Effects of 6 Weeks of Different High-Intensity Interval and Moderate Continuous Training on Aerobic and Anaerobic Performance

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[1]*Department of Physical Culture, Faculty of Natural Science, Mathematics and Education, University of Mostar, Mostar, Bosnia and Herzegovina;* [2]*Faculty of Kineseology, University of Zagreb, Zagreb, Croatia; and* [3]*Exercise Physiology, Training & Training Therapy Research Group, Institute of Sports Science, University of Graz, Graz, Austria*

Abstract

Cavar, M, Marsic, T, Corluka, M, Culjak, Z, Cerkez Zovko, I, Müller, A, Tschakert, G, and Hofmann, P. Effects of 6 weeks of different high-intensity interval and moderate continuous training on aerobic and anaerobic performance. *J Strength Cond Res* XX(X): 000–000, 2018—To provide practical data, we compared the training effects of 3 different programs, using a shuttle run stimulus, on aerobic and anaerobic performance, measured using the 20-m maximal shuttle run (Beep) test and 300-yd shuttle run, respectively. Forty-five physically trained men, with a mean age of 21.1 ± 1.8 years, participated. The 6-week, 12-session training programs included 2 high-intensity interval training (HIIT) protocols, with either a short (SH) or long (LH) shuttle run interval, and a continuous shuttle run (CON), which was used as a control. The training intensity was based on the maximal shuttle run speed (MASS), measured on the Beep test, to elicit the relevant values of the time to exhaustion (TTE). Short (SH) training was performed at 115–120%(MASS), with a 10-second work to 10-second rest scheme, and the number of repetitions to be completed set to 70% of each participant's maximum (~15 repetitions). LH training was performed at an intensity of 90–95%(MASS), with the duration set to 70%(TTE) (~4 minutes). For both SH and LH, 3 sets were completed at each session, with a 2–3 minutes of rest between sets. CON training consisted of continuous shuttle running for 35 minutes at an intensity of 70%(MASS). Both SH and LH yielded a large training effect ($p < 0.01$), with SH preferentially improving anaerobic performance and LH preferentially improving aerobic performance. No effect of CON training was identified. Our findings indicate that these different training protocols cannot be used interchangeably and that the Beep test is useful in prescribing the intensity and duration of HIIT.

Key Words HIIT, beep test, endurance training, time to exhaustion

Introduction

In the science and practice of sport and exercises, particular attention has been paid to the development of training strategies intended to improve performance-related physical qualities. High-intensity interval training (HIIT) has been proposed as a time-saving strategy to improve both aerobic power (maximal oxygen consumption, $\dot{V}O_2$max) and anaerobic capacity (45). Therefore, HIIT has become a preferred method of endurance training for anaerobically dominant sports (e.g., stop-and-go sports, such as soccer), in which $\dot{V}O_2$max influences performance (24) and occupations, such as the military, with a physiological profile that relies on diverse energetic sources and has time constraints in achieving complex training aims.

Despite the increasing interest in HIIT, its application and mechanisms remain poorly understood. Current literature on HIIT (14,18,36) has generally focused on $\dot{V}O_2$max, with interval training performed at intensities at or above the maximal aerobic velocity (MAV), where the MAV is defined, in laboratory procedures, as the minimal speed that yields $\dot{V}O_2$max. These training intensities are referred to as standard and supramaximal HIIT, respectively (18). Therefore, the HIIT concept covers a broad range of training parameters (intensity, duration of intervals and recovery, mode, work-to-rest ratio, type of rest, and mean intensity), which, in combination, produce specific effects that may lead to misinterpretations of their effectiveness by practitioners. One clear example of this issue is Tabata HIIT, which has been incorrectly widely applied (e.g., in weight training and running), with a 20-second work and 10-second rest schedule that was validated exclusively in cycling, with $\dot{V}O_2$max training at 170% MAV (45). Furthermore, a lack of knowledge

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regarding running HIIT modes is partially because of the scarcity of training studies that simultaneously evaluate different HIIT protocols (14,25,40). More frequently, studies explore a single HIIT mode or compare HIIT against moderate endurance training (17,23,27,30,36,38). Despite some contradictory results and a lack of data, the general conclusions that can be drawn from the current literature are as follows: (a) HIIT training is superior to moderate endurance training in improving $\dot{V}O_2$max; (b) standard HIIT is more effective than supramaximal HIIT in improving $\dot{V}O_2$max, whereas the opposite seems to be true for improvements in anaerobic endurance.

Unfortunately, HIIT studies lack objective criteria to define work durations (26) because the duration of intervals in most studies was arbitrarily selected and not varied among participants (14,17,24,25). This practice could likely decrease training outputs because some individuals would be training below their potential, whereas others would be training above their potential. Namely, the intensity measures commonly used in HIIT studies, such as the MAV or %HRmax (17,25,40,41), demonstrate great between-subject variability in the time to exhaustion (TTE), ranging from 4 to 11 minutes for the MAV (9). Although TTE tests are known to be reliable and are easily conducted (no expensive facility is required) (7), only 2 HIIT training studies used these tests for individual load prescriptions (18,42). Additionally, many studies have used complex laboratory measures to determine the appropriate exercise loading (e.g., MAV); these measures cannot be readily reproduced in daily field-based practice. Exceptions to this trend include 2 studies on team athletes (soccer, handball), designed without a control (HIIT was performed as part of the usual preseason/in-season training routine), and one study on individuals with different level of activities (14,17,47). Velocities for the HIIT in these studies were determined using a field-based scenario (e.g., a graded or 3,000-m timed trial test); however, the durations of the intervals in each of the evaluated HIIT programs were universally defined (i.e., the same for all trainees).

