Interval training at 95% and 100% of the velocity at $V_O^2_{max}$: effects on aerobic physiological indexes and running performance

Benedito S Denadai, Marcelo J Ortiz, Camila C Greco, and Marco T de Mello

Abstract: The objective of this study was to analyze the effect of two different high-intensity interval training (HIT) programs on selected aerobic physiological indices and 1500 and 5000 m running performance in well-trained runners. The following tests were completed ($n = 17$): (ii) incremental treadmill test to determine maximal oxygen uptake ($V_O^2_{max}$), running velocity associated with $V_O^2_{max}$ ($v_{V_O^2_{max}}$), and the velocity corresponding to 3.5 mmol/L of blood lactate concentration ($v_{OBLA}$); (ii) submaximal constant-intensity test to determine running economy (RE); and (iii) 1500 and 5000 m time trials on a 400 m track. Runners were then randomized into 95% $v_{V_O^2_{max}}$ or 100% $v_{V_O^2_{max}}$ groups, and undertook a 4 week training program consisting of 2 HIT sessions (performed at 95% or 100% $v_{V_O^2_{max}}$, respectively) and 4 submaximal run sessions per week. Runners were retested on all parameters at the completion of the training program. The $v_{V_O^2_{max}}$ values were not different after training for both groups. There was a significant increase in post-training $v_{V_O^2_{max}}$, RE, and 1500 m running performance in the 100% $v_{V_O^2_{max}}$ group. The $v_{OBLA}$ and 5000 m running performance were significantly higher after the training period for both groups. We conclude that $v_{OBLA}$ and 5000 m running performance can be significantly improved in well-trained runners using a 4 week training program consisting of 2 HIT sessions (performed at 95% or 100% $v_{V_O^2_{max}}$) and 4 submaximal run sessions per week. However, the improvement in $v_{V_O^2_{max}}$, RE, and 1500 m running performance seems to be dependent on the HIT program at 100% $v_{V_O^2_{max}}$.

Key words: training methods, runners, onset of blood lactate accumulation, severe exercise.

Introduction

Several researchers have generated a wide range of variables for use in prescribing exercise intensities for individuals undertaking endurance training (Sjodin et al. 1982; Hill 1993; Billat 2001). A variable that has been used with success in middle- and long-distance runners is the velocity associated with the achievement of the maximal oxygen uptake during an incremental test ($v_{V_O^2_{max}}$) (Billat et al. 1996a; Billat et al. 1999). This intensity has attracted considerable interest from coaches and exercise scientists, because, for athletes who are already trained, improvements in
endurance performance might be achieved mainly through high-intensity interval training (HIT) (Lindsay et al. 1996; Laursen and Jenkins 2002; Smith et al. 2003). The rationale for using vVO$_2$ max in HIT program prescription is based on the assumption that further improvements in maximal oxygen uptake (VO$_2$ max) in the highly trained athlete will only result from exercise training at or above VO$_2$ max (Laursen and Jenkins 2002).

However, vVO$_2$ max is not the only exercise intensity at which VO$_2$ max can be attained during constant-intensity exercise. In fact, during exercise in the severe domain (i.e., above the maximal lactate steady state or critical velocity), VO$_2$ increases progressively in a biexponential fashion (by the development of the VO$_2$ slow component), reaching its maximal values (VO$_2$ max) at the end of exercise (Hill et al. 1997). Confirming this phenomenon, Hill et al. (1997) verified similar values of VO$_2$ max during exhaustive tests at vVO$_2$ max and at 92% of vVO$_2$ max in trained runners. Interestingly, during exercise performed at vVO$_2$ max, VO$_2$ max was attained after 299 ± 74 s and sustained for 32 ± 41 s. At 92% of vVO$_2$ max, it took longer to attain VO$_2$ max (491 ± 156 s), but it was sustained for a longer period (130 ± 66 s). Morton and Billat (2000) have confirmed that the maximal time spent at VO$_2$ max can be achieved running at a pace corresponding to 88% of vVO$_2$ max in active individuals (VO$_2$ max = 59.3 ± 5.0 mL·kg$^{-1}$·min$^{-1}$).

