

WHOLE-BODY HIGH-INTENSITY INTERVAL TRAINING INDUCE SIMILAR CARDIORESPIRATORY ADAPTATIONS COMPARED WITH TRADITIONAL HIGH-INTENSITY INTERVAL TRAINING AND MODERATE-INTENSITY CONTINUOUS TRAINING IN HEALTHY MEN

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ABSTRACT

Schaun, GZ, Pinto, SS, Silva, MR, Dolinski, DB, and Alberton, CL. Sixteen weeks of whole-body high-intensity interval training induce similar cardiorespiratory responses compared with traditional high-intensity interval training and moderate-intensity continuous training in healthy men. *J Strength Cond Res* 32(10): 2730–2742, 2018—Low-volume high-intensity interval training (HIIT) protocols that use the body weight as resistance could be an interesting and inexpensive alternative to traditional ergometer-based high-intensity interval training (HIIT-T) and moderate-intensity continuous training (MICT). Therefore, our aim was to compare the effects of 16 weeks of whole-body HIIT (HIIT-WB), HIIT-T, and MICT on maximal oxygen uptake ($\dot{V}O_{2\max}$), second ventilatory threshold (VT_2), and running economy (RE) outcomes. Fifty-five healthy men (23.7 ± 0.7 years, 1.79 ± 0.01 m, 78.5 ± 1.7 kg) were randomized into 3 training groups (HIIT-T = 17; HIIT-WB = 19; MICT = 19) for 16 weeks ($3 \times$ per week). The HIIT-T group performed eight 20-second bouts at 130% of the velocity associated to $\dot{V}O_{2\max}$ ($v\dot{V}O_{2\max}$) interspersed by 10-second passive recovery on a treadmill, whereas HIIT-WB group performed the same protocol but used calisthenics exercises at an all-out intensity instead of treadmill running. Finally, MICT group exercised for 30 minutes at 90–95% of the heart rate (HR) associated to VT_2 . After the intervention, all groups improved $\dot{V}O_{2\max}$, $v\dot{V}O_{2\max}$, time to exhaustion (T_{\max}), VT_2 , velocity associated with VT_2 (vVT_2), and time to reach VT_2 (tVT_2) significantly ($p < 0.05$). Moreover, T_{\max} , vVT_2 , and tVT_2 were greater after HIIT-T compared with HIIT-WB ($p < 0.05$),

whereas oxygen uptake increased and HR decreased during the RE test in all groups ($p < 0.05$). Our results demonstrate that HIIT-WB can be as effective as traditional HIIT while also being time-efficient compared with MICT to improve health-related outcomes after 16 weeks of training. However, HIIT-T and MICT seem preferable to enhance performance-related outcomes compared with HIIT-WB.

KEY WORDS exercise, performance, body weight exercise, oxygen consumption, ventilatory threshold, running economy

INTRODUCTION

High-intensity interval training (HIIT) can be summarily understood as the performance of high-intensity exercise bouts interspersed by either passive or active recovery periods at lower intensities (4). As with moderate-intensity continuous training (MICT), HIIT is capable of leading to positive cardiorespiratory outcomes when performed by healthy subjects (19,23). High-intensity interval training is remarkably efficient when used to improve cardiorespiratory fitness, usually assessed through the maximal oxygen uptake ($\dot{V}O_{2\max}$) (3,25). Moreover, the intensity equivalent to the second ventilatory threshold (VT_2) and running economy (RE) seem to be important variables that interact with $\dot{V}O_{2\max}$ to determine exercise performance (21) and that can be enhanced by HIIT (2,6,23,32,34).

Accordingly, HIIT is well known for its time efficiency (23), i.e., its capacity to be performed with a reduced time commitment or session duration while yielding similar cardiorespiratory results as MICT (19). This reduction could potentially favor adherence to exercise programs because lack of time is a known barrier to regular engagement in exercise practice (23). However, only few studies to date have assessed cardiorespiratory adaptations to HIIT after longer training periods. Recently, in a systematic review comparing $\dot{V}O_{2\max}$ increases between HIIT and CONT,

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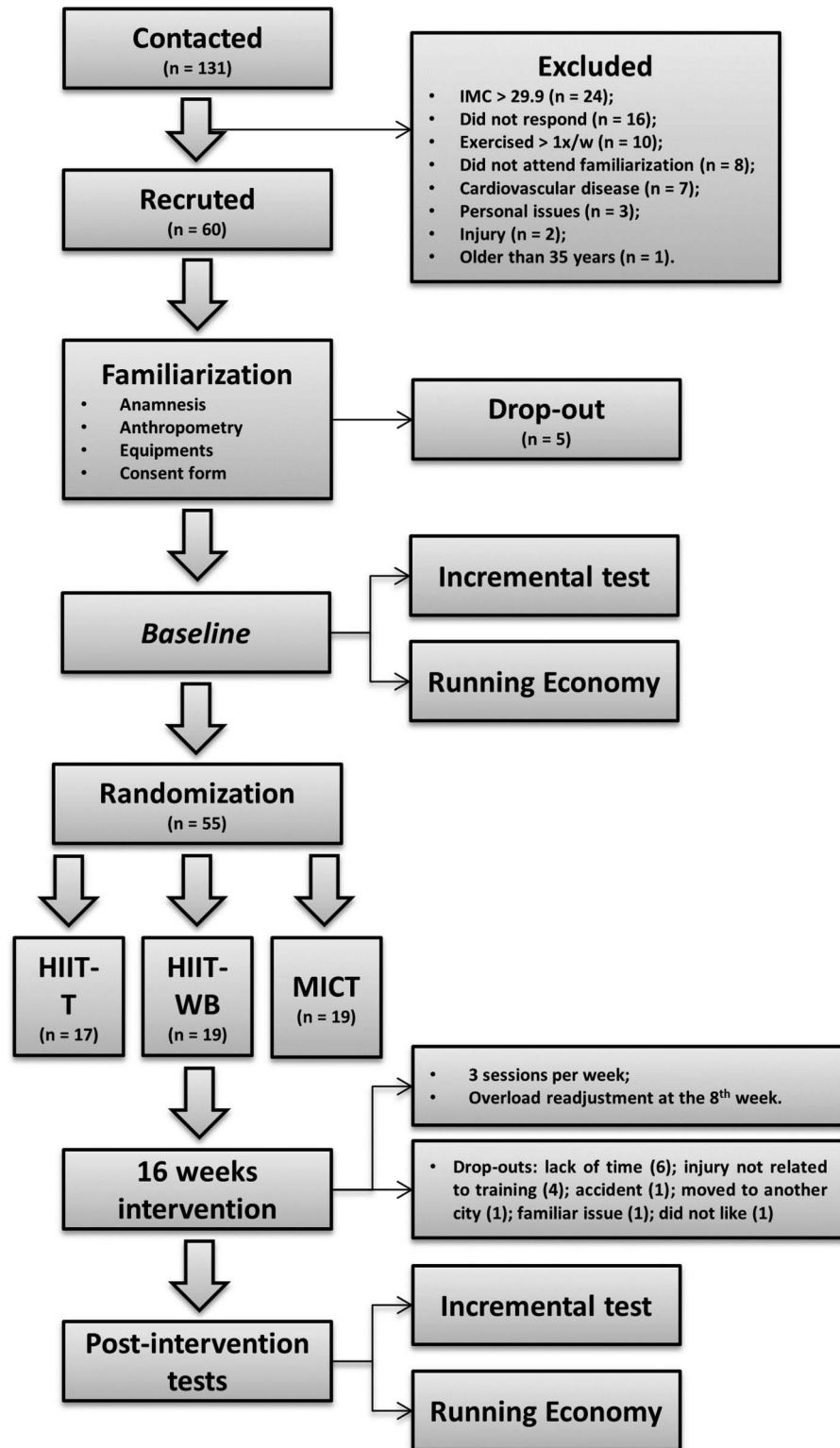


