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IMPACT OF TRAINING INTENSITY DISTRIBUTION ON PERFORMANCE IN ENDURANCE ATHLETES

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ABSTRACT. Esteve-Lanao, J., C. Foster, S. Seiler, and A. Lucia. Impact of training intensity distribution on performance in endurance athletes. *J. Strength Cond. Res. 21(3):943–949. 2007.*—The purpose of this study was to compare the effect of 2 training programs differing in the relative contribution of training volume, clearly below vs. within the lactate threshold/maximal lactate steady state region on performance in endurance runners. Twelve subelite endurance runners (who are specialists in track events, mostly the 5,000-m race usually held during spring-summer months and who also participate in cross-country races [9–12 km] during fall and winter months) were randomly assigned to a training program emphasizing low-intensity (subthreshold) (Z1) or moderately high-intensity (between thresholds) (Z2) training intensities. At the start of the study, the subjects performed a maximal exercise test to determine ventilatory (VT) and respiratory compensation thresholds (RCT), which allowed training to be controlled based on heart rate during each training session over a 5-month training period. Subjects performed a simulated 10.4-km cross-country race before and after the training period. Training was quantified based on the cumulative time spent in 3 intensity zones: zone 1 (low intensity; <VT), zone 2 (moderate intensity; between VT and RCT), and zone 3 (high intensity; >RCT). The contribution of total training time spent in zones 1 and 2 was controlled to have relatively more low-intensity training in Z1 (80.5 ± 1.8% and 11.8 ± 2.0%, respectively) than in Z2 (66.8 ± 1.1% and 24.7 ± 1.5%, respectively), whereas the contribution of high-intensity (zone 3) training was similar (8.3 ± 0.7% [Z1] and 8.5 ± 1.0% [Z2]). The magnitude of the improvement in running performance was significantly greater ($p = 0.03$) in Z1 (−157 ± 13 seconds) than in Z2 (−121.5 ± 7.1 seconds). These results provide experimental evidence supporting the value of a relatively large percentage of low-intensity training over a long period (~5 months), provided that the contribution of high-intensity training remains sufficient.

KEY WORDS. training zones, heart rate, running performance

INTRODUCTION

Although the underlying physiological adaptations associated with improved endurance performance with training are well established, debate abounds regarding how one should train to induce these adaptations and translate them to performance gains. A key issue of debate is the intensity of training and how the day-to-day training intensity should be distributed. Training intensity is typically broken into more or less arbitrary intensity zones, often based on readily accessible intensity measures, such as heart rate (HR) (i.e., 80–90% of maximal heart rate [HRmax]) (12). There is a clear practical need for dividing up the training intensity continuum into zones. However, these zones should be anchored in identifiable physiological markers if they are to be meaningful in interpreting the impact of training organization. Recently we (7, 27) adopted the use of ventilatory thresholds and their associated HR values identified during progressive treadmill or bicycle testing to demarcate 3 training intensity zones. These include zone 1, low-intensity exercise performed below the first ventilatory threshold (VT); zone 2, moderately high-intensity exercise in an intensity range between the VT and the respiratory compensation threshold (RCT); and zone 3, high-intensity aerobic exercise performed above the RCT (7, 27).

Seiler and Kjerland (27) recently reported a 75%-8%-17% training session distribution in zones 1, 2, and 3, respectively, over a 32-day period in competitive junior cross-country skiers who were training 10 to 12 $h \cdot wk^{-1}$. In a previous study (7), we found a similar (71%-21%-8%) distribution based on HR time-in-zone in distance runners during a ~6-month period where training volume was 4 to 5 $h \cdot wk^{-1}$. These data are similar to those reported during training in professional cyclists (21), elite marathoners (2), elite rowers (8, 29), and cyclists performing 3-week tour races (20). The results of one of these descriptive studies (7) showed a positive association between the total training time in zone 1 and competition performance in a 10-km cross-country running race, tentatively suggesting that low-intensity training has a positive impact on performance despite a lack of intensity specificity. What these different studies from cyclists, runners, cross-country skiers, and rowers all share is the finding that well-trained (including world-elite) athletes perform ~75% of their training at intensities below the lactate threshold or VT (i.e., zone 1), despite competing at much higher intensities. They appear to require a relatively small percentage of their total training load at intensities at or above the VT (zone 2 or 3) to achieve top performance. In other words, it seems that substantial volumes of relatively low-intensity training (zone 1) may be a crucial part of competitive endurance training programs and may provide a platform for the specific adaptations that occur in response to the high-intensity or specific (zone 3) workouts. This hypothesis, however, is based on descriptive data alone because experimental studies involving manipulation of intensity distribution in well-trained athletes are nearly absent from the literature.