It is possible to hypothesize that continuous running above the critical velocity (i.e., the maximal velocity that can theoretically be maintained indefinitely), could be more efficient at eliciting VO$_2$ max of longer duration than interval training at vVO$_2$ max. However, Noakes (1991) has suggested that the benefits of training also depend on the distance covered at a high velocity, which determines the muscular adaptation maximizing the number of powerful muscle contractions. Therefore, it would be interesting to compare the influence of training using protocols that elicit VO$_2$ max, but that are run at different velocities. Thus, the objective of this study was to analyze the effect of two different HIT programs on selected physiological indices and on 1500 and 5000 m running performance in well-trained runners.

**Materials and methods**

**Subjects**

Seventeen well-trained male athletes volunteered to participate in this study. These athletes specialized in middle- and long-distance running (1500 m to half-marathon), and had at least 3 y of experience in the modality. They were training a mean weekly volume of ~80 km divided into 6 training sessions. Subjects had the following characteristics (mean ± SD): age, 27.4 ± 4.4 y; mass, 62.7 ± 4.3 kg; and height, 166.1 ± 5.0 cm. All subjects gave informed consent and the protocol was approved by the university’s ethics committee.

**Experimental design**

Subjects were randomized into 95% vVO$_2$ max (n = 9) or 100% vVO$_2$ max (n = 8) groups. Initially, in weeks 1–2 (pre-training), subjects performed the following tests: (i) incremental treadmill test to exhaustion for the determination of VO$_2$ max, vVO$_2$ max, and the velocity corresponding to 3.5 mmol/L of blood lactate concentration (vOBLA); (ii) submaximal constant-intensity test (14 km/h) to determine running economy (RE); (iii) an all-out run at 95% vVO$_2$ max (95% vVO$_2$ max group) and 100% vVO$_2$ max (100% vVO$_2$ max group) to determine $t_{lim95\%vVO_2}$ max and $t_{lim100\%vVO_2}$ max, respectively; and (iv) 1500 and 5000 m time trials (TT) on a 400 m track. Subjects performed only 1 test on any given day, and tests were each separated by at least 48 h, but completed within a 2 week period, during which training was kept relatively constant. All treadmill tests were performed at the same time of day (±2 h) in a climate-controlled (21–22 °C) laboratory. Subjects were directed to be fully rested when reporting to the laboratory or for field testing and to have refrained from using caffeine-containing food or beverages, drugs, alcohol, cigarettes, or any form of nicotine 24 h before testing. Athletes in the 95% vVO$_2$ max and 100% vVO$_2$ max groups then undertook a 4 week training program consisting of 2 HIT sessions and 4 submaximal run sessions per week. Final retesting of VO$_2$ max, vVO$_2$ max, vOBLA, RE, $t_{lim95\%vVO_2}$ max, and $t_{lim100\%vVO_2}$ max, and 1500 and 5000 m TT was completed on all subjects in the 2 weeks after the training program (post-training). Figure 1 describes the experimental design over 8 weeks.

**Determination of VO$_2$ max, vVO$_2$ max, and vOBLA**

VO$_2$ max, vVO$_2$ max and vOBLA were measured using an incremental protocol performed on a motorized treadmill (Life Fitness 9800, Schiller Park, Ill.) with the gradient set at 1%. The initial speed was set at 12 km/h for 3 min and was then increased 1 km/h every 3 min until voluntary exhaustion. All stages of the incremental test were followed by a 30 s period of rest. During this period, an earlobe capillary blood sample was collected. Throughout the tests, pulmonary gas exchange was determined breath-by-breath (Sensor Medics MMC, Anaheim, Calif.). Before each test, the O$_2$ and CO$_2$ analysis systems were calibrated using ambient air and a gas of known O$_2$ and CO$_2$ concentration according to the manufacturer’s instructions. Heart rate (HR) was also monitored throughout the tests (Polar, Kempele, Finland). Breath-by-breath data were smoothed using a 5-step moving average filter, from which rolling 15 s averages were calculated. Earlobe capillary blood samples (25 μL) were collected into glass tubes and were analyzed for lactate concentration using an automated analyzer (YSI 2300, Yello Springs, Ohio). The VO$_2$ max was defined as the highest 15 s VO$_2$ value reached during the incremental test. All subjects fulfilled at least 2 of the following 3 criteria for VO$_2$ max: (i) respiratory exchange ratio (RER) greater than 1.1, (ii) a blood lactate concentration greater than 8 mmol/L, and (iii) peak HR at least equal to 90% of the age-predicted maximum (Taylor et al. 1955). vVO$_2$ max was defined as the minimal velocity at which VO$_2$ max occurred (Billat et al. 1996b). vOBLA was determined by linear interpolation using a fixed lactate concentration of 3.5 mmol/L (Heck et al. 1985).