Athletes and coaches, especially those in stop-and-go sports, would likely derive small benefits from the findings of previous HIIT studies. For example, anaerobic performance, which is of primary importance for court and field athletes, has rarely been assessed (14,43). Furthermore, moderate endurance training, which is the most used reference training method in HIIT studies (4,23,27,36,40), has been shown to have no influence on $\dot{V}O_2$max (e.g., a lack of intensity) in well-trained subjects (22). Another feature reducing the practicality of HIIT studies is the typical application of 3 training units per week in the experimental design; this is hardly applicable for the real-life situation in team sports. In short, busy training and competition schedules (e.g., official and friendly games) limit the used endurance intensive training stimulus to up to 2 weekly trainings (depending on the training phase). Finally, of the 3 field-based HIIT studies, with methodological constraints as stressed in the previous paragraph (14,17,47), 2 studies used only track-running designs, even though one of the studies sampled soccer players. Many sports, including soccer, are not well represented by track running because field and court events involving a change of directions are used. Thus, this specific type of locomotion should be used in the endurance testing and training procedures. Leger et al. (32) were the first to recognize this problem and used a multistage 20-m shuttle run test (Beep test) for the indirect assessment of $\dot{V}O_2$max. Along with the need for only minimal equipment, space, and time, the Beep test shows good reliability and validity, and it is probably the most widely used field test for estimating cardiorespiratory fitness (e.g., in sports, education, and the military) (35). Despite all of these welcomed features, there are no studies that show how to use the results of the Beep test for the purpose of shuttle run endurance training (e.g., load determination) and HIIT training (training at or above MAV), which also reflects on practice. An obstacle to the applicability of the Beep test for HIIT load prescription is a design difference between the Beep test and the standard MAV protocol (5,16). In the Beep test, increased speed at each stage is produced over a shorter duration (1 minute vs. 2–3 minutes in the standard protocol). As a consequence, the final speed in the Beep test (i.e., the maximal shuttle run speed [MASS]) could significantly overestimate the real MAV in the shuttle run by eliciting a much lower TTE, inappropriate with regard to the 4-minute intervals typical in standard HIIT (14,25,38,41,46). Therefore, defining the fraction of MASS for HIIT modes is guaranteed to be of real and practical interest. In this study, we developed a novel noncomplex approach to define the fraction of MASS for HIIT modes on the basis of the findings of Billat et al. (6), who reported that the TTE at the MAV is fairly consistent (e.g., 5.5–6 minutes) across diverse activities. Accordingly, a shuttle run format could be used to define the MAV necessary to achieve a target fraction of the MASS, eliciting the relevant TTE.

The above summary of the current research on HIIT underlines the need to validate the MASS in the Beep test to determine the exercise load prescription and to compare the effectiveness of different shuttle HIIT protocols and moderate continuous exercise training on aerobic and anaerobic energy systems. Recruiting trained samples, with significant past team sport backgrounds, and applying a time frame and weekly frequency that are specific for the real situation in these sports would additionally assure sport practicalities. Accordingly, the purpose of the present study was to evaluate the effects of 3 different shuttle run training methods, performed at different MASS intensities, on the aerobic (Beep test) and anaerobic (300-yd shuttle run) performance. We hypothesized that 6 weeks of 12 training units of periodized programs of different intensities would yield specific training effects, with short-interval HIIT preferentially improving anaerobic performance and long-interval HIIT preferentially improving aerobic performance, whereas moderate continuous exercise would have no influence on performance.

Methods

Experimental Approach to the Problem

A preliminary study was performed in 12 endurance-trained male subjects (Beep test 12.8 ± 1.4 levels) 2 months before the start of the main study to validate the use of the MASS of the Beep test for the exercise prescription in the HIIT program (e.g., exercise at or above the MAV) and the continuous shuttle run. Specifically, the Beep test has the potential to overestimate the real MAV in the shuttle run, as it applies shorter durations in its levels, differing from standard graded MAV protocols (1 minute vs. 2–3 minutes) (5,16). The reference points for validation were defined by the TTE at the MAV and at the anaerobic threshold for various activities, which have been shown to be fairly consistent (6,19,34). A total of 8 TTE tests were performed at different MASS percentages, with 3 of these tests using a 10-second work-rest shuttle run, whereas the other 5 tests used a continuous shuttle run. A minimum of 9 participants completed each test, with a 48-hour rest between testing sessions. Three MASS percentages were defined, eliciting the TTE during standard HIIT, supramaximal HIIT, and moderate endurance continuous running. An intensity of 115%(MASS), used in the interval mode, was defined as being optimal for supramaximal HIIT in our target population (stop-and-go athletes). Namely, the activity profile (the shuttle run performed at supramaximal intensity, with a 10-second rest period) and the participants' capacity to endure it (the average TTE over 20 repetitions) corresponded to those in a testing protocol previously reported as significantly related to high-intensity running during a soccer game match (31). For the continuous TTE-based shuttle run test, an intensity of 90%(MASS) was defined as being appropriate for standard HIIT (running at the MAV in 4-minute intervals), as the TTE (range, 205–350 seconds) corresponded to that previously reported for a running-based MAV protocol (321 ± 83 seconds) (9). An intensity of 70%(MASS), tested in the continuous mode, was identified as the optimal intensity for moderate endurance training, as it yielded TTE values (requiring at least 45 minutes) previously reported for intensities below the lactate threshold (11,37). At an intensity of 70%(MASS), the average heart rate (HR), among 8 participants, was 169 $b \cdot min^{-1}$. With the application of the same criterion of the TTE corresponding to the remaining fractions of the MASS, these intensities were deemed to be inappropriate for the 3 types of training (the intensity was either too low or too high). With regard to supramaximal HIIT, the number of intervals at an intensity of 100% (MASS) was >100 for most participants, decreasing to around 30 at an intensity of 110%(MASS). For standard HIIT, the 100%(MASS) intensity was assessed to be inadequate, as the TTE was significantly smaller than that previously reported for the MAV (128.7 ± 30.89 seconds vs. 321 ± 83 seconds) (9). The TTE values obtained at 80 and 85% (MASS) were 25 minutes and 11 minutes, respectively, indicating that the 80%(MASS) intensity approximated the second lactate threshold, with the 85%(MASS) intensity being between $\dot{V}O_2max$ and the second lactate threshold (11).

In the main phase of the study, we evaluated the effects of the use of the 3 selected proportional MASS intensities (115, 90, and 70%) in 3 different training programs (standard HIIT, supramaximal HIIT, and moderate endurance) on aerobic and anaerobic performance. Training was performed twice per week for 6 weeks, with participants randomly allocated to the different training groups, and we used the Beep test results and activity status to ensure the equivalency of physical training status between the groups. Given that the outcomes for moderate continuous training have been well defined in previous studies, although the effects of interval training are largely undefined, we included a higher number of participants in the HIIT groups than in the moderate continuous exercise group to ensure sufficient statistical power for the between-HIIT-group comparison. The TTE was obtained separately for each of the HIIT groups to define the appropriate HIIT interval, 60–70% (TTE), as previously reported (42). The distance completed and the intensity of training varied between the programs (Table 1), as per real-life training conditions.