Figure 1. Experimental design of the study. BMI = body mass index; HIIT-T = traditional high-intensity interval training; HIIT-WB = whole-body high-intensity interval training; MICT = moderate-intensity continuous training.

only 2 studies with 16 or more weeks of training were identified, both of which applied submaximal intensities (i.e., $<100\% \dot{V}O_{2\max}$) on their HIIT protocols (22). Therefore, the effects of low-volume HIIT protocols on cardiorespiratory fitness, aerobic capacity, and RE after longer interventions are lacking (3), especially those applying supramaximal intensities (25). In this regard, low-volume HIIT protocols are commonly performed on cycle ergometers or treadmills (3), which are not always available. The absence of adequate equipment generally restricts the applicability of this training mode in the general population, and consequently, the performance of more applied HIIT programs are warranted (23).

Low-volume HIIT protocols using the body weight as resistance (i.e., whole-body exercises) could be an interesting and inexpensive alternative. In fact, this training mode was able to improve $\dot{V}O_{2\max}$ in healthy young women after just 4 weeks using calisthenics exercises (20). However, its effects on longer training periods and on other outcomes, such as the VT_2 and RE, remain unknown. Additionally, it is not clear if this training mode is as effective as traditional ergometer-based high-intensity interval training (HIIT-T) and MICT in healthy adults. Such results could assist clinicians, coaches, and researchers and could potentially be applied for health promotion and performance enhancement.

Thus, our aim was to verify the effects of 16 weeks of whole-body HIIT (HIIT-WB) on the $\dot{V}O_{2\max}$, VT_2 , and RE responses and compare it with HIIT-T and MICT. Our initial hypothesis was that all groups would improve cardiorespiratory fitness and RE similarly, while both HIIT protocols would improve VT_2 to a greater extent because of the intensity applied.

METHODS

Experimental Approach to the Problem

After being familiarized, participants performed an incremental and RE test, 96 hours apart from each other, and were randomized into 3 training regimes: HIIT-T ($n = 17$), HIIT-WB ($n = 19$), and MICT ($n = 19$), as can be observed in Figure 1. These groups underwent 16 weeks of training with 3 sessions per week on nonconsecutive days. At the eighth week, HIIT-T and MICT participants repeated the incremental test to adjust their training loads, and all participants were reassessed after the 16th week. An interval of at least 48 hours from the last session was respected, and to avoid interferences of the circadian cycle, the same time was maintained between all pre-intervention and post-intervention tests (± 2 hours). All the tests were performed by the same evaluators, which were blinded to the participants' experimental group.

Subjects

Initially, 60 participants were recruited and familiarized. Of these, 5 dropped out for personal reasons and 55 participants completed pre-intervention tests and were randomized into the experimental groups (mean \pm SD age: 23.7 ± 0.7 years,

height: 1.79 ± 0.01 m, body mass: 78.5 ± 1.7 kg). These men were recruited voluntarily through notes published in newspapers and visual media shared on social networks. As exclusion criteria, subjects could not present cardiometabolic conditions or medication usage that could interfere on the outcomes being assessed. Subjects who missed 3 consecutive sessions or presented less than 80% frequency at the end of the intervention would be excluded from the sample; however, no subject had to be excluded for these reasons.

All participants were asked to record their meals in the 24 hours that preceded baseline tests and were requested to repeat those meals in the days before posttraining assessments. Moreover, they were instructed to have their last meal 3 hours before the tests and also to abstain from intense physical exercises and ingestion of stimulants (e.g., coffee and alcohol) 24 hours before the tests. During the intervention period, participants were asked to maintain their regular eating habits and were not allowed to engage in regular exercise ($>1\times$ per week). Before any procedure was performed, all participants read, agreed, and signed the written consent form, and the project was approved by the Federal University of Pelotas Ethics Research Committee in accordance with the Helsinki Declaration (CAAE 49499415.0.0000.5313).

Procedures

Anthropometrical Measurements. Body mass and height were measured with a digital scale and stadiometer (WELMY, Santa Barbara d'Oeste, Brazil) and body mass index was calculated. Seven skinfolds (chest, axilla, triceps, subscapular, abdominal, suprailium, and thigh) were measured using a skinfold caliper (CESCORF, Porto Alegre, Brazil). Body density was estimated based on the protocol proposed by Jackson and Pollock (15), and subsequently, fat percentage was calculated based on Siri's equation (33). All measures were performed by the same researcher.

Maximal Oxygen Uptake and Second Ventilatory Threshold. Participants were submitted to an incremental treadmill protocol (KX 9000; KIKOS, Sao Paulo, Brazil). After a 5-minute warm-up at $6 \text{ km} \cdot \text{h}^{-1}$, velocity was increased by $1 \text{ km} \cdot \text{h}^{-1}$ until subjects' volitional failure. Those tests that met at least 2 of the following criteria were considered valid: plateau in the $\dot{V}O_{2\max}$; respiratory exchange ratio ≥ 1.10 ; $\pm 10 \text{ b} \cdot \text{min}^{-1}$ of the estimated maximal heart rate (HR) (14). Gas collection was performed by continuous open-circuit spirometry (VO2000; MedGraphics, Ann Arbor, MI, USA), and the gas analyzer was calibrated before each test as recommended by the manufacturer. Heart rate was measured telemetrically with a HR monitor (Polar RS800CX; Polar, Kempele, Finland) throughout the test. $\dot{V}O_{2\max}$, the velocity associated to $\dot{V}O_{2\max}$ ($v\dot{V}O_{2\max}$), and the time to exhaustion at the incremental test (T_{\max}) were assessed.

