Dose-Response Relationship Between Interval Training Frequency and Magnitude of Improvement in Lactate Threshold

Abstract

The purpose of this study was to determine if interval training at 110–120% of peak power output one and two days/wk in addition to habitual training would elicit improvements in lactate threshold (LT) in a dose response manner. Twenty physically active individuals completed this study: age – 21.1 ± 1.3 yr, height – 172.1 ± 7.4 cm, body mass – 68.4 ± 9.1 kg, VO2max – 45.3 ± 5.2 mL/kg/min; and were randomly assigned into two separate 6 wk training groups – either 1 day/wk interval training or 2 days/wk interval training at 110–120% of peak workload (from an incremental exercise test) on a cycle ergometer. After 6 wk, LT (% VO2max) increased significantly (p < 0.05) in both 1 day/wk (4.3 ± 3.2%) and 2 days/wk (8.2 ± 2.6%) groups. A two-factor mixed ANOVA identified a significant interaction between exercise frequency and LT (%VO2max) values (p < 0.05) indicating that LT responded differently to 1 day/wk and 2 days/wk of interval training. Findings from the present study show high-intensity, interval training to be a successful strategy for modifying this important metabolic threshold. Moreover, results suggest that there is a dose-response relationship between frequency of interval training and the magnitude of LT improvement.

Introduction

Endurance performance is determined by numerous factors [8, 26], including maximal oxygen uptake (VO2max), economy, and metabolic thresholds (or the capacity to maintain a high %VO2max). The concept that a critical metabolic threshold, such as lactate threshold (LT), occurs during incremental exercise originated during the 1960s and has since been the topic of much research and debate [16, 24, 25]. Multiple terms and threshold concepts [28, 31] (e.g., LT, anaerobic threshold (AT), onset of blood lactate accumulation (OBLA), maximal lactate steady state (MLSS)) exist in the literature and various methodological approaches (e.g., fixed blood lactate levels, exponential rise in blood lactate) have been applied in efforts to quantify these critical thresholds [3, 5, 11, 30]. Despite the ongoing controversy in these areas, it has been suggested researchers do agree that blood lactate curves and thresholds are among the best and most consistent predictors of performance in endurance-related events [16, 23]. As such, there is interest between scientists and coaches alike as to what training program characteristics will optimize the improvement in blood LT or other metabolic thresholds [16, 21, 29]. Although investigated previously, the attributes of a training program aimed at positively modifying LT are not well understood [19, 23]. Compared to VO2max, for which there are well defined guidelines [2] for the frequency, intensity, and duration required to elicit meaningful changes, no such similar recommendations can currently be made for improving and maintaining LT. To date, most of the research centered on training program characteristics required for LT improvements has focused almost exclusively on the exercise intensity component. Moreover, much of the previous work on training intensity has focused on performing either steady state or intermittent training bouts at intensities corresponding to (or near) the LT [1, 4, 6, 25, 32]. Although these aforementioned strategies have proven to be an effective training regimen, less is known about the utility of high-intensity, interval training for improving LT [14, 15]. It has been suggested that high-intensity interval training might be an effective strategy, as this training interval training is a particularly popular and effective way to improve fitness.
During exercise, gas exchange data were obtained continuously and participants were instructed to consume a similar meal prior to pre-testing. All participants were instructed to strictly maintain current physical activity habits and diet throughout the duration of the intervention. Participants completed a training log that recorded the weekly duration of habitual exercise during the study. Details of the previous meal consumed prior to pre-testing were recorded and participants were instructed to consume a similar meal prior to post-testing.