Subjects

Of the 69 male participants initially enrolled in the study, 24 were excluded from the analysis for the following reasons: illness, absence from >25% of the training sessions, or a change in training habits. Our analysis was, therefore, based on the data of 45 healthy male students, with a mean age of 21.1 ± 1.8 years (range, 19–25 years), mean mass of 78.7 ± 8.8 kg, and mean height of 182.8 ± 6.5 cm. Of these 45 participants, 3 were absent from some anaerobic performance testing sessions and were therefore included only in the Beep test. All participants were students in the Mostar University, Department of Kinesiology (Bosnia and Herzegovina), with multiyear past sport backgrounds (at least 5 years), mostly in team sports (78%), with a prevalence of soccer or futsal (74%), followed by handball (17%) and basketball (9%). Anthropometric data for the participants allocated to the 3 training groups are presented in Table 2.

At least 1.5 months before commencing the experiment, the participants regularly engaged in different physical activities, including strength exercises (2–3 times per week), team sports (once per week), and endurance running on a track (once weekly). Three weeks before the initiation of testing, all participants completed 5, habituation, endurance training sessions of moderate-to-intense running. During the course of the experiment, participants maintained their regular schedule of physical activity, with the exception of endurance running, which was only performed as per the experimental protocol. In addition, participants maintained their standard nutritional habits and agreed to not use ergogenic supplementation over the course of the experiment. Training sessions were performed during the months of

TABLE 1. Program load distribution per training session for trainees with average pretest Beep results.*

	SH	LH	CON
Total distance (m) completed†	From 1,940 to 2,025	From 2,520 to 2,566	5,523
Total duration of training (min)‡	26	23	35
Total duration of work (min)‡	9.2	15	35

*SH = short-interval HIIT; LH = long-interval HIIT; CON = continuous shuttle run; HIIT = high-intensity interval training.
†Without specific warm-up of HIIT group.
‡Without general warm-up, total distance = number of shuttle completed × shuttle distance.

April and May. Participants were advised to come to each session well rested and hydrated and to not eat for at least 2 hours before training. The study was approved by the Mostar University's ethics committee. The participants were informed of the purpose, procedures, and potential benefits and risks associated with the study before participating, and all participants signed a written institutionally approved informed consent document.

Procedures

Testing and Experimental Procedures. Tests were performed over 3 days, with at least a 1-day rest between the testing sessions. For all testing sessions, the Beep test was performed first, followed by the 300-yd all-out running test. The tests were performed before and after the 6-week training period, always in the morning at the same time. All tests were performed on an indoor parquet wooden floor, and participants were encouraged to give their maximum effort during the testing.

The Beep test is a multistage 20-m shuttle run test that is commonly used as a maximal effort field-based test to indirectly estimate $\dot{V}O_2max$ (35). The test is initiated at a running speed of 8.5 $km \cdot h^{-1}$, with the speed subsequently increased in increments of 0.5 $km \cdot h^{-1}$, every 60–67 seconds, with the pace signal emitted by the Beep test software. Participants were instructed to touch each of the 20-m lines with 1 foot at each signal and were allowed to reach the line after the signal only twice during the test. The test was terminated when a participant was no longer able to maintain the required speed, with the number of completed shuttle distances recorded as the score for the Beep test.

The 300-yd shuttle run test is a typical anaerobic (glycolytic) capacity test for team sport athletes, which is performed using a 25-yd shuttle distance (43) marked on a wooden floor using 2 reference lines. The time required to complete the 300-yd distance was measured using an electronic contact mat (Just Jump System Probotics, Huntsville, AL, USA) placed 40 cm behind the start line. Participants started the run with the front foot on the start line and the rear foot on the mat. A start signal was not used to avoid an influence of reaction time on performance. Participants ran to the opposite line, touched the line with 1 foot and ran back to the start line. This cycle was repeated 6 times without stopping; at the end of the last shuttle run, participants were asked to step onto the contact mat and the total duration was recorded in seconds.

Training Procedures. Three training groups were defined using short-interval HIIT (SH, $n = 16$), long-interval HIIT (LH, $n = 18$), and continuous endurance training (CON, $n = 11$). The training intensity for each group was based on the results of our pilot study, as described in the Experimental Approach to the Problem section. The SH program consisted of a 10-second work to 10-second rest shuttle run, performed at an intensity that approximated 115%(MASS) at the start of training and increased to 120%(MASS) over

TABLE 2. Basic anthropometric characteristics of all groups.*†

	SH	LH	CON	*p*
Age (y)	20.9 ± 1.65	21.2 ± 1.89	21.3 ± 2.02	0.80
Body height (cm)	182.2 ± 6.4	183.6 ± 7.6	185.7 ± 3.9	0.16
Body mass (kg)	75.2 ± 6.58	80.5 ± 11.0	80.3 ± 6.8	0.18
BMI	23.4 ± 2.1	24.1 ± 2.2	23.3 ± 1.4	0.43

*SH = short-interval high-intensity interval training; LH = long-interval high-intensity interval training; CON = continuous shuttle run; BMI = body mass index.
†Data are presented as mean ± *SD*.

TABLE 3. Details of the applied 6-week training programs.*†

	Short HIIT, sets × TTE percent	Long HIIT, sets × TTE percent	Continuous at 70% MASS durations (min)
Session 1	1 × 100% (10 s work/rest) at 115% MASS	1 × 100% (continuous) at 90% MASS	35
Session 2	2 × 70% (~15 reps)	2 × 60% (~3.5 min)	35
Session 3	3 × 70%	3 × 70% (~4 min)	35
Session 4	3 × 70%	3 × 70%	35
Session 5	Overloading	Overloading	35
Session 6	Deloading	Deloading	35
Session 7	Deloading	Deloading	35
Session 8	3 × 70%	3 × 70%	35
Session 9	Overloading	Overloading	35
Session 10	3 × 70%	3 × 70%	35
Session 11	Deloading	Deloading	35
Session 12	1 × 100% (10 s work/rest) at 120% MASS	1 × 100% (continuous) at 95% MASS	35