Accordingly, this study was designed to compare the performance effects of 2 training programs distinguished by different relative contributions of low-intensity zone 1 and lactate threshold zone 2 training intensity to the total training load while maintaining the high-intensity zone 3 contribution constant. Based on the findings of previous research showing that endurance athletes spontaneously organize their training to spend the majority of training time in zone 1 (7, 8, 10, 20, 23, 27), we hypothesized that the largest improvements in endurance performance would be elicited by a training program that emphasized relatively low-intensity (zone 1) training.

Methods

Experimental Approach to the Problem

We subjected 2 groups of well-trained runners to a 5-month training program that differed only in the distribution of training intensity without a difference in total training load. Specifically, 1 group of athletes performed a relatively higher percentage of their total training volume in zone 1, below their VT. The second group trained relatively more in zone 2, between VT and RCT, while training less within zone 1. Both groups trained essentially identical volumes in zone 3 (i.e., intensities ≥90% $\dot{V}O_2$max). To ensure that total training loads (i.e., volume × intensity) were similar in both study groups despite differences in intensity (lower or higher total contribution of zone 1), we used a modified approach to the training impulse (TRIMP) approach to monitoring training (9). To assess the impact of the 2 training programs, we compared competitive performance on a simulated 10.4-km cross-country race before and after the training period.

Subjects

The institutional research ethics committee (European University of Madrid) approved the study, and the subjects provided informed consent prior to participation. Twenty competitive subelite (regional to national level, competition experience ≥5 years) male Spanish runners were originally selected for this study. They participated in track events (mostly 5,000-m races) during the spring-summer months and in cross-country races (9–12 km) during fall-winter months. The subjects' personal records (PR) in a 10-km race ranged between 30 minutes, 30 seconds and 35 minutes 00 seconds.

All subjects lived and trained in the area around Madrid, Spain (~600-m altitude). Only the data of the subjects who met the following conditions were entered in our study: (a) completion of at least 98% of all the planned training sessions; (b) complete HR recordings of each training session (with no missing single session) over the total training period; (c) performing each daily training session under the supervision of one of the authors (J.E.-L.), who is a professional coach; (d) showing no signs or symptoms of overreaching/overtraining over the entire training period (i.e., prolonged increases in basal HR, inability to reach high HR values, inability to sustain the required running speed during very intense workouts, failure to recover from training sessions, decreased performance, significant muscle soreness even after easy days); and (e) performing both pre- and posttraining simulated competitions.

Prior to initiation of the training intervention period, the recruited runners all performed the same initial 3-week program of training with 100% zone 1 training in week 1 followed by 87/9/4 and 93/3/4 HR-based time-in-zone percentage distributions in weeks 2 and 3, respectively. Pretraining physiological testing was performed at the end of this baseline period. The twenty runners were then randomly assigned to 2 different training groups ($N = 10$ each) for a 5-month period, following a training program with increased contribution of zone 1 (group Z1) or decreased contribution of zone 1 and thus increased contribution of zone 2 (group Z2), relative to the normal training pattern observed in this population (7). Both groups had to perform the same total training load (volume × intensity) over the training period, based on the TRIMP score method described below, but with different distribution of the 3 intensity zones. Seven subjects were excluded because they failed to successfully record HR for at least 98% of their training sessions. One subject developed a chronic injury during the training period and was excluded. The results are therefore based on a comparison of the 6 subjects for each group who met all the inclusion criteria. Their mean age, body mass, and height at the start of the study was 27 ± 2 years, 63.5 ± 1.1 kg, and 174.8 ± 2.6 cm (Z1) and 27 ± 2 years, 65.4 ± 1.0 kg, and 174.3 ± 1.2 cm (Z2).