Second ventilatory threshold was determined based on the ventilation by intensity graph and confirmed by the

TABLE 1. Summary of the protocols used in the study.*†

	HIIT-T	HIIT-WB	MICT
Intensity	130% $\dot{V}O_{2\max}$	All-out	90–95% HR VT_2
Effort duration	20 s	20 s	30 min
Recovery duration	10 s	10 s	—
Sets per session	8	8	1
Sessions per week	3	3	3
Session duration	~8 min	~8 min	30 min
Total volume accumulated	384 min	384 min	1,440 min

*HIIT-T = traditional high-intensity interval training; HIIT-WB = whole-body high-intensity interval training; MICT = moderate-intensity continuous training; $\dot{V}O_{2\max}$ = velocity associated to the maximal oxygen consumption; HR = heart rate; VT_2 = second ventilatory threshold.

†All-out intensity refers to the maximal intensity that the subject is capable to perform the exercise.

ventilatory equivalent of carbon dioxide ($\dot{V}_E/\dot{V}CO_2$) (36). Two experienced physiologists independently performed the threshold detection through visual inspection while blinded to participants' experimental group (26), as previously described (30). When there was no consensus among them, a third physiologist was consulted and the median value was adopted. Intraclass correlation coefficients between them were $r = 0.98$ and 0.99 for the pre-intervention and post-intervention, respectively. Specifically, VT_2 in $ml \cdot kg^{-1} \cdot min^{-1}$ and as a percentage of the $\dot{V}O_{2\max}$ ($\% \dot{V}O_{2\max}$), the velocity associated with VT_2 (vVT_2), and the time to reach VT_2 (tVT_2) were determined.

Running Economy. For this study, RE was considered as the submaximal $\dot{V}O_2$ associated with a constant submaximal

running velocity (i.e., the metabolic cost at a fixed submaximal velocity) (1). The test lasted 6 minutes (35), and the velocity was determined from a subsample of our subjects in an attempt to adjust the intensity to 92% of pretraining vVT_2 . Thus, based on the first 22 subjects' incremental tests, mean vVT_2 was determined ($12 \text{ km} \cdot h^{-1}$). Accordingly, the velocity equivalent to 92% vVT_2 , i.e., corresponding to $11 \text{ km} \cdot h^{-1}$ was used for all subjects.

This specific intensity was selected to allow an evaluation within the aerobic exercise domain, so that participants could reach a plateau in $\dot{V}O_2$. If we opted for an arbitrary velocity, we could incur in some performing the effort above and others below their VT_2 , hindering the tests comparison. Therefore, this method was adopted to allow a comparison both from the biomechanical (i.e., same velocity) and the

TABLE 2. Descriptive variables according to protocol performed in response to 16 weeks of training in healthy young adults ($n = 41$).*

	HIIT-T ($n = 15$)		HIIT-WB ($n = 12$)		MICT ($n = 14$)	
	Pre	Post	Pre	Post	Pre	Post
	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD
Age (y)	23.0 \pm 1.0	—	24.2 \pm 1.5	—	24.1 \pm 1.0	—
Height (m)	1.77 \pm 0.07	1.77 \pm 0.07	1.8 \pm 0.06	1.8 \pm 0.06	1.79 \pm 0.06	1.79 \pm 0.06
Body mass (kg)	74.3 \pm 12.2	74.6 \pm 12.3	82.9 \pm 6.6	83.6 \pm 5.4	79.3 \pm 11.7	78.2 \pm 11.7
BMI	23.63 \pm 3.31	23.78 \pm 3.39	25.63 \pm 2.12	25.85 \pm 1.78	24.78 \pm 2.82	24.4 \pm 2.61
\sum Skinfold (mm)	100.07 \pm 37.57	92.2† \pm 37.2	134.92 \pm 31.97	132.33† \pm 31.4	118.64 \pm 49.97	108.79† \pm 49.3
BF (%)	13.51 \pm 5.19	12.4† \pm 5.35	18.4 \pm 4.08	18.08† \pm 4.24	15.98 \pm 6.55	14.66† \pm 6.64

*HIIT-T = traditional high-intensity interval training; HIIT-WB = whole-body high-intensity interval training; MICT = moderate-intensity continuous training; BMI = body mass index; \sum Skinfold = sum of 7 skinfold; BF = body fat.

†Significantly different from pre ($p < 0.001$).

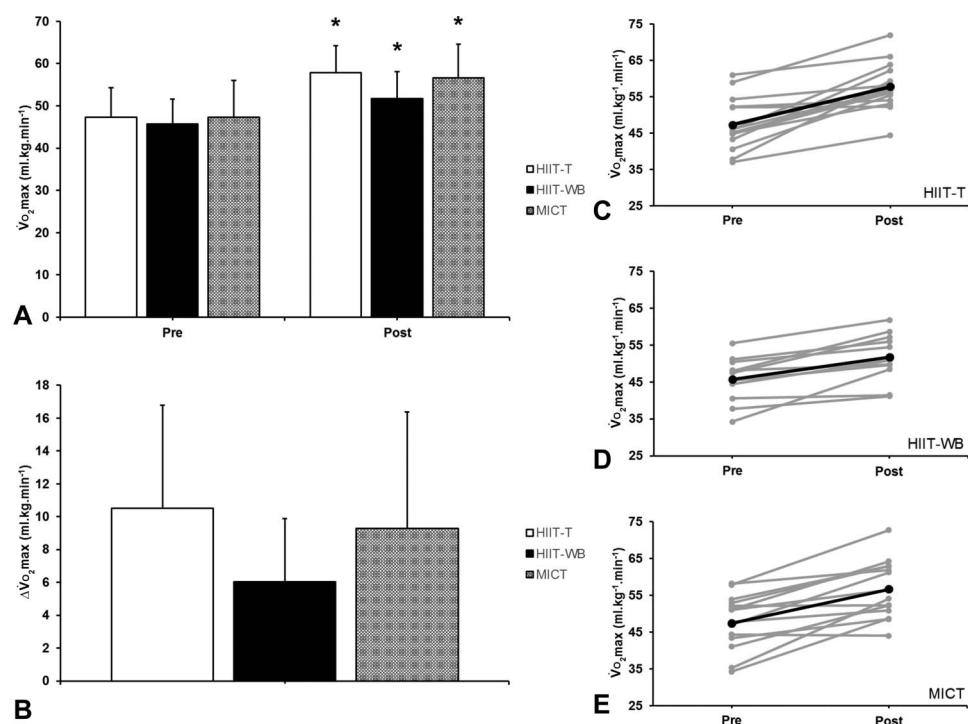


Figure 2. Maximal oxygen uptake ($\dot{V}O_2\text{max}$) responses to 16 weeks of high-intensity traditional (HIIT-T) and whole-body (HIIT-WB) interval training as well as moderate-intensity continuous training (MICT). Comparisons between pretraining and posttraining (A); average changes (B) and individual (gray line) and mean (black line) responses according to training mode (C–E); *Significantly different from pre ($p < 0.001$).

physiological (i.e., same exercise domain) perspectives. Additionally, it was also chosen to compare the VT_2 responses of both HIIT groups to those of MICT, which trained close to this intensity (Table 1). To be considered valid, expiratory exchange ratios should not have exceeded 1.0 (7). Finally, mean HR and the $\dot{V}O_2$ in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and in $\%\dot{V}O_2\text{max}$ were measured.

