Physiological Responses during Interval Training with Different Intensities and Duration of Exercise

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Abstract

Zuniga, JM, Berg, K, Noble, J, Harder, J, Chaffin, ME, and Hanumanthu, VS. Physiological responses during interval training with different intensities and duration of exercise. *J Strength Cond Res* 25(5): 1279–1284, 2011—The purpose of this study was to compare 4 interval training (IT) sessions with different intensities and durations of exercise to determine the effect on mean $\dot{V}O_2$, total $\dot{V}O_2$, and duration of exertion ≥95% maximum power output (MPO), and the effects on biomarkers of fatigue such as blood-lactate concentration (BLC) and rating of perceived exertion. The subjects were 12 recreationally competitive male ($n = 7$, mean ± *SD* age = 26.2 ± 3.9 years) and female ($n = 5$, mean ± *SD* age = 27.6 ± 4.3 years) triathletes. These subjects performed 4 IT sessions on a cycle ergometer varying in intensity (90 and 100% MPO) and duration of exercise (30 seconds and 3 minutes). This study revealed that IT using 30-second duration intervals (30–30 seconds) allows the athlete to perform a longer session, with a higher total and mean $\dot{V}O_2$ HR and lower BLC than 3-minute durations. Similarly, submaximal exertion at 90% of MPO also allows performing longer sessions with a higher total $\dot{V}O_2$ than 100% intensity. Thus, the results of the present study suggested that to increase the total time at high intensity of exercise and total $\dot{V}O_2$ of a single exercise session performed by the athlete, IT protocols of short durations (i.e., 30 seconds) and submaximal intensities (i.e., 90% MPO) should be selected. Furthermore, performing short-duration intervals may allow the athlete to complete a longer IT session with greater metabolic demands ($\dot{V}O_2$) and lower BLC than longer (i.e., 3 minutes) intervals.

Key Words exercise, maximum oxygen consumption, cardiovascular response, oxygen cost of exercise

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Introduction

Interval training (IT) has been widely used in endurance sports to improve aerobic performance and facilitate conditioning (6). The benefits of IT are well documented (4,14,20) and include allowance of a greater volume of high-intensity exercise and enhancement of lactate kinetics (22). Although IT has been widely studied (2,3,6–9,11,12,17,18), the optimal exercise duration and intensity to enhance athletic performance in endurance events have not been established. Generally, exercise intensities for IT are in the range of 70–100% of $\dot{V}O_2$max. Short intervals of 30–30 seconds and long intervals of 3–3 minutes are the 2 most common extremes of IT durations used by endurance athletes (22). One advantage of relatively short exercise bouts is the minimization of intramuscular acidosis. By controlling or limiting the drop in intramuscular pH during the exercise bout and providing a partial recovery, the total exercise time can be extended (8). The primary benefit of IT is believed to be the volume of high-intensity exercise that can be accomplished during the training session (9). Longer work bouts of IT such as 2–3 minutes, although popular in training, cause intramuscular pH to drop to lower levels than shorter bouts that reduce the time at high-intensity work that can be maintained (6). Billat (6) and Billat et al. (8) indicated that the total time completed for an intense IT session and the corresponding total $\dot{V}O_2$ (L) consumed are criteria that scientists and coaches should use when judging the benefits of interval or continuous training. Previous studies (1,17) have also suggested that the benefits of IT on aerobic capacity and especially $\dot{V}O_2$max are likely dependent not only in the time spent at $\dot{V}O_2$max but also in the time or distance performed at high intensity.

Few studies (1,9,11,19) have addressed the total duration of high-intensity IT that can be sustained in a single session. The total duration of the exercise stimulus plays an important role in the conditioning response (4,8), and therefore, it should be addressed in research. Consequently, studies are needed to clarify the effect of various exercise intensities and exercise bout durations on the total time exercise can be performed at high intensity and the associated total $\dot{V}O_2$. Based on previous findings (4,6,8,9,11,21), it is not clear whether short (i.e., 30–30 seconds) or long (i.e., 3–3 minutes) intervals at submaximal (i.e., 90% maximum power output [MPO]) or maximal (i.e., 100% MPO) intensities would allow the highest oxygen consumption, longest exercise time for the exercise bout with low markers of fatigue. Therefore, the purpose of this study was to compare 4 IT sessions with different intensities and durations of exercise to determine the effect on mean $\dot{V}O_2$, total $\dot{V}O_2$ in protocol, and total exercise time. Also, markers of fatigue such as blood lactate concentration (BLC) and rating of perceived exertion (RPE) were compared among protocols.