Procedures

Main Characteristics of Training and Periodization. The training plan of one of the groups (Z1) was designed to achieve a total percentage distribution in zones 1, 2, and 3 of ~80/10/10. The other group (Z2) followed a training plan designed to achieve a total percentage distribution in zones 1, 2, and 3 of ~65/25/10. The 2 training programs were designed to reach a similar score in the 2 groups for both: (a) total TRIMP accumulated from the 4th to the 21st week of the 5-month macrocycle (~8,900 TRIMPs) and (b) mean TRIMP accumulated in the same period (mean of ~495 TRIMPs·wk^{-1}).

Daily training loads were based on time goals rather than distance, with the intent of controlling the relative time in each zone for each athlete. Apart from the 3-week baseline training period, the training load was adjusted every week to ensure achievement of similar TRIMP scores in both groups. Daily feedback from the athletes was also taken into account to avoid injuries or overreaching. All the athletes shared the same coach (J.E.-L.). The intensity of each subject's session was individualized based on normal coaching practice but constrained by the experimental treatment.

Overall, the main difference in training schedules was that subjects in Z2 typically performed several running bouts per week at a constant or "tempo" pace eliciting a HR in zone 2 (i.e., at a HR value equidistant to both VT and RCT), whereas for subjects in Z1 these sessions were performed in zone 1 (HR ~5 beats·min^{-1} below VT) over a longer duration. This allowed the 2 groups to achieve similar TRIMP scores. At the end of the training program (final 3-week mesocycle), intense sessions were performed at high intensities (i.e., achieving maximal HR values) by subjects of both groups. In both Z1 and Z2, the 5-month period of study (i.e., 21-week macrocycle) was divided in 2 initial 3-week mesocycles, followed by 3 4-week mesocycles and a final 3-week mesocycle. The initial 3-week mesocycle was identical for the 2 groups (i.e., identical distribution in intensity zones) because it included foundation, low-intensity running, and basic strength training sessions. In both groups, each 3-week mesocycle had a 2:1 load structure (i.e., 2 weeks of high load followed by an easy week), whereas the 4-week mesocycles followed a 3:1 load structure.

The training program was divided in 3 main periods, each with a different goal. The preparatory period (weeks 1–10) was used for foundation training (zone 1 and basic circuit weight training) followed by circuit weight training and short-to-long interval training (at ~RCT). In the specific period (weeks 11–18), strength training sessions were performed specifically during actual running (see below for more details on strength exercises). The competition period (weeks 19–21) included long intervals at a running speed above race pace, 1 easy session per week, and 1 weekly session of weight training (see below for more details on strength exercises).

Running distance averaged ~80 to 90 km·wk^{-1} in both groups over the study period, increasing through the preparatory period to reach a maximum of ~120 km·wk^{-1} in the 16th week and finally decreasing over the competition period (mean of 40–50 km·wk^{-1}). Overall, running intensity followed the opposite pattern. Although considerable variations existed depending upon the period of the macrocycle and the hard or easy weeks of each mesocycle, the runners' usual training weekly program included 2 hard sessions·wk^{-1} (including interval or repetition workouts at high intensities) and 1 or 2 strength training sessions·wk^{-1}. The remaining sessions were composed of continuous training (performed mainly in zone 1 for Z1 and zone 2 for Z2). During the specific and competition period, all the runners participated in 2 cross-country races of ~5-km distance and 3 cross-country races of ~10-km distance. Heart rate was continuously monitored during these preparatory races and included in the quantification of training loads. Although these competitions were not the target ones, they were used as an important part of the training schedule of these runners and the subjects in both groups were required to perform as well as possible.