Exercise Training: Traditional High-Intensity Interval Training. The HIIT-T was performed on the same motorized treadmill as the incremental test. Subjects were submitted to a 4-minute warm-up at the intensity corresponding to 90–95% vVT_2 . After that, they performed eight 20-second bouts at 130% $v\dot{V}O_2\text{max}$ interspersed by 10 seconds of passive recovery (Table 1).

Whole-Body High-Intensity Interval Training. Whole-body high-intensity interval training sessions were performed similarly to those of HIIT-T, as it can be observed in Table 1. However, exercises were performed on an all-out intensity. That is, at the maximum intensity in which the participant was able to perform the exercise throughout the protocol. Furthermore, effort intervals composed of whole-body calisthenics exercises instead of treadmill running. Specifically, the exercises used were the same as those in

McRae et al. (20): burpees, mountain climbers, squat and thrusts with 3-kg dumbbells, and jumping jacks. They were performed in this order, and the 4 exercises sequence was repeated twice, totaling 8 sets, as proposed by Schaun and Del Vecchio (30). In addition, the 4-minute warm-up was performed at low intensity (i.e., self-selected) using the same exercises. It should be noted that during all sessions participants received strong verbal encouragement to ensure that a maximum effort was kept during all efforts. Moreover, to guarantee that all subjects adhered to the all-out protocol, one session on the 1st, 8th, and 16th week was recorded to confirm that the subjects did not reduce the number of repetitions throughout the intervention.

Moderate-Intensity Continuous Training. Subjects randomized to MICT ran 30 minutes on a motorized treadmill at an intensity corresponding to 90–95% of the HR associated with VT_2 (Table 1). The intensity associated to VT_2 allows us to individualize the training load for all subjects while it allows also a more precise control of the training domain in which the subjects exercise (38).

Data Handling. $\dot{V}O_2$ data from the incremental tests were 15-second time-averaged, and $\dot{V}O_2\text{max}$ was considered as the highest 15-second average (28). For the RE tests, the mean

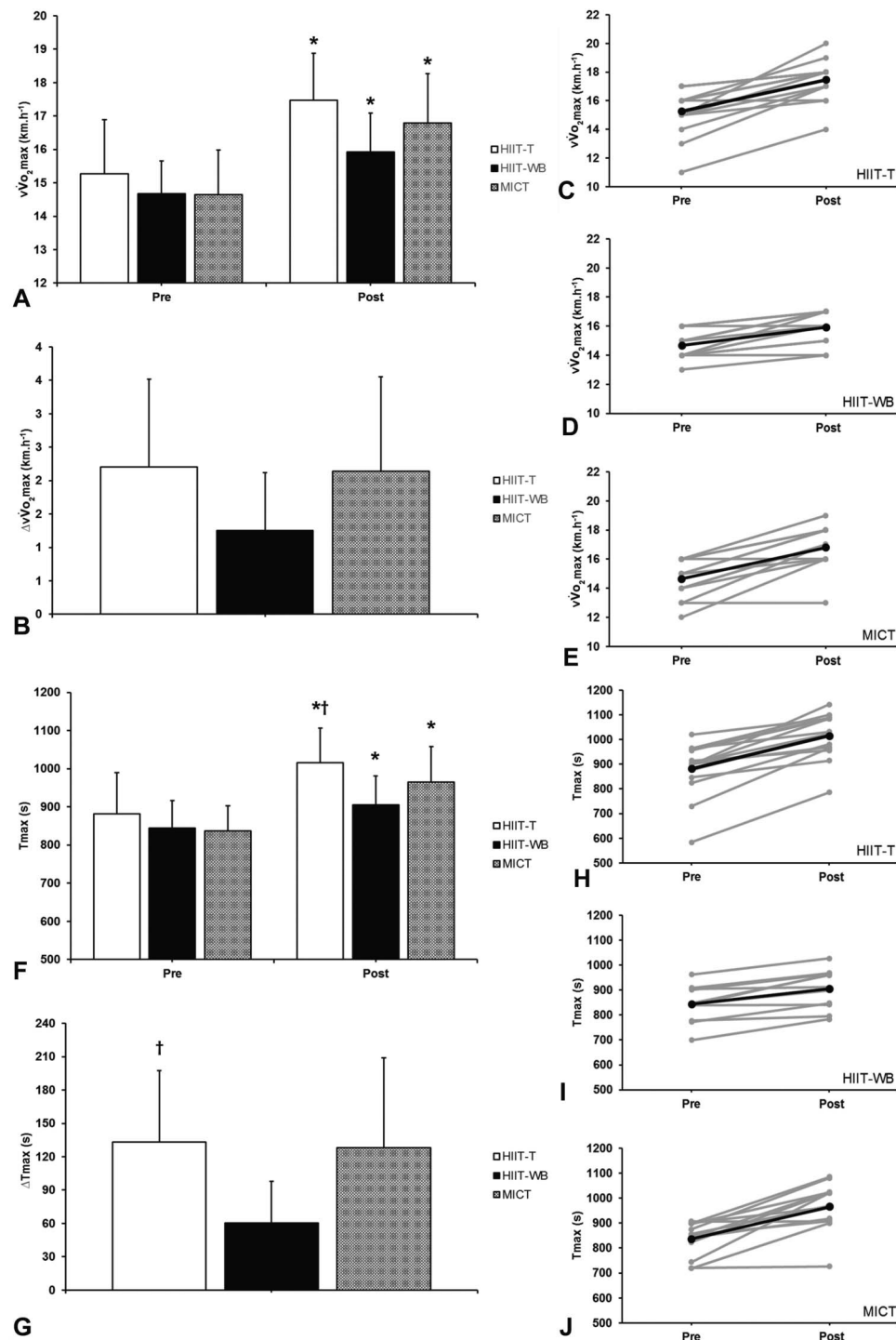


Figure 3. Velocity associated to the maximal oxygen uptake ($v\dot{V}O_{2\max}$) and time to exhaustion during the incremental test (T_{\max}) responses to 16 weeks of high-intensity traditional (HIIT-T) and whole-body (HIIT-WB) interval training as well as moderate-intensity continuous training (MICT). $v\dot{V}O_{2\max}$ comparisons between pretraining and posttraining (A); average changes (B) and individual (gray line) and mean (black line) responses according to training mode (C–E). T_{\max} comparisons between pretraining and posttraining (F); average changes (G) and individual and mean responses according to training mode (H–J); *Significantly different from pre ($p < 0.05$); †Significantly greater than HIIT-WB ($p < 0.05$).