Methods

Experimental Approach to the Problem

Twelve recreationally competitive male and female triathletes performed an incremental maximal cycling test to estimate MPO and $\dot{V}O_2$max. On separate days, 4 different IT protocols varying in intensity (90 and 100% MPO) and duration of exercise (30 seconds and 3 minutes) were performed. A 2 by 2 factorial ANOVA (intensity × duration) with repeated-measures analysis was used on each physiologic measure and RPE to identify main effects and interactions. This design was chosen to analyze the synergy between intensity and duration of IT that are commonly use by endurance athletes on several physiological parameters and RPE. Furthermore, mean $\dot{V}O_2$, total $\dot{V}O_2$, duration of exertion ≥95% MPO, and biomarkers of fatigue such as BLC and RPE have been shown (1,6,8,16) to be important factors for the development and design of IT programs.

Subjects

Subjects were 12 recreationally competitive male and female triathletes. They are described in Table 1. Subjects were volunteers who were injury-free at the time of the data collection and had participated in a cycling or triathlon competition in the previous 6 months. Based on the information reported in the health questionnaire form, all subjects performed ≥4 hours of aerobic training including cycling, running, and swimming. Subjects were asked to alter their training programs to accommodate the protocol used in the study during approximately 4 weeks. The IT sessions were performed at the same time of the day (±2 hours) with the same tester. In addition, subjects were encouraged to have an appropriate hydration and the last meal 2–3 hours before the IT sessions and $\dot{V}O_2$max test. The subjects performed a test to assess their MPO and $\dot{V}O_2$max followed by 4 IT sessions varying in intensity and duration of exercise. The MPO values were used to determine the exercise intensity for each of the 4 IT sessions. The 5 sessions were conducted on different days with a minimum of 2 days separating tests and within a 4-week time frame. All 12 subjects were accustomed to IT because they employed it in various stages of their previous training. The study was approved by the Institutional Review Board for Human Subjects, and written informed consent was obtained from the subjects before testing.

Procedures

Descriptive data of the athletes were collected including height, body mass, and percent body fat (Table 1). Height and body mass were measured with a medical rated scale (Detecto Medic; Detecto scales, Inc. Brooklyn, NY, USA). Body density was determined by skinfold assessment at 3 sites (right triceps, suprailiac, and thigh for women and right chest, abdomen, and thigh for men) using the generalized equation for men and women (15,16). A Harpenden skinfold caliper (Model 68875; Baty International, West Sussex, United Kingdom) was used to measure the skinfold thickness at each site. The mean of these values at each site was used for calculation of fat percent.

The MPO/$\dot{V}O_2$max test and the 4 IT sessions were assessed on a Monark cycle ergometer (Monark, 828E, Varberg, Sweden). The seat was adjusted so that the subject's legs were at near full extension during each pedal revolution. The subjects wore a face mask connected to a metabolic cart (Vmax 29, SensorMedics, Yorba Linda, CA, USA). The MPO/$\dot{V}O_2$ protocol started with the initial workload set

Table 1. Description of subjects.*†

Variable	Women (n = 5)	Men (n = 7)
Age (y)	27.6 ± 4.3 (24.0–35.0)	26.2 ± 3.9 (23.0–33.0)
Body weight (kg)	69.2 ± 12.3 (53.9–83.6)	77.8 ± 7.2 (65.5–86.4)
Height (cm)	171.3 ± 8.8 (160.0–183.0)	177.7 ± 9.6 (160.5–186.0)
Percent body fat (%)	25.2 ± 2.8 (21.8–28.0)	9.0 ± 2.2 (6.4–13.0)
$\dot{V}O_2$max (ml·kg^{-1}·min$^{-1)}$	40.34 ± 6 (32.9–47.8)	52.8 ± 4.5 (47.0–59.5)
MPO (W)	264.0 ± 21.9 (240.0–260.0)	351.4 ± 25.4 (320.0–380.0)

*MPO = maximum power output.
†Values are given as mean ± *SD* (range).