Maximal oxygen uptake test
Participants completed incremental maximal exercise on the same cycle ergometer (Viasprint 150P; Sensormedics Corp., Palm Springs, CA) at baseline and post training during which gas exchange data, blood lactate values, and heart rate were assessed. Subjects completed 1 min of pedaling at 50 W as a warm up. Workload was then increased in a ramp-like manner equal to 5 W/15 s for women and 10 W/20 s for men to elicit volitional fatigue in approximately 10–12 min. Pedal cadence was maintained at 70–90 rev/min, with volitional fatigue representing a failure to sustain pedal cadence greater than 40 rev/min. During exercise, gas exchange data were obtained continuously and averaged over 30 s using a metabolic cart attached to a personal computer (MedGraphics Corporation, St. Paul, MN). Before exercise, the metabolic cart was calibrated to gases of known concentration (16% O2 and 4% CO2 as well as to room air (20.93% O2 and 0.03% CO2). Furthermore, a 3-1 syringe (MedGraphics Cardiorespiratory Diagnostic Systems Calibration Syringe, St. Paul, MN) was used to calibrate flow. The criteria for attainment of VO2\text{max} was two out of three of the following: 1) a plateau (ΔVO2 < 150 mL/min) in VO2 with increases in workload, 2) maximal respiratory exchange ratio (RER) > 1.1, and 3) maximal HR within 15 b/min of the age-predicted maximum (220 – age). VO2\text{max} was defined as the highest VO2 obtained over any continuous 30-s time period, provided two out of the three aforementioned VO2\text{max} criteria were attained. Continuous HR measurements were obtained using a Polar F1 heart rate monitor (Polar Electro Inc., Woodbury, NY) that was interfaced with the metabolic cart.

Blood Lactate Sampling and Analytical Procedures
Finger-prick blood samples were obtained during incremental exercise testing in each participant at baseline and following 6 wk of training. Blood samples (0.7 μL) were collected each minute during the first 4 min of exercise, thereafter blood samples were obtained every 30 s until minute 10, after which blood samples were taken if necessary every minute until cessation of exercise. Samples were immediately analyzed for lactate using a NOVA Lactate Plus Meter (Nova Biomedical Corporation, Waltham, USA). The coefficient of variation for the lactate samples during pilot testing was < 2%. The LT was detected by plotting log [La] (in mmol/L) versus time (min) for each individual’s VO2\text{max} protocol. Incidence of the LT was then transformed to a VO2\text{max} equivalent based on the VO2 versus time plot for each participant during each protocol. Bi-segmental linear regression was performed on the data resulting in two regression lines that fit the data with the smallest residual error. The intersection of these lines denoted the LT [3]; the work intensity and oxygen uptake at which blood lactate exhibited a marked increase above resting values.

Interval training program
After baseline testing participants were randomly assigned into two separate 6 wk training groups – either 1 day/week interval training or 2 days/week interval training. Interval training sessions consisted of a standardized 4 min warm up at 50 watts (W). Interval training workload was equivalent to 110–120% of participant’s peak watt workload from baseline incremental exercise testing. Weeks 1–2 consisted of six, 30 s intervals performed at ~110% of peak workload, weeks 3–4 consisted of seven, 30 s intervals performed at ~115% of peak workload, and weeks 5–6 consisted of eight, 30 s intervals performed at ~120% of peak workload. Throughout training there was 3.5 min active recovery at 50 W between each interval and all interval training sessions concluded with a 4 min cool down at 50 W. Participants in the 2 days/week interval training group were required to separate interval sessions by at least one day. All interval training sessions were supervised by one of the investigators. A summary of the interval training program is presented in Table 1.
Statistical Analyses

Data are reported as mean ± standard deviation (SD) and were analyzed using GraphPad Prism 5.01. (San Diego, CA). Primary outcome measures (e.g., VO\textsubscript{2}max, LT at %VO\textsubscript{2}max, peak workload) were analyzed using a two-factor mixed ANOVA, with the between factor “group” (interval group one, interval group two) and repeated factor “trial” (pre-training, post-training). All significant main effects and interactions were subsequently analyzed using Tukey’s honestly significant difference post hoc test. The independent-samples t-test was used to find out whether there was a significant difference between interval training groups for any of the primary outcome measures at baseline. Statistical significance was established as p < 0.05.

Results

Training was well tolerated with 100% adherence in both groups to scheduled interval sessions. Only two participants (20 of 22 completed the study) were unable to finish the study due to injuries sustained that were unrelated to the investigation. At baseline and after 6 wk training, groups did not differ in physical characteristics. The physical and physiological characteristics at baseline and 6 wk for participants in both training groups are presented in Table 1. The group means for the weekly habitual training volume before and during the study were 4.3 ± 0.9 versus 4.5 ± 0.6 h/wk and 4.2 ± 0.6 versus 4.3 ± 0.6 h/wk for the 1 day/wk and 2 days/wk interval training groups, respectively. Differences between and within subjects were not significant (p > 0.05).