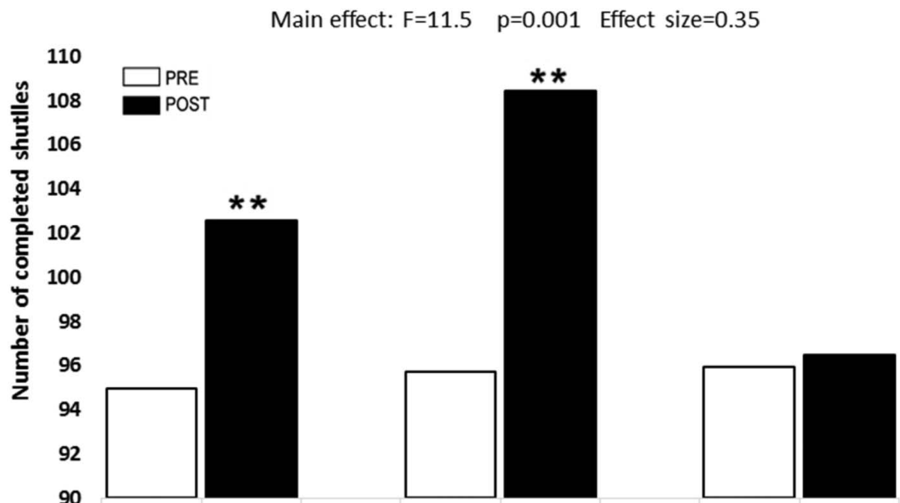
*HIIT = high-intensity interval training; TTE = time to exhaustion; MASS = maximal shuttle run speed; reps = repetitions.
†A 3-minute recovery period was used between sets for both HIIT programs over the first 4 training sessions and was decreased to 2 minutes for the remainder of the training sessions. For the overloading component of the program, the intensity of the shuttle run was increased by 0.5 $km \cdot h^{-1}$ for both the HIIT groups, with an incremental decrease of 0.5 $km \cdot h^{-1}$ used for both the HIIT groups during the deloading intensity component of the program. For the LH group, this decrease in intensity was accompanied with a 1-minute reduction in the duration of the interval run, with a 20% decrease in the number of repetitions performed per set for the SH group.

the training session. The number of repetitions completed was determined using the 70%(TTE) criterion (26), which was approximately 15. The LH program consisted of a continuous shuttle run, initially performed at an intensity of 90% (MASS) and progressing to 95%(MASS) over the training session. Again, the duration of running was individualized to 70%(TTE), which was approximately 4 minutes. To achieve this TTE criterion, increments or decrements of 0.5 $km \cdot h^{-1}$ were used to match the intensity within each HIIT group, such that, ultimately, the TTE of each participant was not significantly different from the group mean (20 repetitions for SH and 5.5–6 minutes for LH). Therefore, a similar exercise volume was completed by each participant within each HIIT group. The manipulation of running speed by increments or decrements of 0.5 $km \cdot h^{-1}$ was effective in ensuring a similar subjective experience of the exercise intensity and motivation, and it provided an opportunity to control individual performance. The participants of all 3

TABLE 4. Shuttle run path lengths for varying MASSs.*

		SH (10 s intervals)		LH (3 × 4 min)		CON
Beep level	MASS ($km \cdot h^{-1}$)	115% MASS path length (m) in 5 s	120% MASS path length (m) in 5 s	90% MASS path length (m) in 6 s	95% MASS path length (m) in 6 s	70% MASS path length (m) in 8 s
15	15.5	24.76	25.83	23.25	24.54	24.11
14	15	23.96	25	22.5	23.75	23.33
13	14.5	23.16	24.17	21.75	22.96	22.56
12	14	22.36	23.33	21	22.17	21.78
11	13.5	21.56	22.5	20.25	21.38	21
10	13	20.76	21.67	19.5	20.58	20.22
9	12.5	19.97	20.83	18.75	19.79	19.44
8	12	19.17	20	18	19	18.67

*SH = short-interval high-intensity interval training; LH = long-interval high-intensity interval training; CON = continuous shuttle run; MASS = maximal shuttle run speed.



	SH	SH		LH	LH		CON	CON
Mean	94.9	102.6		95.7	108.4		95.9	96.5
SD	13.3	10.8		20.0	19.2		15.7	13.0

Figure 1. Trial (3 levels) × time (2 levels) interaction effect for Beep test performance (** $p < 0.01$). SH = short-interval high-intensity interval training; LH = long-interval high-intensity interval training; CON = continuous shuttle run.

groups completed a general warm-up, consisting of low-intensity shuttle running and Callanetics exercises. Both HIIT groups then proceeded to a specific warm-up. Participants in the SH group performed 10 repetitions of 10-second work and 10-second rest shuttle runs at 100% (MASS), whereas those in the LH group performed 3-minute shuttle runs at 85%(MASS). After a 3-minute rest period, both groups completed their main training program, which consisted of 3 sets.

In the CON group, continuous shuttle running was performed at an intensity of 70%(MASS), with a duration (HR response based) previously associated with a steady-state exercise below the anaerobic threshold (25), rather than a duration matching for %TTE. This allowed us to

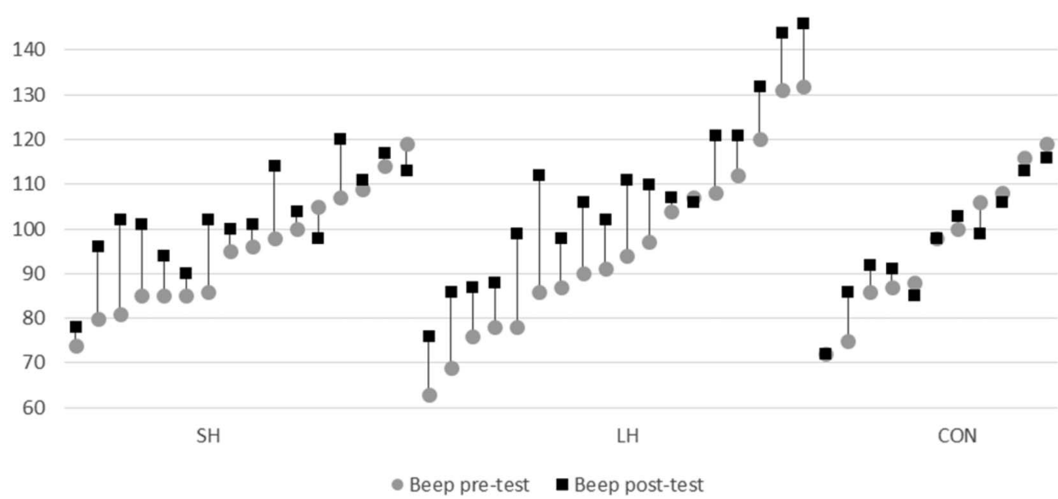


Figure 2. The pre-to posttraining change in beep test performance is shown for each participant in each of the experimental groups (SH, LH, and CON). SH = short-interval high-intensity interval training; LH = long-interval high-intensity interval training; CON = continuous shuttle run.