**Determination of RE, $t_{lim95\%vVO_2}$ max, and $t_{lim100\%vVO_2}$ max**

For determination of RE, runners warmed up at 12 km/h for 7 min, rested for 3 min, and then ran for 8 min at
14 km/h $\text{VO}_2$ (mL·kg$^{-1}$·min$^{-1}$) was averaged between the 6th and 7th min at 14 km/h and taken as reference for an athlete’s RE. After 5 min of rest, the subjects remounted the treadmill at 17 km/h and velocity was increased to 100% $\text{vVO}_2_{\text{max}}$. When the treadmill speed equaled 100% $\text{vVO}_2_{\text{max}}$, the stopwatch was started. Subjects were verbally encouraged to run to volitional exhaustion ($t_{\text{lim}}$). A test was terminated when the subject grasped the handrails for support and (or) straddled the moving belt. Time was recorded to the nearest second. On a different day, $t_{\text{lim}}$ at 95% $\text{vVO}_2_{\text{max}}$ was also determined in the 95% $\text{vVO}_2_{\text{max}}$ group.

**Determination of 1500 and 5000 m TT**

Each athlete undertook individually a 1500 m and 5000 m TT on a 400 m track, as quickly as possible. The time taken to run each distance was recorded using a manual chronometer. One event was run per day in random order. Pre and post tests were performed in similar ambient conditions (23–26 °C).

**Training program**

Table 1 shows an example of weekly programs given to the 95% $\text{vVO}_2_{\text{max}}$ and 100% $\text{vVO}_2_{\text{max}}$ groups. Subjects completed 2 HIT sessions per week at 95% $\text{vVO}_2_{\text{max}}$ or 100% $\text{vVO}_2_{\text{max}}$. Runners in the 95% $\text{vVO}_2_{\text{max}}$ group completed 4 intervals per session (interval = 60% $t_{\text{lim}}$ 95% $\text{vVO}_2_{\text{max}}$ at 95% $\text{vVO}_2_{\text{max}}$; active recovery = 30% $t_{\text{lim}}$ 95% $\text{vVO}_2_{\text{max}}$ at 50% $\text{vVO}_2_{\text{max}}$), whereas subjects in the 100% $\text{vVO}_2_{\text{max}}$ group completed 5 intervals per session (interval = 60% $t_{\text{lim}}$ 100% $\text{vVO}_2_{\text{max}}$ at 100% $\text{vVO}_2_{\text{max}}$; active recovery = 60% $t_{\text{lim}}$ 100% $\text{vVO}_2_{\text{max}}$ at 50% $\text{vVO}_2_{\text{max}}$). In addition, the training week comprised 1 running session at OBLA (2 × 20 min with 5 min of rest between the 2 runs at 60% $\text{vVO}_2_{\text{max}}$) and 3 submaximal continuous sessions (45–60 min at 60%–70% $\text{vVO}_2_{\text{max}}$). Total week volume (77.5 ± 3.8 km and 78.2 ± 3.9 km) and distance covered during each HIT session (6.4 ± 1.5 km and 6.1 ± 1.9 km) were similar between the 95% $\text{vVO}_2_{\text{max}}$ and 100% $\text{vVO}_2_{\text{max}}$ groups. Training logs for all subjects were monitored before and during the training period to ensure that running volumes and intensities were attained. This information was reviewed regularly by the investigator. The continuous and interval sessions were performed on a 400 m track. In a previous study, a similar training program performed by the 100% $\text{vVO}_2_{\text{max}}$ group significantly increased $\text{vVO}_2_{\text{max}}$ and RE (Billat et al. 1999).

**Statistical analysis**

Values are presented as mean ± SD. The normality of data was checked using a Shapiro–Wilk’s test. The data were analyzed using 2-way analysis of variance (ANOVA; group × time), with Scheffé’s post hoc tests where appropriate. Significance was set at $p \leq 0.05$.