TABLE 2. Main effects for intensity and duration.*

Variable	Main effect intensity (mean ± *SD*)	Main effect duration (mean ± *SD*)	Observed power	*F*	Effect size	95% Confidence intervals	
Mean $\dot{V}O_2$ (ml·kg^{-1}·min^{-1})							
90% MPO	38.9 ± 7.9		0.07	0.15	0.01	34.64	43.23
100% MPO	39.4 ± 8.0					35.02	43.80
30–30 s		40.3 ± 8.7†	0.97	18.28†	0.62	36.00	44.75
3–3 min		37.9 ± 6.8				33.99	41.94
Heart rate (b·min^{-1})							
90% MPO	169.2 ± 8.2		0.06	0.05	0.01	164.45	173.93
100% MPO	169.5 ± 9.0					164.14	174.80
30–30 s		171.6 ± 6.8†	0.98	19.87†	0.64	167.40	175.91
3–3 min		167.0 ± 9.3				161.42	172.62
BLC (mmol·L^{-1})							
90% MPO	8.2 ± 1.4		0.42	3.72	0.42	7.70	8.70
100% MPO	9.3 ± 2.2					8.10	10.54
30–30 s		8.1 ± 1.6†	0.80	9.47†	0.80	7.40	8.80
3–3 min		9.4 ± 1.9				8.42	10.40
RPE							
90% MPO	14.7 ± 1.2		0.30	2.45	0.18	14.10	15.33
100% MPO	14.9 ± 1.0					14.40	15.48
30–30 s		14.8 ± 1.2	0.05	0.00	0.00	14.13	15.51
3–3 min		14.8 ± 1.0				14.28	15.40
Total $\dot{V}O_2$(L)							
90% MPO	68.6 ± 27.7†		0.99	29.55†	0.73	52.63	84.53
100% MPO	49.9 ± 21.2					38.51	61.37
30–30 s		68.5 ± 25.4†	1.00	39.51†	0.78	54.64	82.49
3–3 min		49.9 ± 23.8				36.40	63.51
Total time completed (min)							
90% MPO	23.3 ± 6.3*		1.00	40.60†	0.79	19.72	27.02
100% MPO	16.4 ± 5.9					13.20	19.72
30–30 s		22.3 ± 6.4†	1.00	36.80†	0.77	19.01	25.61
3–3 min		17.5 ± 6.8				14.10	20.94
Total time ≥95% of $\dot{V}O_2$max (min)							
90% MPO	5.4 ± 6.0		0.05	0.02	0.00	2.25	8.60
100% MPO	5.2 ± 6.0					3.02	7.40
30–30 s		6.1 ± 6.8	0.52	2.99	0.21	3.14	9.07
3–3 min		4.5 ± 2.9				2.84	6.21

*BLC = blood lactate concentration; MPO = maximum power output; RPE = rating of perceived exertion; 30–30 seconds = 30-second interval with 30-second recovery; 3–3 min = 3-minute interval with 3-minute recovery; $n = 12$.
†Significant difference between main effects at $p < 0.05$.

at 80 W and increased by 40 W every 2 minutes until 160 W was reached. At this point, the resistance was increased by 20 W every minute until exhaustion. Each subject was instructed to maintain 75–80 rpm during the entire test. $\dot{V}O_2$max was defined as the highest $\dot{V}O_2$ value in the last 30 seconds of the test if the subject met at least 2 of the following 3 criteria (13): (a) 90% of age-predicted maximum heart rate (220 − age), (b) respiratory exchange ratio >1.20, and (c) a plateau of oxygen uptake (≤150 ml·min^{-1} in $\dot{V}O_2$ over the last 30 seconds of the test). At the completion of the test, the subjects were allowed to cool down for as long as they liked.

Heart rate was measured using a Polar heart rate monitor with a Polar T61 coded transmitter (Polar S610i Heart Rate Monitor; Polar Electro Oy, Kemple, Finland). Blood lactate concentration was measured using a lactate monitor (Accusport, Boeringer Mannheim, Castle Hill, Australia) at rest, every 10 minutes during and immediately at the end of the IT sessions by a finger stick using the second drop of blood to avoid sweat contamination. Borg's 15 point RPE (10) was also assessed during each stage of the MPO/$\dot{V}O_2$max test to familiarize subjects with the RPE assessment procedure, which was used for the IT protocols. The RPE was taken at the end of each stage of the

MPO/$\dot{V}O_2$max test and during every exercise and recovery period of the IT sessions.

A 10-minute warm-up consisting of cycling at a self-selected pace was performed before each IT protocol. Four IT protocols were administrated randomly using a 2 by 2 factorial design (intensity × duration). Thus, 2 sessions were conducted at 90% of the MPO alternating either 30-second exercise with 30-second recovery or 3-minute exercise with 3-minute recovery. The other 2 sessions occurred at 100% MPO alternating either 30-second exercise with 30-second recovery or 3-minute exercise with 3-minute recovery. Consequently, a 1 to 1 exercise-recovery ratio was used in all 4 IT protocols. The recovery for each protocol was active at 50% MPO. In addition, each IT protocol was performed for 30 minutes or until the subject was unable to maintain the given power output. At the end of all sessions, a cooldown was conducted at self-selected pace for 10–15 minutes.