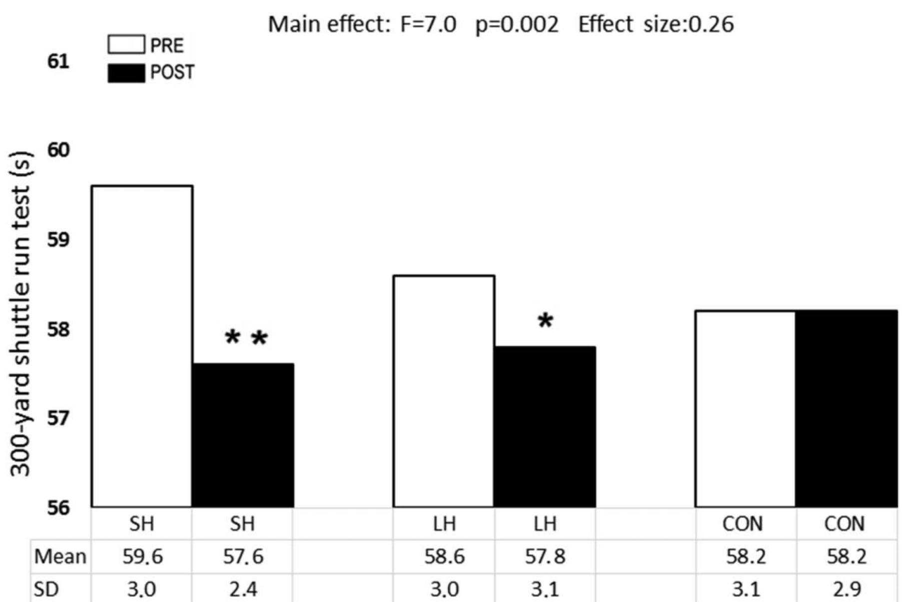


Figure 3. Trial (3 levels) × time (2 levels) interaction effect for the 300-yd shuttle run test; $^{**}p < 0.01$; $^{*}p < 0.05$. SH = short-interval high-intensity interval training; LH = long-interval high-intensity interval training; CON = continuous shuttle run.

use the CON group as a standard against the SH and LH programs. Following the warm-up, participants in the CON group performed 35 minutes of shuttle running at a constant intensity that was maintained for all 12 training sessions.

All training sessions were performed outdoors, on a flat grass surface, which easily accommodated all 45 participants, allowing the 3 groups to train at the same time. All training sessions were held in the morning, on fixed days of the week (usually Monday and Thursday). Deloading sessions for the HIIT groups were included to avoid the risk of overtraining injuries during the 6-week training period. Detailed information about each program is presented in Table 3.

Minimal equipment was needed for the realization of the exercise programs. The equipment included measurement

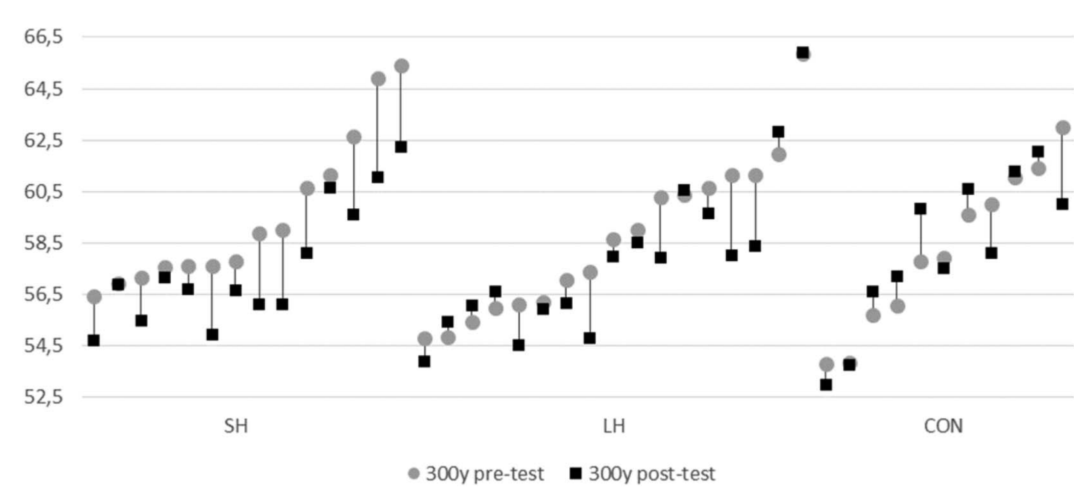


Figure 4. The pre-to posttraining change in the 300-yd test performance is shown for each individual in each of the experimental groups (SH, LH, and CON). 300y = 300-yd test, SH = short-interval high-intensity interval training; LH = long-interval high-intensity interval training; CON = continuous shuttle run.

tape and cones for the measurement and marking of path lengths. Additionally, to maintain an accurate control of the pace during the shuttle runs for all training sessions, as well as for the TTE testing session, each group was provided with an electronic pacer (free mobile version software) that emitted constant signals for all participants in each group. Signals were presented every 5, 6, and 8 seconds in the SH, LH, and CON programs, respectively, indicating the time for a change in direction, with the path lengths of the shuttle runs matched to the electronic timing. These timing parameters were predefined to meet the standards for the Beep test. The predefined shuttle run path lengths, matched to the MASS for each training protocol, are presented in Table 4.

Statistical Analyses

Statistical analyses were performed using STATISTICA software (Version 10; Tulsa, OK, USA). All data were normally distributed, as evaluated using the Shapiro-Wilks test. The assumptions of the homogeneity of the variance were confirmed before analysis using Levene's test. A trial (3 levels) × time (2 levels) analysis of variance (ANOVA) was used to evaluate whether the SH, LH, and CON protocols differed in the changes in Beep and 300-yd shuttle run performance across the 6 weeks of training. In addition, within-group changes in the Beep and 300-yd shuttle run performance were evaluated using the Fisher's least squares (least significant difference [LSD]) post hoc test (to determine the significance of pretest to posttest improvement). For groups with a significant pretest to posttest improvement, a trial (2 levels) × time (2 levels) ANOVA was used to evaluate the significance of the difference in training effects between 2 training protocols. A p value of ≤ 0.05 was considered statistically significant for all analyses, and 95% confidence intervals (CIs) for the mean difference were calculated for each dependent variable. For insignificant results, the power of the observed comparison is provided. To compare the magnitude of the between-group differences, partial eta-squared (η^2) values were calculated as the effect size (ES), which was interpreted using the following criteria (33): ≥0.01, small ES; ≥0.09, medium ES; and ≥0.25, large ES.

Results

Significant differences in the effect of the SH, LH, and CON programs on aerobic (Beep) and anaerobic (300-yd shuttle run) performance were identified. The SH program improved anaerobic performance to a greater extent than LH, whereas LH improved aerobic performance to a greater extent than SH. In contrast, the CON protocol did not yield significant effects on either anaerobic or aerobic performance. Details regarding these results are provided below.

