV for 15–25 min) appears at least as efficacious as HIIT for improving aerobic performance using lower exercise intensity and comparable exercise time during a short-term training period. Exercise scientists and coaches working in fitness, recreation, and athletic settings may consider performing training in the heavy-intensity domain in either continuous or interval pattern.

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Data availability

Data generated or analyzed during this study are available from the corresponding author upon reasonable request.

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