Statistical Analyses

Descriptive statistics were conducted for all measures. A repeated measures 2 × 2 factorial ANOVA (intensity × exercise duration) was used on each physiologic measure and RPE. An alpha of $p \leq 0.05$ was used for statistical significance for all mean comparisons. All statistics were performed on SPSS 14.0 for Windows.

The total $\dot{V}O_2$ per training session was expressed in liters (L) and represents the sum of all values for the exercise and rest intervals. For each IT session, the time spent ≥95% $\dot{V}O_2$max was calculated by applying a custom autofilter function in Excel to the data file. The mean $\dot{V}O_2$ represented 30-second values during the exercise and recovery periods.

Results

Table 2 shows the main effects for intensity and duration. The main effect intensity was significant for the 90% MPO ($p \leq 0.05$) for both total $\dot{V}O_2$ ($p < 0.001$) and time completed ($p < 0.001$). The mean total $\dot{V}O_2$ values for the 90 and 100% MPO conditions were 68.6 ± 27.7 and 49.9 ± 21.2 L, respectively. The mean total exercise times completed for the 90 and 100% MPO conditions were 23.3 ± 6.3 and 16.4 ± 5.9 minutes, respectively.

The main effect duration was also significant with the mean for the 30-second sessions having higher values for total $\dot{V}O_2$ ($p < 0.001$), exercise time completed ($p < 0.001$), mean $\dot{V}O_2$ ($p < 0.001$), and HR ($p < 0.001$). The mean of the 30-second sessions also yielded significantly lower BLC levels ($p < 0.01$) than the 3-minute protocols. The mean total $\dot{V}O_2$ values for the 30-second and 3-minut durations were 68.5 ± 25.4 and 49.9 ± 23.8 L, respectively. The mean total exercise time completed for the 30-second duration and 3-minute duration protocols were 22.3 ± 6.4 and 17.5 ± 6.8 minutes, respectively. The mean $\dot{V}O_2$ for the 30-second and 3-minute duration were 40.3 ± 8.7 and 37.9 ± 6.8 ml·kg^{-1}·min^{-1}, respectively. The mean HR for the 30-second and 3-minute duration was 171.6 ± 6.8 and 167 ± 9.3 b·min^{-1}, respectively,

Table 3. Summary of variables for 4 protocols of IT.*†‡

Variables	Protocol 1 (30–30 s/90% MPO)	Protocol 2 (3–3 min/90% MPO)	Protocol 3 (30–30 s/100% MPO)	Protocol 4 (3–3 min/100% MPO)
Mean $\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	41.6 ± 8.1 (37.7–59.7)	36.3 ± 6.9 (21.9–45.4)	39.1 ± 9.4 (43.0–50.2)	39.7 ± 6.6 (32.3–51.3)
Heart rate (b·min^{-1})	171.7 ± 6.7 (156.0–180.0)	166.7 ± 9.0 (151.4–183.0)	171.7 ± 7.2 (155.6–182.1)	167.3 ± 10.2 (144.0–178.0)
BLC (mmol·L^{-1})	7.5 ± 1.1 (5.6–9.7)	8.9 ± 1.4 (6.0–11.8)	8.7 ± 1.9 (4.6–11.4)	9.9 ± 2.4 (4.2–13.5)
RPE	14.8 ± 1.3 (13.0–16.9)	14.7 ± 1.1 (11.8–16.0)	14.9 ± 1.1 (12.6–16.2)	15.0 ± 0.9 (13.4–16.3)
Total $\dot{V}O_2$ (L)	78.8 ± 27.1 (39.4–126.3)	58.4 ± 25.3 (14.0–99.8)	58.4 ± 19.8 (30.0–98.1)	41.5 ± 19.8 (21.4–89.1)
Total time completed (min)	25.5 ± 5.3 (16.5–30.0)	21.2 ± 6.8 (12.0–30.0)	19.1 ± 6.0 (13.0–30.0)	13.9 ± 4.8 (10.0–22.0)
Total time ≥95% of $\dot{V}O_2$max (min)	6.4 ± 7.8 (0.0–22.0)	4.5 ± 3.2 (0.0–9.5)	5.8 ± 5.8 (0.0–15.5)	4.6 ± 2.4 (1.0–9.0)