The pre- to posttraining changes in aerobic performance (Beep test) are shown for the SH, LH, and CON groups in Figure 1. The greatest progress in the Beep test was observed in the LH group (LSD $p < 0.001$; ES = 0.82; 95% CI, 15.7–9.7), followed by the SH group (LSD $p < 0.01$; ES = 0.48; 95% CI, 11.9–3.3), with a significantly greater increase in the number of shuttles in the LH group than in the SH group (2 × 2 ANOVA, 12.94 vs. 7.63, respectively; $F = 4.0$; $p < 0.05$; ES = 0.12). No effect of the CON training program was identified (LSD $p = 0.96$; observed power, 0.06; 95% CI, 4.0 to −2.9). Examination of the pre- to posttraining changes in the Beep test performance for each participant, shown in Figure 2, identified only 1 case of nonresponse in the LH group, with the remainder of the participants in the LH group increasing by 13.5 shuttles, on average. By comparison, only 7 of the 16 participants in the SH group achieved a meaningful improvement in the Beep test performance, with decrements in performance identified in 2 participants.

A significant group × time interaction for the 300-yd shuttle run test was observed, as shown in Figure 3. The highest improvement in the 300-yd shuttle run was observed in the SH group (LSD $p < 0.001$; ES = 0.74; 95% CI, −1.2 to −2.6), followed by the LH group (LSD $p < 0.05$; ES = 0.30; 95% CI, −0.2 to −1.5). A 2 × 2 ANOVA identified significant differences in the average improvement in the 300-yd shuttle run between the SH (1.95 seconds) and LH (0.80 seconds) groups ($F = 6.43$; $p < 0.05$; ES = 0.18), with no improvement observed in the CON group (LSD $p = 0.96$; observed power 0.05; 95% CI, −0.9 to 1.0). The pre- to posttraining change in the performance of the 300-yd shuttle run for each participant is shown in Figure 4. In the LH group, no improvement was identified in 35% of cases (0.49 seconds decrease on average), with a 1.51-second improvement, on average, in the remaining participants. In the CON group, performance improved in 2 participants (18%) and regressed by >1.9 seconds in 2 participants, with the remaining participants showing no meaningful change in performance.

Discussion

The present study compared the effects of different HIIT and moderate endurance shuttle run protocols on aerobic and anaerobic performance. Our hypothesis was confirmed because the HIIT programs significantly improved both aerobic and anaerobic performance, with SH preferentially improving anaerobic performance and LH preferentially improving aerobic performance. No significant changes in aerobic and anaerobic performance were observed for the moderate endurance training program (CON group). In the individual improvements on the Beep test, dependency on the pretest results was evidenced in the CON and SH training groups but not in the LH group. Relying on a novel and completely field-based methodology to prescribe the load using a popular field test, the current study is the first to compare the effects of the applied training programs in the shuttle run mode.

The superiority of LH over SH in improving Beep ($\dot{V}O_2max$) performance observed in the present study is in agreement with previous laboratory-based studies of similar duration (6–10 weeks) that evaluated the response of

$\dot{V}O_2$max to different modes of HIIT in trained adults (18,20,25). The higher $\dot{V}O_2$max trainability evidenced with long-interval (standard) HIIT training is explained by the fact that this mode assures a longer time spent at the oxygen consumption levels (e.g., ≥90%$\dot{V}O_2$max) needed for the improvement of aerobic power in trained subjects (3,18,48). The observed rate of improvement in the estimated $\dot{V}O_2$max with the LH protocol (6%) is within the range of directly measured $\dot{V}O_2$max changes (6–9%) evidenced in the above-cited laboratory-based studies with long-interval HIIT. The SH program elicited a lower rate of improvement in the present study than that reported in previous laboratory-based studies applying short intervals (25). The potential reason for this difference could be that the active rest and lower intensity applied in previous studies rendered their short-interval HIIT programs more dependent on oxygen consumption. However, comparisons in the amount of improvement in the estimated and directly measured $\dot{V}O_2$max are hardly objective. Namely, the calculation of $\dot{V}O_2$max using the Beep test systematically underestimates the $\dot{V}O_2$max in adult men, with significant intersubject variability (44). Therefore, head-to-head comparisons, assuring a more objective assessment of our training methods, are only possible with the rare HIIT studies on adults that used the Beep test as a performance variable. Slettalokken and Ronnestad (41) evaluated male semiprofessional soccer players and reported results that are contradictory to the present results because 6 weeks of 6 training units of long-interval HIIT, combined with normal off-season activity (strength training, soccer, moderate running), resulted in a significant 8% decline in Beep performance. Interestingly, the applied program maintained the directly measured $\dot{V}O_2$max and MAV (a nonsignificant improvement was observed), for which the authors of the previous study gave no clear explanation. However, it is of relevance to note that, like the testing of $\dot{V}O_2$max and MAV, the HIIT program in the previous study involved linear running. This could explain why performance maintenance was achieved in these 2 variables and not in shuttle run Beep test. In comparison, the training programs in the present study comprised the shuttle run, which most likely optimized the LH program for better results on the Beep test. The shuttle run movement pattern includes periods of acceleration and deceleration, and changes in direction, rendering it biomechanically more complex (e.g., a diversity of movements and types of voluntary muscle contractions) and significantly different from a uniform constant pace with continuous (forward) linear running. The previous reporting of higher values of $\dot{V}O_2$max and lactate concentration in the shuttle run than in the forward run (1) supports the specificity of these training programs. Therefore, in addition to load parameters, HIIT protocol effects seem to be quite specific to the movement pattern applied in the training. This is generally accepted in sport practice, as optimizing endurance activity training stimuli should involve the application of the appropriate locomotion form (e.g., cyclists, cycling; runners, running; rowers, rowing, etc.). Yet, it seems that this need for HIIT training specificity is not valid for all performance levels, as the Beep test performance in lower achievers can benefit from nonspecific training approaches with regard to the movement pattern. For example, with the application of 4-minute intervals twice weekly for 8 weeks, another previous HIIT study focusing on the changes in Beep test performance reported significant positive results, even though the training intervention comprised track running (38). Of note, the Beep test baseline scores in the cited study were lower by 25 and 42% than those in the present study and the above-mentioned study, respectively (41). Lower achievers typically demonstrate a lower minimal threshold for enhanced training adaptations, which can also be applied to the results of the present study. Specifically, participants with relatively lower scores (≤87 shuttles) were only ones to benefit from the CON program in terms of Beep test performance (Figure 2).