**Results**

Maximal and submaximal variables obtained during incremental running tests are presented in Table 2. There were no significant differences between 95% $\text{vVO}_2_{\text{max}}$ and 100% $\text{vVO}_2_{\text{max}}$ group values for $\text{VO}_2_{\text{max}}$, $\text{vVO}_2_{\text{max}}$, and $\text{vOBLA}$, in both pre- and post-training conditions. The $\text{VO}_2_{\text{max}}$ values were not different after the training period for both groups. There was a significant increase ($p < 0.05$) in post training $\text{vVO}_2_{\text{max}}$ only in the 100% $\text{vVO}_2_{\text{max}}$ group. The $\text{vOBLA}$ was significantly higher after the training period for both groups, compared with their baselines.

Table 3 shows the $t_{\text{lim}}$95%$\text{vVO}_2_{\text{max}}$, $t_{\text{lim}}$100%$\text{vVO}_2_{\text{max}}$, and RE values obtained in pre- and post-training conditions. The $t_{\text{lim}}$100%$\text{vVO}_2_{\text{max}}$ values were significantly different be-
between groups in the pre-training condition. However, there was no significant difference in the \( t_{\text{lim}} \) 100% \( \dot{V}O_2 \) \(_{\text{max}} \) values between groups in the post-training condition. The \( t_{\text{lim}} \) 100% \( \dot{V}O_2 \) \(_{\text{max}} \) values were unchanged in both groups after the training period. In the same way, there were no significant differences between 95% \( \dot{V}O_2 \) \(_{\text{max}} \) group values for 1500 and 5000 m TTs, in either pre- and post-training conditions. However, there was an improvement of RE in the 95% \( \dot{V}O_2 \) \(_{\text{max}} \) group after the training period. In the same way, the delivery of oxygen to working muscles (maximal cardiac output \times \text{arterial oxygen content}) is strongly related to \( V_O_2 \) \(_{\text{max}} \) (Saltin and Strange 1992), it is possible to hypothesize that HIT cannot modify the plasma volume and stroke volume in previously trained athletes.

Many studies have verified that the \( V_O_2 \) \(_{\text{max}} \) of well-trained endurance runners is not improved by a further increase in submaximal training volume (Daniels et al. 1978; Costill et al. 1988). Thus, it has been proposed that improvements on the endurance performance and associated physiological variables (\( V_O_2 \) \(_{\text{max}} \)) can be achieved only through HIT. However, our main finding is that these modifications (except for the 5000 m running performance), seem to be dependent on the HIT sessions at 100% \( \dot{V}O_2 \) \(_{\text{max}} \), since the 95% \( \dot{V}O_2 \) \(_{\text{max}} \) group did not present significant improvement on the \( \dot{V}O_2 \) \(_{\text{max}} \), RE and 1500 m running performance. As in these athletes, the delivery of oxygen to working muscles (maximal cardiac output \times \text{arterial oxygen content}) is strongly related to \( V_O_2 \) \(_{\text{max}} \) (Saltin and Strange 1992), it is possible to hypothesize that HIT cannot modify the plasma volume and stroke volume in previously trained athletes.

The \( V_O_2 \) \(_{\text{max}} \), which reflect the best association between maximal aerobic power (\( V_O_2 \) \(_{\text{max}} \)) and RE, can be improved in response to HIT in previously trained athletes (Billat et al. 1999). Similar to our results, Billat et al. (1999) have

### Table 1. Example of weekly programs for 95% \( \dot{V}O_2 \) \(_{\text{max}} \) and 100% \( \dot{V}O_2 \) \(_{\text{max}} \) groups.