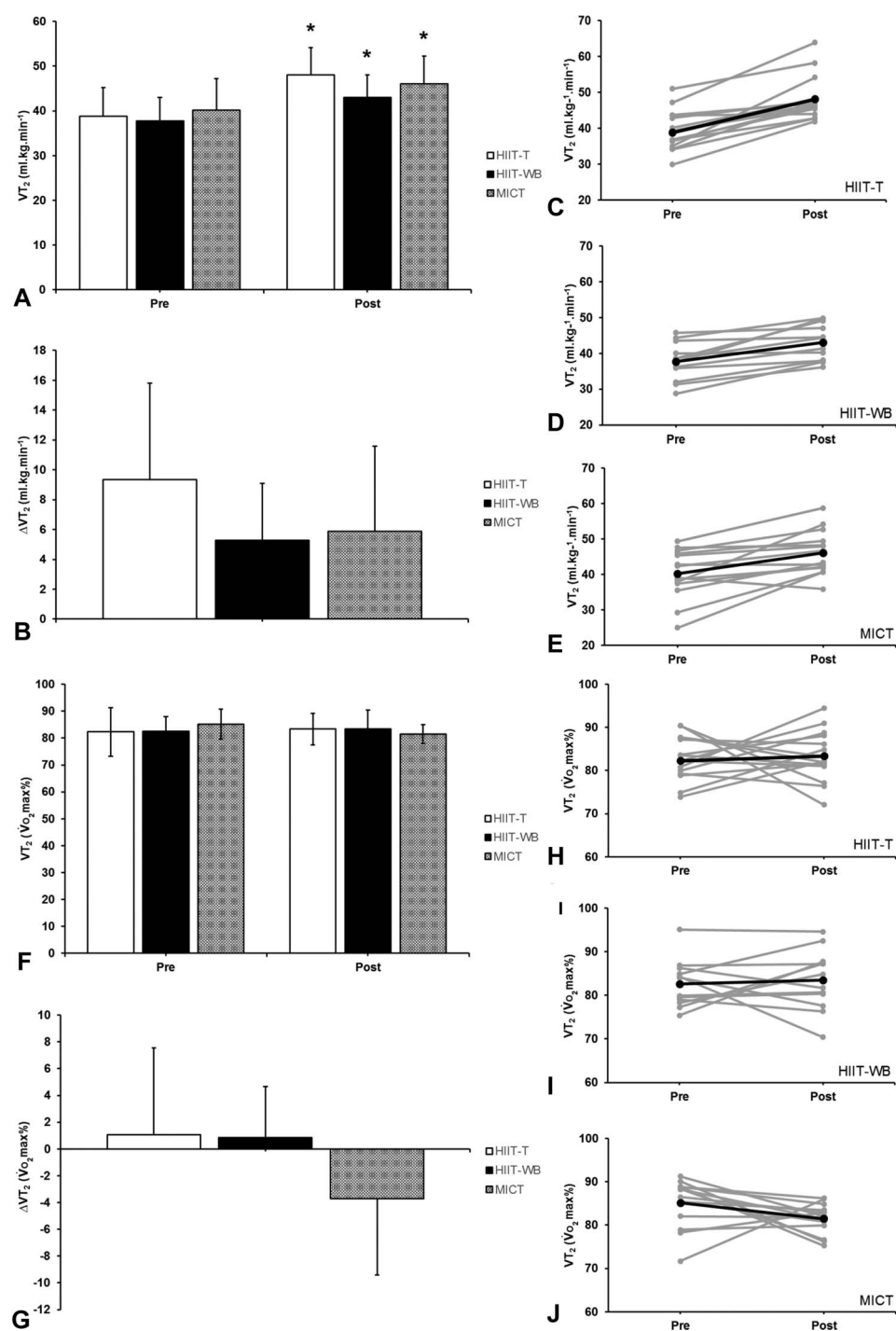


Figure 4. Second ventilatory threshold (VT₂) responses to 16 weeks of high-intensity traditional (HIIT-T) and whole-body (HIIT-WB) interval training as well as moderate-intensity continuous training (MICT). Second ventilatory threshold (ml.kg⁻¹.min⁻¹) comparisons between pretraining and posttraining (A); average changes (B); and individual (gray line) and mean (black line) responses according to training mode (C–E). Second ventilatory threshold (%V̇O₂max) comparison between pretraining and posttraining (F); average changes (G); and individual and mean responses according to training mode (H–J); *Significantly different from pre ($p < 0.001$).