*BLC = blood lactate concentration; MPO = maximal power output; IT = interval training; RPE = rating of perceived exertion; 30–30 second = 30-second interval with 30-second recovery; 3–3 minutes = 3-minute interval with 3-minute recovery. $n = 12$.
†No interactions were significant ($p > 0.05$).
‡Values are given as mean ± *SD* (range).

whereas the mean BLC for the 30-second and 3-min duration was 8.1 ± 1.6 and 9.4 ± 1.9 mmol·L^{-1}, respectively (Table 2).

Table 3 summarizes the physiological responses to each of the 4 IT protocols. None of the cell means for the variables was significantly different because there was no significant interaction between intensity and duration for any of the variables ($p > 0.05$). The relatively large variability in responses should be noted because it may have prevented selected mean values from being significantly different.

Discussion

A major finding in this study was that short intervals (30 seconds) produced higher values for total $\dot{V}O_2$ (L), total time completed for each session (minutes), mean $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}), and HR but with lower values for BLC than longer intervals (3 minutes) (Table 2). Secondly, the 90% MPO intensity of IT produced higher values for total $\dot{V}O_2$ (L) and total exercise time (minutes) completed for each protocol than 100% MPO (Table 2). The higher $\dot{V}O_2$ response produced by a submaximal intensity found in the present study has been supported by recent studies (5–7,14) that showed that a submaximal exercise intensity of approximately 90% reach maximal or supramaximal $\dot{V}O_2$ values because of the rise associated with the $\dot{V}O_2$ slow component. These studies reported that a submaximal power output corresponding to the LT plus 50% of the difference between LT and $\dot{V}O_2$max achieves this effect (50% Δ) (8). It has been also reported that the intensity associated with the 50% Δ was approximately 90–92% of the maximal running velocity (6,8,21). The intensities used in the present study were 90 and 100% MPO, with the 90% MPO having significantly greater ($p \le 0.01$) total $\dot{V}O_2$ (L) and total time completed (minutes) mean values than 100% MPO during the IT sessions.

The primary benefit of IT is believed to be the volume of high-intensity exercise that can be accomplished. Using middle-aged endurance athletes Billat et al. (8) showed that intervals with low duration (15-second exercise and 15-second rest) performed at 90% $v\dot{V}O_2$max elicited $\dot{V}O_2$max for a longer time ($p \le 0.05$) as compared to 15-second duration with supramaximal intensity of 110% $v\dot{V}O_2$max (14.4 ± 4 and 7.4 ± 2 minutes, respectively). Åstrand and Rodahl (1) recommended the use of short-interval durations (10-second interval with 5-second pauses) near $\dot{V}O_2$max because they allowed the athlete to perform exercise at high intensity with high heart rate and $\dot{V}O_2$ with low BLC at the end of the IT session. They also showed that during intervals with short resting periods (10-second intervals with 5-second pauses) $\dot{V}O_2$ during the recovery period remained elevated for a longer period of time than 4-minute intervals with 4-minute exercise recovery. They suggested that this elevation in metabolism during the recovery period explains the higher mean $\dot{V}O_2$ and HR during the entire exercise session. Thus, the significantly higher mean $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}), HR, and total $\dot{V}O_2$ (L) found in the present study during the 30-second IT protocols may be explained by the heightened $\dot{V}O_2$ during the recovery periods.

Previous studies have suggested that intervals of short duration (i.e., 15 seconds) may minimize BLC during IT sessions. Billat (8) indicated that short intervals of 15 seconds at 90% $v\dot{V}O_2$max produced significantly lower lactate levels ($p \le 0.05$) than an interval session of 4 minutes at 90% $v\dot{V}O_2$max (9.2 ± 1.3 mmol·L and 11.3 ± 1.2 mmol·L^{-1}, respectively). Similarly, in the present study, BLC was significantly lower ($p \le 0.01$) in the 30-second than in the 3-minute IT durations (8.1 ± 1.6 and 9.4 ± 1.9 mmol·L^{-1}, respectively) (Table 2). It has been reported (6,9) that IT at running velocities around $v\dot{V}O_2$max stimulates the rate of lactate removal by exposing the athlete to high BLC, thereby improving enzyme activity for its removal. Additionally, an active recovery during the IT session further improves and accelerates blood lactate removal avoiding blood lactate accumulation (9). Billat et al. (9) suggested that a short active recovery (i.e., 30-second recovery) between the submaximal exercise intervals will allow the athlete to reach $\dot{V}O_2$max by stimulating lactate removal maintaining the BLC close to the steady state.