<table>
<thead>
<tr>
<th>Days</th>
<th>95% ( \dot{V}O_2 ) (_{\text{max}} )</th>
<th>100% ( \dot{V}O_2 ) (_{\text{max}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mon</td>
<td>Warm-up: 4 km</td>
<td>Warm-up: 4 km</td>
</tr>
<tr>
<td></td>
<td>Interval training: 4x60% ( t_{\text{lim}} ) 95% ( \dot{V}O_2 ) (<em>{\text{max}} ) at 95% ( \dot{V}O_2 ) (</em>{\text{max}} )</td>
<td>Interval training: 5x60% ( t_{\text{lim}} ) 100% ( \dot{V}O_2 ) (<em>{\text{max}} ) at 100% ( \dot{V}O_2 ) (</em>{\text{max}} )</td>
</tr>
<tr>
<td></td>
<td>Active recovery: 30% ( t_{\text{lim}} ) 95% ( \dot{V}O_2 ) (<em>{\text{max}} ) at 50% ( \dot{V}O_2 ) (</em>{\text{max}} )</td>
<td>Active recovery: 60% ( t_{\text{lim}} ) 100% ( \dot{V}O_2 ) (<em>{\text{max}} ) at 50% ( \dot{V}O_2 ) (</em>{\text{max}} )</td>
</tr>
<tr>
<td></td>
<td>Cool-down: 2 km</td>
<td>Cool-down: 2 km</td>
</tr>
<tr>
<td>Tue</td>
<td>45 min at 70% ( \dot{V}O_2 ) (_{\text{max}} )</td>
<td>45 min at 70% ( \dot{V}O_2 ) (_{\text{max}} )</td>
</tr>
<tr>
<td>Wed</td>
<td>Interval training as on Monday</td>
<td>Interval training as on Monday</td>
</tr>
<tr>
<td>Thu</td>
<td>60 min at 60% ( \dot{V}O_2 ) (_{\text{max}} )</td>
<td>60 min at 60% ( \dot{V}O_2 ) (_{\text{max}} )</td>
</tr>
<tr>
<td>Fri</td>
<td>Warm-up: 3 km</td>
<td>Warm-up: 3 km</td>
</tr>
<tr>
<td></td>
<td>2x20 min at OBLA velocity with 5 min of active recovery at 60% ( \dot{V}O_2 ) (_{\text{max}} ) between bouts</td>
<td>2x20 min at OBLA velocity with 5 min of active recovery at 60% ( \dot{V}O_2 ) (_{\text{max}} ) between bouts</td>
</tr>
<tr>
<td></td>
<td>Cool-down: 2 km</td>
<td>Cool-down: 2 km</td>
</tr>
<tr>
<td>Sat</td>
<td>Rest</td>
<td>Rest</td>
</tr>
<tr>
<td>Sun</td>
<td>60 min at 60% ( \dot{V}O_2 ) (_{\text{max}} )</td>
<td>60 min at 60% ( \dot{V}O_2 ) (_{\text{max}} )</td>
</tr>
<tr>
<td>Total volume</td>
<td>75–80 km</td>
<td>75–80 km</td>
</tr>
</tbody>
</table>

### Table 2. Maximal oxygen uptake (\( V_O_2 \) \(_{\text{max}} \)), velocity at \( V_O_2 \) \(_{\text{max}} \) \( \dot{V}O_2 \) \(_{\text{max}} \), and velocity at onset of blood lactate accumulation (\( V_O_2 \) \(_{\text{max}} \)) \( \dot{V}O_2 \) \(_{\text{max}} \) and \( \dot{V}O_2 \) \(_{\text{max}} \) groups, before (pre) and after (post) training.

<table>
<thead>
<tr>
<th>Group</th>
<th>( \dot{V}O_2 ) (_{\text{max}} ) (km/h)</th>
<th>( \dot{V}<em>2 ) (</em>{\text{max}} ) (mL kg(^{-1}) min(^{-1}))</th>
<th>( \dot{V}_\text{OBLA} ) (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>95% ( \dot{V}O_2 ) (_{\text{max}} ) (n = 9)</td>
<td>19.00±1.0</td>
<td>19.22±0.9</td>
<td>59.05±6.0</td>
</tr>
<tr>
<td>100% ( \dot{V}O_2 ) (_{\text{max}} ) (n = 8)</td>
<td>18.30±0.5</td>
<td>19.06±1.0*</td>
<td>59.98±6.0</td>
</tr>
</tbody>
</table>

*Note: Values are mean ± SD.