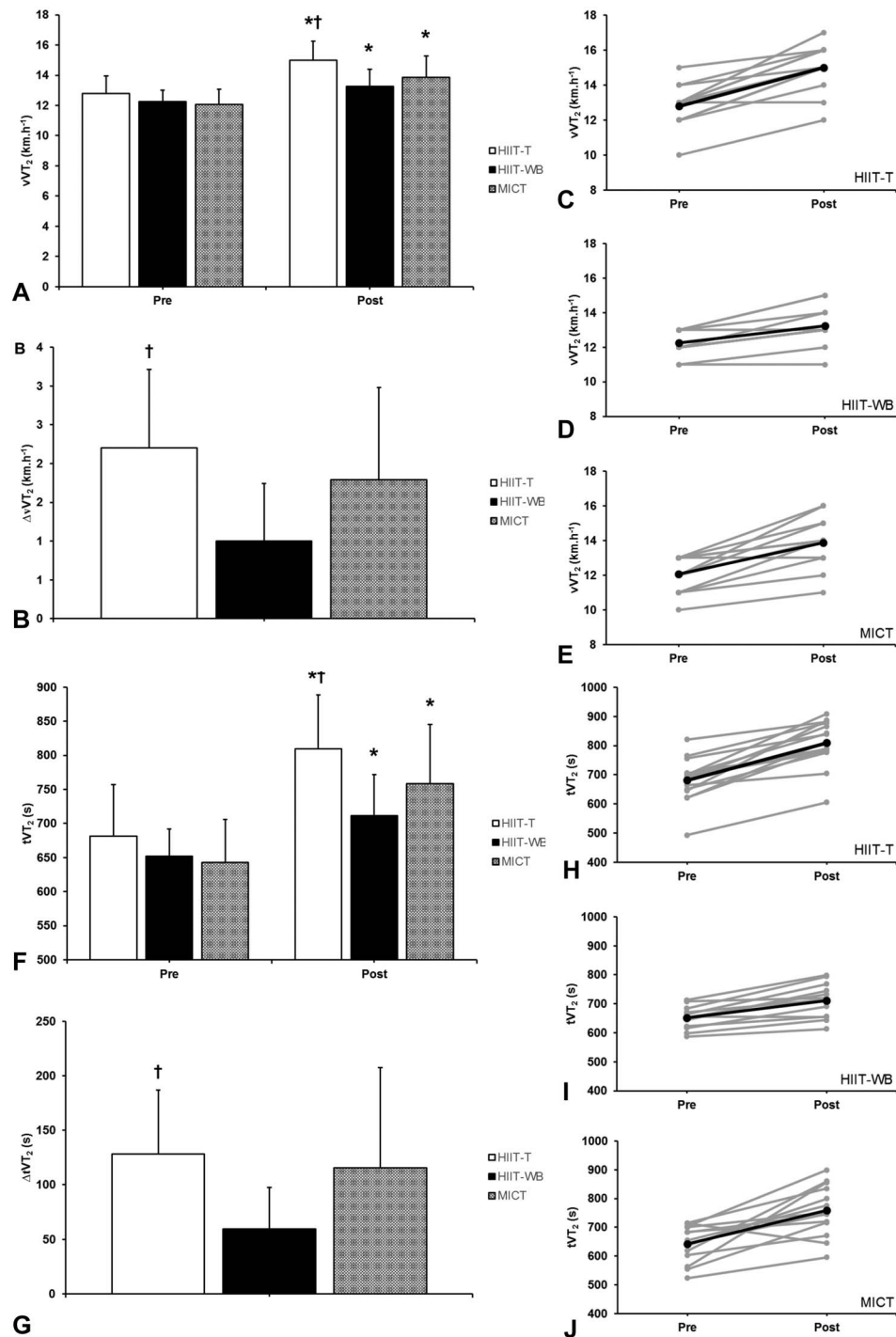


Figure 5. Velocity associated to the second ventilatory threshold (vVT₂) and time to reach VT₂ (tVT₂) responses to 16 weeks of high-intensity traditional (HIIT-T) and whole-body (HIIT-WB) interval training as well as moderate-intensity continuous training (MICT). Velocity associated to vVT₂ comparisons between pretraining and posttraining (A); average changes (B); and individual (gray line) and mean (black line) responses according to training mode (C–E). Time to reach VT₂ comparisons between pretraining and posttraining (F); average changes (G); and individual (gray line) and mean (black line) responses according to training mode (H–J); *Significantly different from pre ($p < 0.001$); †Significantly greater than HIIT-WB ($p < 0.01$).

TABLE 3. Running economy responses to 16 weeks of training according to protocol performed in healthy adult men ($n = 41$).*

	HIIT-T ($n = 15$)		HIIT-WB ($n = 12$)		MICT ($n = 14$)	
	Pre		Pre		Pre	
	Mean \pm SD	Post	Mean \pm SD	Post	Mean \pm SD	Post
RE ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	36.33 \pm 3.48	38.64 [†] \pm 2.41	33.83 \pm 2.83	38.19 [†] \pm 2.77	38.59 [§] \pm 6.07	40.11 ^{†§} \pm 3.51
RE ($\% \dot{V}O_{2\text{max}}$)	76.07 \pm 14.76	68.63 [†] \pm 9.36	76.95 \pm 7.60	75.26 [†] \pm 6.94	83.88 \pm 16.94	70.98 [†] \pm 8.65
Mean HR ($\text{b} \cdot \text{min}^{-1}$)	157.00 \pm 12.16	148.57 [†] \pm 11.14	161.00 \pm 12.07	159.30 [†] \pm 8.99	164.83 \pm 9.04	151.58 [†] \pm 12.35

*HIIT-T = traditional high-intensity interval training; HIIT-WB = whole-body high-intensity interval training; MICT = moderate-intensity interval training; RE = running economy; HR = heart rate.

[†]Significantly different from pre ($p < 0.001$).

[‡]Significantly different from pre ($p < 0.01$).

^{§§}Significantly different from HIIT-WB ($p < 0.05$).

$\dot{V}O_2$ was calculated for the last 3 minutes of the tests, suppressing the values in which occurs the initial $\dot{V}O_2$ adjustment to the load applied.

Statistical Analyses

Variables were tested for normality and homogeneity of variances with the Shapiro-Wilk and Levene tests, respectively, and are presented as mean \pm SD. For the comparisons between pre-intervention and post-intervention, 2-way analysis of variance with repeated measures (3 groups \times 2 time points) and Bonferroni's post hoc were applied. In case of significant interactions, F tests were applied to test main factors. Finally, an $\alpha = 5\%$ was adopted for all analyzes, and the tests were performed in SPSS software v. 20.0. Effect sizes (ESs) were calculated and considered as trivial (<0.35), small (0.35–0.80), moderate (0.80–1.50), and large (>1.50), as described by Rhea (27).

RESULTS

Participants' descriptive variables are summarized in Table 2. It should be noted that all groups were matched at the beginning of the program. After the intervention, significant, but trivial, reductions were observed in the sum of skinfolds ($p < 0.001$) and in the percentage of body fat ($p < 0.001$), both with no difference between protocols (ES < 0.20). For the remaining outcomes, no changes were found between time points or groups.

There were 14 dropouts throughout the program. Of these, 11 occurred during the first 8 weeks and the remaining 3 in the second half. Specifically, 6 subjects reported that despite the low volume of the training regimes, the time they had to spent to get to the laboratory and back home was too high to continue the intervention (HIIT-T = 3; HIIT-WB = 3); 4 were injured in activities not related to the program (i.e., nonregular soccer games, HIIT-WB = 3, MICT = 1); 1 had a traffic accident (MICT = 1); 1 was transferred to another city (MICT = 1); 1 claimed to be experiencing family problems (MICT = 1); and, finally, 1 of the subjects of the HIIT-WB group did not report the reason. Thus, 41 subjects concluded the training program (HIIT-T: 15; HIIT-WB: 12; MICT: 14).

Maximal Oxygen Uptake

No differences in $\dot{V}O_{2\text{max}}$ were identified at the beginning of the intervention ($p = 0.679$). Figures 2A, 3A and 3F demonstrate that the training regimes were efficient in increasing $\dot{V}O_{2\text{max}}$ (all $p < 0.001$, ES = HIIT-T: 1.35; HIIT-WB: 1.13; MICT: 1.22), $v\dot{V}O_{2\text{max}}$ (all $p < 0.05$, ES = HIIT-T: 1.44; HIIT-WB: 1.14; MICT: 1.51), and T_{max} (all $p < 0.05$, ES = HIIT-T: 1.33; HIIT-WB: 0.82; MICT: 1.56) in all 3 groups. Although $\dot{V}O_{2\text{max}}$ and $v\dot{V}O_{2\text{max}}$ increases were similar between groups, T_{max} presented a significant group \times time point interaction ($p < 0.05$). Main factor analysis revealed that T_{max} was

more markedly increased after HIIT-T compared with HIIT-WB ($p < 0.05$) but not with MICT ($p > 0.05$). Furthermore, average changes and individual responses according to protocol are available for $\dot{V}O_{2\max}$ (Figure 2B–E), $v\dot{V}O_{2\max}$ (Figure 3B–E), and T_{\max} (Figure 3F–I).