In the present study, the RPE showed no significant difference ($p > 0.05$) across the 4 IT protocols. The mean for all 4 protocols ranged from 14 to 15 (Table 3). In partial agreement with these results, Seiler and Sjursen (21) reported that when athletes performed intervals of short (1-minute) and long (6-minute) durations at a self-selected pace, subjects adjusted their exercise intensity such that BLC and RPE responses throughout each session were essentially identical showing no significant differences ($p > 0.05$). Similarly, Seiler and Hetlelid (20) found that RPE responses were uniform across 3 different IT sessions completing 6 exercise bouts of 4 minutes with 1-, 2-, and 4 minute-recovery periods. Thus, the nonsignificant differences in RPE found in the present study across the 4 protocols were consistent with previous studies that have reported no difference between IT protocols using short (21) and long (20,21) intervals durations.

Billat (5,6) and Billat et al. (9) indicated that the total time completed for an intense IT session and the corresponding total $\dot{V}O_2$ (L) consumed are criteria that scientists and coaches should use in judging the benefits to be gained from either interval or continuous training. Previous studies (17) have also suggested that the benefits of IT on aerobic capacity and especially in $\dot{V}O_2$max are likely dependent not only in the time spent at $\dot{V}O_2$max but also in the time or distance performed at an intensity close to $\dot{V}O_2$max. However, only few studies have assessed these variables (9). Our results show that 90% MPO intensity resulted in longer total exercise time than 100% MPO intensity and that 30 seconds also resulted in longer total exercise time than 3 minutes did (Table 2). The same pattern was found for total $\dot{V}O_2$ for the exercise session. Total $\dot{V}O_2$ was greater for 90% MPO than for 100% MPO and 30 seconds greater than 3 minutes (Table 2). Although interaction of these variables was not significant, there was a trend ($p = 0.08$) favoring longer exercise time completed for both IT protocols performed at 90% MPO as compared to 100% MPO as can be seen in Table 3. The same trend, also with no significant interaction, occurred with the total $\dot{V}O_2$ for the training session ($p = 0.09$). These trends did not present a statistically significant interaction seemingly because of the large variability in the measures that can be seen with the *SD*s reported in Table 3. These trends are supported by those of Demarie et al. (14) who found that runners were able to train for a longer time ($p \leq 0.05$) at v 50% Δ using IT as compared to continuous exercise at the same intensity. It was suggested (14) that IT allows greater phosphocreatine resynthesis during each short recovery period thus enhancing the ability to perform at a high-power output for a longer period.

Further work appears necessary in determining the optimum IT regimen (i.e., duration and intensity) to enhance athletic performance. The present study used a factorial design to address the value of varying intensities and durations of exercise. Additional work using a factorial approach may be useful in determining what combination of intensity and duration best allows the highest total $\dot{V}O_2$ (L) and longest duration of exercise at or near MPO or $\dot{V}O_2$max (6,9).

In conclusion, this study revealed that IT duration of 30 seconds in comparison to 3 minutes allowed the athlete to perform a longer session with a higher total $\dot{V}O_2$ (L), mean $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}), and HR yet at a lower BLC. The study also indicated that a submaximal intensity of 90% of MPO allowed the athlete to perform a longer session with a higher total $\dot{V}O_2$ (L) than IT duration performed at 100% MPO. The findings from this study may provide useful information for coaches in designing IT programs for athletes. Additional work is needed to determine how much improvement in performance is associated with IT sessions that optimize total training time at high intensity.

Practical Applications

The current findings suggested that to increase the total time of high-intensity exercise and the total $\dot{V}O_2$ in a single exercise session, IT protocols with shorter durations (i.e., 30 seconds) and submaximal intensities (i.e., 90% MPO) should be selected. The present study provides useful information for coaches and athletes to optimize IT programs for endurance events. It is possible that including short intervals of 30-second duration at a submaximal intensity of 90% MPO may give the athlete the chance to increase the duration of high-intensity exercise during the IT session with greater metabolic demands. Furthermore, performing several short-duration intervals of about 30 seconds at 90 or 100% MPO could allow the athlete to obtain a greater mean oxygen consumption, reaching higher HR values and completing a longer IT session with lower BLC than longer (i.e., 3-minute) intervals at the same intensity.

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