* \( p < 0.05 \) compared with before training.
shown that a 4-week training program, which included only 1 interval training session per week, caused a significant improvement on RE and \( v_{\text{O2 max}} \) (from 20.5 to 21.1 km/h), with no significant change in \( v_{\text{OBLA}} \) (from 71.2 to 72.7 mL·kg\(^{-1} \)·min\(^{-1} \)), in 8 trained males. Thus, the improvement on RE in previously trained athletes, can explain, at least in part, the higher \( v_{\text{O2 max}} \) values after a HIT program. However, it is important to note that \( v_{\text{O2 max}} \) is influenced not only by aerobic power and RE but also by the so-called muscle power factor, which is related to neuromuscular and anaerobic characteristics (Noakes 1988). Neuromuscular and anaerobic characteristics were not determined in our study. So, we cannot exclude the contribution of these factors to the improvement of \( v_{\text{O2 max}} \) after HIT (100% \( v_{\text{O2 max}} \)). Studies that have investigated the effect of endurance training on RE have produced equivocal results (Wilcox and Bulbulian 1984; Lake and Cavanagh 1996). Jones and Carter (2000) have suggested that the total duration of most longitudinal studies (typically of 6 to 12 weeks duration) are too short to produce a measurable improvement on RE, especially among trained individuals. However, the results of the present study, which are corroborated by other studies also conducted with trained individuals (Billat et al. 1999), show that the inclusion of 1 or 2 weekly HIT sessions performed at \( v_{\text{O2 max}} \) over the course of only 4 weeks may improve RE. As the 95% \( v_{\text{O2 max}} \) group did not present this modification, it is possible to propose that the improvement on RE in previously trained athletes after a short period of training (4–6 weeks) may depend on the intensity of the HIT. Improvements on RE with HIT may result from improved muscle oxidative capacity and associated changes in motor unit recruitment patterns (Jones and Carter 2000). The importance of neuromuscular characteristics in determining RE and performance has recently been pointed out by Nummela et al. (2006). Therefore, it may be that, in our study, the neuromuscular (motor unit recruitment and contractile properties) adaptations determined by HIT (100% \( v_{\text{O2 max}} \)) may have contributed to the improvement in RE.

The MLSS, defined as the highest exercise intensity at which there is a balance between the rate of lactate appearance in the blood and its rate of removal, has been considered the “gold standard” for the assessment of endurance capacity (Jones and Doust 1998). Investigations involving a heterogeneous group (endurance runners and active individuals) (Heck et al. 1985), endurance athletes (Simões et al. 1999), and soccer players (Denadai et al. 2005) showed that \( v_{\text{OBLA}} \) presents good validity to estimate MLSS. Moreover, Sjödin et al. (1982) verified that \( v_{\text{OBLA}} \) was valid in determining aerobic training effects, even in well-trained middle- and long-distance male runners. In our study, the improvement on the velocity corresponding to OBLA after training (4%) was similar between the 95% \( v_{\text{O2 max}} \) and 100% \( v_{\text{O2 max}} \) groups. Smith et al. (2003) verified improvements on the ventilatory threshold (6.8%) in well-trained athletes after 4 weeks of a treadmill interval-training program (5 × 60% \( t_{\lim}100\%v_{\text{O2 max}} \) at 100% \( v_{\text{O2 max}} \)). On the other hand, Billat et al. (1999) observed no improvements for the velocity corresponding to OBLA in highly trained runners (\( v_{\text{O2 max}} = 71.6 ± 4.8 \) mL·kg\(^{-1} \)·min\(^{-1} \)), after 4 weeks of normal training (1 session/week at \( v_{\text{O2 max}} \)) or 4 weeks of overload training (3 interval training sessions at \( v_{\text{O2 max}} \)). These different effects of HIT on \( v_{\text{OBLA}} \) may be explained, at least in part, by the different training levels of athletes employed in our study, when compared with athletes analyzed by Billat et al. (1999). Regardless, 4 weeks of training, in which runners performed 2 weekly HIT sessions at intensities of 95% or 100% \( v_{\text{O2 max}} \), seem suitable for the improvement on the \( v_{\text{OBLA}} \) of well-trained athletes.

Very little information is available concerning the rate at which aerobic performance improves following a given HIT stimulus (Laursen and Jenkins 2002). In our study, the ef-

### Table 3. Time to exhaustion at 95% (\( t_{\lim}95\%) \) and 100% (\( t_{\lim}100\%) \) of velocity corresponding to maximal oxygen uptake and running economy (RE) before (pre) and after (post) training.