The absence of a significant change in Beep ($\dot{V}O_2$max) test performance in the CON group corroborates with findings from previous laboratory-based studies evaluating $\dot{V}O_2$max response to moderate endurance training below the lactate second threshold in trained male subjects (see the text above). Estimated according to the criterion of the TTE (see the Experimental Approach to the Problem), this inadequate intensity in the CON program allowed us to control for the potential effects of advanced exercise (shuttle run) economy on the measured posttraining Beep test. A previous study indicated that improvement in exercise economy is not dependent on the training intensity and that a significant improvement in exercise economy can increase $\dot{V}O_2$max (25). As participants in the present study cohort had a background in stop-and-go sports (such as soccer, futsal, basketball, and handball), we consider that they were all well trained with regard to exercise economy (shuttle run), and therefore, the intensity of the CON program was ineffective in producing any improvement in Beep ($\dot{V}O_2$max) test performance. By comparison, the minimal intensity requirement for continuous training to induce $\dot{V}O_2$max changes among trained men has been shown to be slightly above the lactate second threshold (22). A constant work rate at this training intensity is characterized by a non–steady state in diverse physiological parameters, including $\dot{V}O_2$ (10), reaching values sufficient for $\dot{V}O_2$max improvement (e.g., ≥90%$\dot{V}O_2$max). The TTE specific for exercising at this intensity is limited and is approximately below 30 minutes (19,28). In our pilot study, we determined that continuous running at an intensity of 80%(MASS) yielded a comparable TTE (25 minutes of continuous shuttle running, on average). This finding supports the use of this proportional MASS as an effective minimum intensity for continuous shuttle run training to improve Beep test performance in trained men (e.g., the appropriate duration with regard to the TTE should also be considered).

Result-based differences in the improvements observed in the SH and CON groups suggest the limited potential of these programs to improve, or even maintain, $\dot{V}O_2$max and Beep test performance. Despite the previously mentioned training benefits of continuous exercise training (as in our CON protocol) in lower achievers, an identical stimulus in well-trained individuals might not even maintain performance on the Beep test and $\dot{V}O_2$max. Specifically, in the CON group, all participants with baseline Beep results beyond 100 shuttles experienced decrements in the posttraining scores. Most likely, the 6-week cessation of intensive training stimuli at this performance level was sufficient to induce negative changes in Beep test performance. The observed results could have implications for the selection of higher than moderate intensity for endurance training aimed at preventing a profound decline in $\dot{V}O_2$max (Beep test) during the off-season period in team sports (6–8 weeks). The results of the participants in the SH group, depicted in Figure 2, suggest that well-trained individuals, with a baseline performance similar to that previously reported for professional soccer players (≥110 shuttles) (2), may not improve their Beep test performance and $\dot{V}O_2$max with this protocol. In contrast, in the LH group, as per Figure 2, result-based differences in the Beep test improvements were not evident, as the highest scorers similarly benefited from this more efficient training program (Beep results, ≥120 shuttles). Bouchard et al. (12) argued that genetics were likely to influence $\dot{V}O_2$max training, which might lead to noneffects of training and even negative training outcomes. Interestingly, we identified similar results for the Beep ($\dot{V}O_2$max) test in the LH group, where 2 individuals, with pretraining test scores that were not among the highest, showed little or no improvement in posttraining Beep test performance (Figure 2).

The observed diversity of training impact on the 300-yd shuttle run test (from nonsignificant to significant) is difficult to compare with the HIIT training effects on anaerobic performance previously reported in rare running mode studies. Although previous studies have reported positive changes, some applied different anaerobic performance tests or lacked a control group or explored one HIIT mode combined with another training content (14,15,43). Nevertheless, the present results are aligned with the energetic profiles of the 3 different training programs (18,21,39). Specifically, supramaximal and standard HIIT, in contrast to a control program of moderate intensity, require a significant fraction of anaerobic glycolysis, which is crucial in the performance of the 300-yd running test (43). Furthermore, supramaximal HIIT (18) and the early phase of the 300-yd running test partially rely on phosphocreatine sources. This explains the higher gains in the 300-yd running test obtained with the SH program than with the LH program and the lack of effects with the CON protocol. It is important to highlight the fact that the 300-yd shuttle run test is hardly an optimal choice of test for the SH program. Namely, this test does not replicate the intermittent nature of the stimulus provided by the SH protocol, which would be of specific important to the performance of stop-and-go sports (31). Specifically, we designed the SH protocol to have a similar activity profile (e.g., shuttle run mode, supramaximal intensity, 10-second rest period) as that for a testing procedure known to be associated with the amount of high-intensity running covered by soccer players during a game (the Yo-Yo intermittent recovery test). For pragmatic reasons (e.g., we limited the testing procedure to 1 aerobic test and 1 anaerobic test), we did not include the Yo-Yo intermittent recovery test, which has both significant anaerobic and aerobic components. Regardless, insight into the training outputs of the SH program could be derived from specific TTE measurements, performed as a part of a regular progressive training program, at the first and last training sessions (Table 3). Accordingly, at a 5% higher shuttle run intensity (~120% MASS) than that at the first measurement (~115%MASS), the SH group advanced the number of 10 seconds of work and 10 seconds of rest shuttle run repetitions (LSD: $p < 0.001$; ES = 0.43), indicating the trainability of this type of endurance with a specific training approach.

There are several novel and practical aspects of the present study that should be emphasized, along with the reproducibility of the new methodology that we used. Only a few studies have applied field-based methodology to prescribe the load for HIIT protocols. This is the first study that applied a shuttle run mode of exercise for different HIIT and continuous endurance training methods, adding to the sparse literature that has examined both versions (standard, supramaximal) of HIIT simultaneously. The novel and simple method used in our pilot study to validate the MASS of the Beep test for the load prescription in HIIT and moderate endurance training (see Experimental Approach to the Problem) was shown to be reproducible in the main phase of the study. Specifically, the predefined (pilot study) ranges of the MASS intensity for the LH program (90–95% MASS) applied in the present study (first training session) elicited relevant TTE values at the MAV (see Experimental Approach to the Problem). In the main study, we found slightly higher interindividual differences in the TTE results at 90% MASS (from 4 to 10.8 minutes) than those in the pilot study. This could be explained by the larger number of participants and lower MASS results (e.g., Beep test scores) in the main study, as the TTE has been shown to be inversely proportional to the intensity applied (8,26). A similar conclusion could be made for the intensities applied in the SH program. Manipulation of the shuttle run intensity by $0.5\ km \cdot h^{-1}$ (allowing the adaptation of path lengths according to the HIIT group-specific timing signal) in participants with a TTE significantly different from the group mean enabled a similar subjective experience of intensity and motivation within each HIIT group. The proposed training and testing methods require only minimal equipment, and relatively little space and time, while providing simultaneous and individualized (intensity, extensity) performance for a large group of individuals. Another novel aspect of the present study is the presentation of result-based differences in the improvement of $\dot{V}O_2max$ (Beep) for the applied programs. Namely, students of kinesiology, in comparison to athletes of the same sport and competition level, typically demonstrate greater interindividual differences in diverse qualities, including endurance. The diversity of the pretraining Beep test scores in the present study (e.g., ranging from 9 to 14 levels) suggests the applicability of our conclusions to cohorts with similar levels of Beep test results, ranging from amateur to highly trained professional team athletes.