Second Ventilatory Threshold

After the intervention, similar improvements in VT_2 were also found among the protocols tested ($p < 0.05$; Figure 4A). The magnitudes of these increases were large for HIIT-T ($ES = 1.66$) and moderate for HIIT-WB ($ES = 1.00$) and MICT ($ES = 0.88$). However, when VT_2 was expressed in $\% \dot{V}O_{2\max}$, it remained at the same pre-intervention values in all 3 groups ($p > 0.05$; Figure 4F).

Both the velocity and the tVT_2 were also increased after 16 weeks ($p < 0.05$, $ES =$ HIIT-T: 1.83 and 1.67; HIIT-WB: 1.00 and 1.20; MICT: 1.43 and 1.49, respectively). Still, a significant interaction ($p < 0.05$) demonstrated that these increases were more pronounced in HIIT-T compared with HIIT-WB for both vVT_2 ($p < 0.05$) and tVT_2 ($p < 0.05$) after the main factor analysis. These results along with the average changes and the individual values are presented in Figures 4 and 5.

Running Economy

In relation to RE, a significant increase in $\dot{V}O_2$ for the same submaximal running velocity was observed ($p < 0.05$), which corresponded to moderate ($ES = 0.99$), large ($ES = 1.55$), and trivial ($ES = 0.29$) ES s for the HIIT-T, HIIT-WB, and MICT groups, respectively (Table 3). In addition, a group effect ($p < 0.05$) was identified and the post hoc indicated a higher $\dot{V}O_2$ in the MICT group compared with the HIIT-WB group. All tests presented a respiratory exchange ratio lower than 1.0 and, therefore, were considered as valid.

When expressed as $\% \dot{V}O_{2\max}$, it was observed that, despite the aforementioned increase in $\dot{V}O_2$, subjects were actually running at a lower $\% \dot{V}O_{2\max}$ after the training regime ($p < 0.05$), and this reduction was not different between protocols (Table 3). Specifically, small ($ES = 0.64$), trivial ($ES = 0.05$), and moderate ($ES = 0.86$) ES s were observed for HIIT-T, HIIT-WB, and MICT.

Reductions in the mean HR were also identified on the RE test after the intervention ($p < 0.05$) without differences as to the protocol performed ($p > 0.05$; Table 3). High-intensity interval training, HIIT-WB and MICT ES s were equal to 0.69, 0.16, and 1.20, respectively. Finally, based on the vVT_2 values for the 3 groups before the intervention, it is evident that the velocity used in the RE test was adequate for assessing subjects as intended.

DISCUSSION

The main finding of the present investigation is that all 3 training programs were effective in increasing the $\dot{V}O_{2\max}$ and VT_2 after 16 weeks of training. These results highlight that the HIIT-WB protocol may be an interesting alternative

to traditional training models to improve health-related outcomes. Notwithstanding, HIIT-T seems preferable to increase performance-related outcomes (e.g., T_{\max} , vVT_2 , tVT_2) in comparison with HIIT-WB but not MICT.

According to our initial hypothesis, no differences were found between groups for $\dot{V}O_{2\max}$ after the intervention. Only 2 studies to date assessed $\dot{V}O_{2\max}$ adaptations after a HIIT-WB program composed by calisthenics exercises. McRae et al. (20) showed an $\sim 8\%$ increase in recreationally active women after 4 weeks (8×20 seconds:10 seconds; $4 \times$ per week), which was similar ($\sim 7\%$) to a MICT group (30 minutes at 85% maximal HR; $4 \times$ per week). Our results confirm and extend these findings demonstrating that HIIT-WB is capable of achieving positive outcomes in men as well ($\sim 16\%$), and that when a longer training period is considered (i.e., 16 vs. 4 weeks), the minimum dose of high-intensity exercise required to increase aerobic capacity may lie at 4 minutes per day, 3 days per week, instead of the 4 days previously suggested (20).

Contrary to this, no $\dot{V}O_{2\max}$ improvements were observed in young cadets after 4 weeks of HIIT-WB composed of 4–7 sets of all-out burpees (30 seconds:4 minutes; $3 \times$ per week) in replacement to traditional military physical training (11). This finding does not corroborate our results, which showed an increase after 16 weeks. Although periods of up to 4 weeks have already been shown as sufficient to increase $\dot{V}O_{2\max}$ (13,22,37), difference on the duration of the studies (4 vs. 16 weeks) may suggest that calisthenics protocols require longer durations so that increases can be detected when lower training frequencies are applied (e.g., 3 sessions per week). To the best of our knowledge, this is the first study that compared HIIT-T and HIIT-WB protocols, and no differences were found in $\dot{V}O_{2\max}$ increases between them. This is an important finding as it identifies a protocol that can be performed without the need of a specific ergometer and yet remains time-efficient when compared with MICT (3).

Our results are also in agreement with a recently published meta-analysis and meta-regression (37). According to the authors, exercise intensities above 60% $\dot{V}O_{2\max}$ would not have an effect per se on the magnitude of aerobic power improvements (19), although this is not a consensus (37). However, it seems that higher intensities, especially those above 100% $\dot{V}O_{2\max}$, may require a significant reduced dose per session and a lesser total training volume to achieve similar results compared with when lower intensities are applied (31). This highlights the potential HIIT has to improve $\dot{V}O_{2\max}$ while requiring or using a shorter training time (3).

Increases in $v\dot{V}O_{2\max}$ and T_{\max} were also observed after training. Although no difference was observed between groups for $v\dot{V}O_{2\max}$, maximal exercise capacity (i.e., T_{\max}) increased more markedly after HIIT-T compared with HIIT-WB. This may be related to the specificity of the training mode, as no differences were found between HIIT-T and

MICT, which trained at different intensities and volumes but at the treadmill. Absence of difference between HIIT-T and MICT may be associated to the way MICT was prescribed. That is, %HR associated with VT_2 allows a session-to-session readjustment of training speed as subjects become apt to run at higher speeds in the same HR range. This is not the case when intensity is prescribed based on % $\dot{V}O_{2max}$, as MICT normally is (38).

Also, it is well accepted that low-volume HIIT generates peripheral adaptations, such as local enzymatic adaptations or increased mitochondrial volume and density (17). It is possible that the differences between HIIT-WB and HIIT-T movement patterns may have resulted in different local adaptations in the lower limbs. Therefore, it can be suggested that HIIT-T and MICT protocols are preferable if the exercise goal is not only to improve cardiorespiratory fitness but also to enhance exercise capacity.

Similar increases were observed among training regimes in VT_2 . Even though results contradict our initial hypothesis, the absence of difference between protocols is encouraging. Increases in VT_2 are associated with the ability to perform work at higher intensities for a longer duration while still within an aerobic training domain (5). As important, an increase in the anaerobic threshold has also the potential to increase performance in the severe domain regardless of training level (8).