After 6 wk, changes in VO\textsubscript{2}max were not significantly (p > 0.05) different in the 1 day/wk or 2 days/wk interval training groups compared with baseline. LT (% VO\textsubscript{2}max) increased significantly (p < 0.05) in both 1 day/wk (4.3 ± 3.2%) and 2 days/wk (8.2 ± 2.6%) groups. A two-factor mixed ANOVA identified a significant interaction between frequency of interval training and LT (% VO\textsubscript{2}max) values (p < 0.05) indicating LT responded differently to 1 day/wk and 2 days/wk of interval training (Fig. 1). Peak workload increased significantly (p < 0.05) in both 1 day/wk (9.5 ± 14.7 W) and 2 days/wk (14.4 ± 8.8 W) groups. A two-factor mixed ANOVA identified a significant interaction between frequency of interval training and peak workload values (p < 0.05) indicating that peak workload achieved responded differently to 1 day/wk and 2 days/wk of interval training. The mean blood lactate responses to incremental exercise testing before and after 6 wk for participants completing 1 day/wk and 2 days/wk of interval training are illustrated in Fig. 2.

Table 1  Summary of interval training programs.

<table>
<thead>
<tr>
<th>Week</th>
<th>Session duration</th>
<th>Repetitions and Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 2</td>
<td>4 min warm up (50 W)</td>
<td>6 intervals at ~110% of peak workload cadence kept between 70 and 90 rpm</td>
</tr>
<tr>
<td></td>
<td>30 s interval</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.5 min recovery (50 W)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 min cool down (50 W)</td>
<td></td>
</tr>
<tr>
<td>3 and 4</td>
<td>4 min warm up (50 W)</td>
<td>7 intervals at ~115% of peak workload cadence kept between 70 and 90 rpm</td>
</tr>
<tr>
<td></td>
<td>30 s interval</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.5 min recovery (50 W)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 min cool down (50 W)</td>
<td></td>
</tr>
<tr>
<td>5 and 6</td>
<td>4 min warm up (50 W)</td>
<td>8 intervals at ~120% of peak workload cadence kept between 70 and 90 rpm</td>
</tr>
<tr>
<td></td>
<td>30 s interval</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.5 min recovery (50 W)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 min cool down (50 W)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2  Physical and physiological characteristics at baseline and 6 wk for interval training groups (mean ± SD).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1 day/wk group (n=11)</th>
<th>2 days/wk group (n=9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>6 wk</td>
</tr>
<tr>
<td>age (yr)</td>
<td>21.3 ± 1.0</td>
<td>–</td>
</tr>
<tr>
<td>height (cm)</td>
<td>172.4 ± 7.2</td>
<td>–</td>
</tr>
<tr>
<td>body mass (kg)</td>
<td>69.1 ± 10.6</td>
<td>69.3 ± 10.5</td>
</tr>
<tr>
<td>HR\textsubscript{max} (bpm)</td>
<td>198 ± 4.3</td>
<td>198.4 ± 3.0</td>
</tr>
<tr>
<td>L\textsubscript{a}\textsubscript{max} (mM/L)</td>
<td>9 ± 1.4</td>
<td>9.5 ± 1.7</td>
</tr>
<tr>
<td>R\textsubscript{ER}\textsubscript{max}</td>
<td>1.12 ± 0.04</td>
<td>1.14 ± 0.03</td>
</tr>
<tr>
<td>VO\textsubscript{2}max (mL/kg/min)</td>
<td>44.6 ± 6.6</td>
<td>44.3 ± 6.0</td>
</tr>
<tr>
<td>peak workload (W)</td>
<td>279.1 ± 65.0</td>
<td>288.6 ± 63.1 *</td>
</tr>
</tbody>
</table>

Fig. 1  Lactate threshold (%VO\textsubscript{2}max) before and after 6 wk of interval training for 1 day/wk and 2 days/wk. Values are mean ± SD. * Within-group change is significantly different from baseline, p < 0.05; † Improvement from baseline is significantly different from 1 day/wk interval training group, p < 0.05.