Among the limitations of current study is the lack of the inclusion of laboratory measures that could clarify the mechanisms of the improvements after 6 weeks of exercise training. We intentionally used this time frame because it is typical for the preseason phase in team sports, during which, the bulk of the development of performance-related physical qualities is addressed. Based on previous HIIT studies on trained males with similar short-term designs (4–8 weeks), we may suppose that among the diversity of adaptions, some occur in time periods even shorter than 6 weeks. For example, research on well-trained competitive male cyclists showed that the skeletal muscle buffering capacity can increase by 16% after only 6 sessions (4 weeks) of long-interval (5 minutes) HIIT training (49). In addition, the density of a number of membrane transport proteins (e.g., glucose, lactate, fatty acid) has been reported to substantially increase (16–35%) in trained males after 6–8 weeks of HIIT (13,29). Furthermore, stroke volume increases of 10 and 13% after 8 weeks of short- and long-interval HIIT, respectively, have been reported, with passive rest, although such changes are not elicited with continuous training at and below the lactate second threshold (25). Another limitation of the present study is that although the target population was stop-and-go athletes, the sample consisted of students of kinesiology. It was practically impossible to recruit an appropriate number of active athletes (e.g., athletes from diverse clubs needed to be recruited) who would limit and control their activity status. Therefore, we recruited eligible kinesiology students with (a) a significant past team-sport background and (b) baseline Beep test results similar to those reported for athlete cohorts, with training before the experiment. With regard to the prior training, all participants (as a part of their regular obligation to the faculty) were involved in an exercise training program with duration and content (see subjects) typical for the off-season phase of team sports. In terms of the baseline Beep test results (the number of shuttle runs), the present cohort had a mean score that was 23% higher than that reported for physically active adult men with various sport backgrounds, including basketball, volleyball, soccer, and running (44), and 25% higher than that reported for Asian University soccer players (38), but it was 16% lower than that reported for Asian professional soccer players at the end of the preseason period (2). After training, the LH group demonstrated similar Beep test results to those in professional Asian soccer players (2). Finally, a potential limitation of the present study is the absence of individualized (TTE-based) exercise durations and load progressions in the CON group, which could contribute to the ineffectiveness of this program in improving Beep test performance and $\dot{V}O_2max$. Our reasons for the design of the CON protocol were entirely pragmatic. Namely, during our pilot study, we observed a difficulty in precisely determining the TTE for this low-intensity exercise (which is below the anaerobic threshold). At this intensity, obtaining the TTE would be extremely time consuming and significantly influenced by the individual's motivation. Additionally, the regular academic obligations of the students limited the duration of all training sessions to 45 minutes, with only 35 minutes of continuous running being possible, considering the time needed for instruction and warm-up. Similarly, in the practice of team sports, longer durations for endurance training are rarely used because it would hardly fit into the busy schedule of the typical training unit with multiple goals (e.g., technique, tactics, etc.). It is important to note that previously published results of CON training in trained men (22) suggest that the training effect on $\dot{V}O_2max$ would likely be small, even with a greater duration of continuous running (even those approaching the TTE). Thus, this increase in training stimulus has been shown to be insufficient to compensate for an inadequate intensity of training.

In conclusion, the present study results on the effects of SH and LH programs, using a completely field-based testing and load prescription methodology, support the findings of previous laboratory-based studies. Our findings provide novel insights into the differential effectiveness (result-based) of short- and long-interval HIIT in improving anaerobic and aerobic performance, respectively.

Practical Applications

High-intensity interval training is the preferred training method in stop-and-go sports; however, previous studies on its effects are lacking in practicality (e.g., the use of complex laboratory measures to prescribe the load, the evaluation of track running performance instead of tests with changes in direction, etc.). Thus, detailed instructions on how to use results of the Beep test and TTE to prescribe loads for diverse HIIT and continuous training programs in the shuttle run mode could be of great importance for coaches and trainees in team sports. Coaches are advised to conduct LH as an effective $\dot{V}O_2max$ (Beep) stimulus for cohorts of different training levels, including professional team athletes (e.g., Beep test results of over 13 levels), as advancement in LH was shown to be independent of Beep pretraining achievements. Nevertheless, because of the genetic component of $\dot{V}O_2max$ (Beep) trainability, coaches may encounter low responders, even for this type of stimuli (e.g., two trainees in the present study). When applying SH, practitioners should be aware of the limited (result-based) benefit of this specific stimulus for Beep ($\dot{V}O_2max$) test improvement. Namely, individuals with a baseline performance in-line with that of professional team athletes

(Beep test scores of over 12 levels), may not improve in Beep test performance with the SH program. The lack of a sufficient intensity in the CON program (i.e., below the second lactate threshold) is the reason why this high-volume exercise program cannot improve the Beep test performance in trained individuals. The present study results suggest that some positive changes in Beep test performance can be expected with the CON program but only among lower achievers (e.g., Beep test results <10 levels).

Regarding the influence of training on the 300-yd test, which is typically used as the standard for testing the anaerobic performance of stop-and-go athletes, coaches can assume some beneficial training effect to occur with HIIT. Although the most intensive SH program elicited the highest 300-yd test effect among the 3 evaluated programs, this test is not the optimal choice for the assessment of SH outputs (because of different activity and energetic profiles). As our training protocols for different HIIT modes involved the testing of their load scheme-specific TTE at the first and last training sessions, specific SH effects can be simply determined from the change in the TTE results. The obtained results support the good trainability of this specific type of endurance training because individual improvements in the TTE were observed in all participants in the SH group. In conclusion, although SH is not focused on $\dot{V}O_2$max, as is LH, SH is highly recommended for team sport athletes, as its activity profile (the shuttle run performed at supramaximal intensity, with a 10-second rest period) has well-established importance for these cohorts. Therefore, both SH and LH stimuli can be used, not as training alternatives, but rather as specific training stimuli that might be applied during different days of the preseason period in team sports. When designing a shuttle run continuous program to improve Beep ($\dot{V}O_2$max) test performance, coaches should apply a higher intensity than that used in the CON program (above the lactate threshold, e.g., 80% MASS) and ensure that trainees perform it for an appropriate duration (TTE based).

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