Our study is one of the first we are aware of that assessed VT_2 responses after low-volume HIIT protocols, and the first to evaluate its response to a HIIT-WB protocol. Results are in accordance with previous investigations that applied HIIT-T and MICT (6,34). However, these protocols involved higher total training volumes (~30–60 minutes), especially compared with the present HIIT-T and HIIT-WB sessions (~4 minutes). Such difference highlights that extremely low-volume HIIT can be effective to increase VT_2 in this population while also being time-efficient.

Despite the lack of difference, the magnitude of the effect was different between protocols. A large ES was observed after HIIT-T, whereas moderate ES was observed after both HIIT-WB and MICT. This advantage is already well established in competitive level endurance runners (16). Replacement of a portion of their training volume, usually composed by high volumes of MICT, by HIIT seems to be beneficial even considering their minimal training window. Thus, our results also suggest that HIIT-T may be advantageous to improve VT_2 and is reinforced by its greater effect on vVT_2 and tVT_2 . Therefore, HIIT-T seems to be preferable to enhance subjects' exercise capacity after 16 weeks while requiring less than 24 minutes per week. Furthermore, despite the positive increase observed for VT_2 in $ml \cdot kg^{-1} \cdot min^{-1}$, when expressed as a percentage of $\dot{V}O_{2max}$, no increases were observed for any group, suggesting that VT_2 was able to accompany the increases in $\dot{V}O_{2max}$. In this regard, VT_2 was already high before training (~80–85% $\dot{V}O_{2max}$). Taken together, these results indicate that

post-intervention all subjects were able to exercise at higher $\dot{V}O_2$, running velocities, and for greater durations below their VT_2 . Further research is needed to better comprehend the potential of low-volume HIIT programs on this parameter in nonathlete populations.

Training resulted in an increase in $\dot{V}O_2$ for the same submaximal velocity in all groups (Table 3). However, when expressed as % $\dot{V}O_{2max}$, it was observed that subjects were actually running at lower percentages of $\dot{V}O_{2max}$ (77 vs. 70%, on average). Ultimately, one can only run for a certain period at an absolute % of $\dot{V}O_{2max}$ and, therefore, being able to run at the same velocity at a lower % $\dot{V}O_{2max}$ is clearly an enhancement in fitness. Such result contrasts with the literature because improvements of 2.8–6.5% in RE were previously observed in endurance athletes (1,24). Considering our sample had a larger adaptive window (i.e., recreationally active participants), RE improvements were expected after the intervention. Although the reason for this is not clear, previous authors emphasize the importance of longer training sessions to increase RE from a cardiorespiratory perspective, suggesting that the training volumes applied may have been insufficient to generate these adaptations (10).

Accordingly, Saunders et al. (29) recommend that studies aimed at reducing cardiorespiratory energy demand should focus on improving HR, ventilation, lactate concentration, and central temperature responses. Among the aforementioned outcomes, we identified a large reduction in the mean HR during the RE test after training, evidencing a lower cardiac overload for the same running velocity. As stated previously, a lower submaximal HR after training is reflective of positive adaptations on central factors such as stroke volume; however, this central mechanism seems to be dissociated from peripheral muscle adaptations and, consequently, to increased oxygen uptake efficiency (i.e., RE) (12). Improvement in RE may also be related to its evaluation in an exercise or exercise mode that is close to that practiced during training (9). Finally, based on a recent review that summarized RE normative values (1), it seems that our subjects were already economical according to their fitness and training level (especially because they were not athletes).

The study has also limitations. First, the absence of measurements between pretraining and posttraining limits the understanding on the time-course of the outcomes' adaptations. Although it does not reduce the relevance of the findings, it prevents more appropriate load readjustments from being suggested to professionals and practitioners. In addition, HIIT-T training load was readjusted only once after the eighth week, whereas HIIT-WB and MICT were able to readjust their training load session-by-session. This may have influenced on the absence of differences between the protocols on outcomes such as $\dot{V}O_{2max}$, for example. Nevertheless, frequent repetition of maximal incremental tests in nonathlete populations may be too stressful and demanding and it is not always possible outside the laboratory. Finally, even though an effort was made to adjust our RE test to

~92% of the intensity corresponding to the VT_2 , it seems that a few subjects performed their pre-intervention tests at intensities higher than intended (despite a respiratory exchange ratio <1.0), which may have impacted our results compared with an individualized velocity corresponding to 92% of each subject own VT_2 . It is suggested that future studies incorporating HIIT-WB protocols evaluate both economy and $\dot{V}O_{2\max}$ in a more specific test or compare specific and ergometer-based economy tests. In addition, investigations applying more than one of these protocols on the same training program are warranted, as it may prove advantageous in stimulating different central and peripheral mechanisms and adaptations.

In conclusion, our results demonstrate that a training program composed of calisthenics exercises can be as effective as traditional interval training while also being time-efficient compared with a continuous protocol to improve aerobic power and capacity after 16 weeks of intervention. More importantly, it was achieved without the need for specific ergometers, and it can be performed almost everywhere, facilitating its employment for the general population. However, HIIT-T and MICT seem preferable to improve performance-related outcomes compared with HIIT-WB.

PRACTICAL APPLICATIONS

Based on these results, HIIT-WB seems to be an efficient alternative to improve aerobic power and capacity, and allow subjects to run at a lower $\% \dot{V}O_{2\max}$ for the same running velocity. Thus, this training mode can be suggested as a great possibility for training regimes aimed at health and physical fitness promotion. Despite the need for large-scale studies in nonlaboratory environments (23), positive results observed in physically active young adults can indicate that HIIT-WB may also be useful for less fit populations, such as sedentary adults, for example. However, their capacity to perform this type of exercise still needs to be verified. Instead of emphasizing a better protocol, our results highlight that all 3 training regimes are suitable to induce improvements in cardiorespiratory fitness and, thus, provide another valuable tool to be added to conditioning coaches' toolbox. Ultimately, public health research may consider to test the feasibility of calisthenics exercises along already recommended training modes on health promotion.

According to McCann and Higginson (18), at least 4 variables need to be assessed to evaluate performance: $\dot{V}O_{2\max}$, maximum running velocity, the ability to maintain a high $\% \dot{V}O_{2\max}$ (i.e., VT_2), and RE. Accordingly, if the training program is also aiming to enhance performance, HIIT-T seems preferable to HIIT-WB because it results in greater improvements in running T_{\max} , vVT_2 , and tVT_2 , but not greater than MICT. However, the transference of these results to performance in real settings (i.e., not on a treadmill) still needs to be confirmed. Nevertheless, HIIT-WB can be suggested as an alternative to traditional training during maintenance or gen-

eral conditioning phases, for example, as it was able to improve the aforementioned performance outcomes.

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