Fig. 2  Interval Training & Testing.

* Within-group change is significantly different from baseline, p < 0.05; † Improvement from baseline is significantly different than interval group one, p < 0.05; HR\textsubscript{max}, maximal heart rate; L\textsubscript{a}\textsubscript{max}, maximal lactate concentration; R\textsubscript{ER}\textsubscript{max}, maximal respiratory exchange ratio; VO\textsubscript{2}max, maximal oxygen uptake
Discussion

The main findings of this study were: 1) high-intensity, interval training (110–120% of peak workload) was sufficient in raising the LT for both training groups, and 2) greater interval training frequency yielded additional training adaptations, with the 2 days/wk interval training group experiencing greater improvements in LT compared to the 1 day/wk interval training group. The finding that high-intensity, interval training can be an effective stimulus for augmenting LT has been previously reported in the literature. In an early study, Poole and Gaesser [27] concluded 8 wk of interval training for 3 days/wk on a cycle ergometer (10×2 min at 105% VO2max) was a useful training regimen for improving LT. Likewise, and more recently, Esfarjani and Laursen [15] demonstrated improved LT in moderately trained runners following 10 wk of high-intensity, interval training (12×30 s at 130% of running velocity at VO2max) for 2 days/wk. The physiological mechanisms responsible for the improved LT (Fig. 1) and a right shift in LT so that higher workloads are achieved at similar blood lactate levels (Fig. 2) are multi-factorial, including heightened mitochondrial enzymatic activity [18], increased capillary density [22], and greater MCT protein content [13]. In fact, it has recently been reported that MCT 4 protein content can be elevated following a single week of interval training, with a more prolonged time course for the rise in MCT 1 protein content [9]. These adaptations, though not measured in the present study, are possible explanations for the improvement in LT observed in both interval training groups.

A novel aspect of the current study was the investigation of whether frequency of interval training days (two vs. one) would yield additional benefits. Indeed, the experimental group completing 2 days/wk of interval training, compared to 1 day/wk, appreciated a two-fold greater improvement in LT and 50% greater increase in peak workload achieved during incremental exercise testing (Table 2). Previous work suggests the more favorable changes observed in the 2 days/wk interval training group would correspond to superior performances in endurance-related events [7,12], however, quantifying this would have strengthened the present study. Our study also has good ecological validity in that we recruited active individuals and gradually incorporated interval training either one or two days per week while continuing to have them maintain previous training habits. This scenario emulates the real world whereby coaches or trainers maybe looking to supplement their athlete’s or client’s existing training regimen with more specialized workouts aimed at improving physiological parameters (e.g., LT) linked to better performance. Lastly, it has been previously suggested by Londeree [19] that the incorporation of higher intensity training into the current regimen of trained individuals is an essential requisite for continued improvement in LT.

The paradoxical finding, in both interval training groups, of increased peak workloads coupled with unchanged VO2max values merits further discussion. Given the moderate training status (at the onset) of participants in the present study, the unchanged VO2max values following training were not completely unexpected. In fact, it has been noted elsewhere [15] that greater training duration and volume beyond short intervals (e.g., 30 s in the present study) is required to modify the central and peripheral adaptations pertaining to VO2max. Conversely, short-term interval training has been previously reported to contribute to greater peak power outputs with minimal [10] or no change in VO2max values [20]. However, we can only speculate on the potential mechanisms responsible for these findings, including enhanced skeletal muscle buffering capacity [33] and increased glycolytic flux [20].

In conclusion, although most researchers agree that LT is among the best and most consistent predictors of performance in endurance-related events, the attributes of a training program aimed at positively modifying LT are not well defined. Findings from the present study show that high-intensity, interval training is a successful strategy for modifying this important metabolic threshold. Moreover, our results suggest that there is a dose-response relationship between exercise frequency and the magnitude of LT improvement in physically active men and women. Future research should continue on this front and be aimed at elucidating additional characteristics of a training program (e.g., duration of interval sessions, recovery between intervals) focused on optimizing LT and other metabolic thresholds.

References


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