<table>
<thead>
<tr>
<th>Group</th>
<th>( t_{\lim}100% ) (s) Pre</th>
<th>Post</th>
<th>( t_{\lim}95% ) (s) Pre</th>
<th>Post</th>
<th>RE (mL·kg(^{-1} )·min(^{-1} )) Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>95% ( v_{\text{O2 max}} ) ( (n=9) )</td>
<td>287.8 ± 8.7</td>
<td>353</td>
<td>554.4 ± 13.5</td>
<td>642.6</td>
<td>37.25 ± 2.2</td>
<td>36.3</td>
</tr>
<tr>
<td>100% ( v_{\text{O2 max}} ) ( (n=8) )</td>
<td>271.1 ± 13.5</td>
<td>269.0 ± 13.4</td>
<td>1001.0 ± 61.8</td>
<td>986.0 ± 56.9</td>
<td>986.0±56.9*</td>
<td></td>
</tr>
</tbody>
</table>

* \( p < 0.05 \) compared with before training.

<table>
<thead>
<tr>
<th>Group</th>
<th>( v_{\text{O2 max}} ) (n=9)</th>
<th>( v_{\text{O2 max}} ) (n=8)</th>
<th>1500 m (s)</th>
<th>5000 m (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>95% ( v_{\text{O2 max}} )</td>
<td>271.1 ± 13.5</td>
<td>269.0 ± 13.4</td>
<td>1001.0 ± 61.8</td>
<td>986.0 ± 56.9*</td>
</tr>
<tr>
<td>100% ( v_{\text{O2 max}} )</td>
<td>270.7 ± 8.7</td>
<td>265.5 ± 8.4*</td>
<td>994.7 ± 44.8</td>
<td>981.0 ± 39.6*</td>
</tr>
</tbody>
</table>

* \( p < 0.05 \) compared with before training.
ffects of training on the running performance were analyzed at distances of 1500 and 5000 m. These events are performed at different intensities and hence with different contributions of the aerobic system (1500 m = 105%–115% VO2 max and 80%–85%; 5000 m = 90%–95% VO2 max and 90%–95%, respectively) (Billat 2001). Some studies have verified that the physiological indices associated with performance at these distances may also be different (Billat et al. 1996a; Denadai et al. 2004). In short, these studies have verified that, for trained individuals, 1500 m running performance seems to be more dependent on VO2 max, whereas 5000 m running performance is more dependent on the indices associated with the blood lactate response to exercise (i.e., MLSS, OBLA, critical velocity) (Denadai et al. 2004). Our results are in agreement with these studies, yet the improvement in 1500 m running performance was observed only in 100% VO2 max group, which presented higher VO2 max after training. Besides, the 95% VO2 max and 100% VO2 max groups did improve the VOBLA and 5000 m running performance. However, other factors (i.e., neuromuscular and anaerobic characteristics) might explain the increase in the 1500 and 5000 m running performance after HIT program (Nuummela et al. 2006). Regardless, the improvement on the aerobic performance at a given distance may depend on the characteristics of the stimuli used in HIT.

Finally, as in our study, the distances covered by 100% VO2 max and 95% VO2 max groups were similar, and the effects of HIT on the aerobic physiological indices (VO2 max and RE) and performance (1500 m) seem to be more dependent on exercise intensity. This is consistent with the training concept of Noakes (1991), who suggested that the benefits of training also depend on the distance covered at a high velocity, which determines the muscular adaptation and the number of powerful muscle contractions. On the other hand, it has been hypothesized that the training protocol should allow the cardiovascular and aerobic enzymatic system to be stimulated at its maximum (at or above VO2 max) for a longer time. In this context, it is important to consider that the criterion used in this study to equalize HIT may not have allowed a similar amount of time to be spent at VO2 max between the 95% VO2 max and 100% VO2 max groups. Thus, it is not possible to reject the hypothesis that HIT performed by the 100% VO2 max group may have experienced a more extended overload on the cardiovascular and aerobic enzymatic system, optimizing the training effects. This is an important consideration because Demarie et al. (2000) have shown in runners during intermittent exercise (very similar to HIT performed by the 95% VO2 max group) performed until exhaustion (tlim = 19 min), that the time spent at VO2 max (10 min) cannot be neglected.

We conclude that VOBLA and 5000 m running performance can be significantly improved in well-trained runners using a 4 week training program consisting of 2 HIT sessions (performed at 95% or 100% VO2 max) and 4 submaximal running sessions per week. However, in these training conditions, the improvement on VO2 max, RE, and 1500 m running performance seems to be dependent on the HIT program at 100% VO2 max.

Acknowledgements
This research was supported by grants from Conselho Nacional de Desenvolvimento Científico e Tecnológico and Fundação de Amparo à Pesquisa do Estado de São Paulo.

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