Strength Training During the Study Period. All the subjects performed strength training exercises (see below) because this type of supplemental training has been shown to prevent the occurrence of injuries and to improve running economy (13, 25). Strength training was identical for all subjects and was not related to the experimental manipulation of the training program. During the initial 3-week mesocycle, the runners performed isometric and dynamic, body mass–wearing exercises (with no external load), exercises (30- to 60-s duration) at different joint angles, and aerobic circuit weight training with light loads. Subjects also performed 8 to 10 different types of weight lifting exercises (3–4 sets corresponding to 15–25 RM of half squat in multipower, lunge, leg curl, leg press, bench press, calf raises, and lateral pull) and other local exercises with elastic bands, such as skipping and mat and Swiss ball core exercises, as well as foot, ankle, and knee propioceptive exercises.

During the preparatory period (up to the 10th week), weight and resistance training exercises were mostly 1-leg half squat, clean, snatch, eccentric harmstring exercises; eccentric-concentric calf exercises (to strengthen Achilles tendon and prevent injuries in this zone); and ankle-loaded skipping exercises. Loads varied from 10 to 20 RM with a 1-/3-second ratio between concentric/eccentric phase to more explosive exercises (3–8 repetitions with 15–25 RM loads) at fast stretch-shortening cycle. Light-intensity plyometric training was also performed. Finally, subjects performed some specific routine exercises, such as the Oregon circuit training over 10 × 50-m to 100-m running bouts interspersed with 9 explosive exercises of 10 repetitions each with light loads (clean, snatch, squats) or without load (skipping, jumps).

In the specific period (weeks 11–18), strength training sessions were performed specifically during actual running (using weighted vests, short running intervals on steep hills, or longer repetitions on muddy terrain) at specific competition speeds or above them.

During the competition period (weeks 19–21), subjects performed 1 single weight-training session per week consisting of basic exercises (i.e., 1–2 sets each of half squat, leg curl, and curl raise), with loads corresponding to 60% of estimated 1RM at a moderate speed (ratio concentric/eccentric: 1 s/1 s) and avoiding reaching failure (i.e., stopping each exercise 2–3 repetitions before muscle failure). The goal of this single weekly session was to maintain strength levels without inducing further muscle damage during this demanding phase that included intense running sessions.

Baseline Laboratory Testing and Performance Test. Subjects reported to the laboratory (~600-m altitude) at the beginning of the training period to perform a physiological (ramp) test on a treadmill (Technogym Run Race 1400 HC, Gambettola, Italy) for VT and RCT determination. After a general warm-up, starting at 11 km·h^{-1}, running velocity was increased by 0.5 km·h^{-1} every 30 seconds until volitional exhaustion. During the tests, gas exchange data were collected continuously using an automated breath-by-breath system (Vmax 29C; Sensormedics, Yorba Linda, CA). The following variables were measured: oxygen uptake ($\dot{V}O_2$), pulmonary ventilation (VE), ventilatory equivalents for oxygen (VE·$\dot{V}O_2{}^{-1}$) and carbon dioxide (VE·$CO_2{}^{-1}$), and end-tidal partial pressure of oxygen ($P_{ET}O_2$) and carbon dioxide ($P_{ET}CO_2$).

Maximal oxygen uptake ($\dot{V}O_2$max) was recorded as the highest $\dot{V}O_2$ value obtained for any continuous 1-minute period during the tests. At least 2 of the following criteria were also required for the attainment of $\dot{V}O_2$max: a plateau in $\dot{V}O_2$ values despite increasing velocity, a respiratory exchange ratio ≥1.15, or the attainment of a peak HR value above 95% of the age-predicted maximum (6). The VT was determined using the criteria of an increase in both VE·$\dot{V}O_2{}^{-1}$ and $P_{ET}O_2$ with no increase in VE·$VCO_2{}^{-1}$, whereas the RCT was determined using the criteria of an increase in both VE·$\dot{V}O_2{}^{-1}$ and VE·$VCO_2{}^{-1}$ and a decrease in $P_{ET}CO_2$ (7). Two independent observers detected VT and RCT. If there was disagreement, the opinion of a third investigator was obtained (7). Heart rate (beats·min^{-1}) was continuously monitored during the tests using radio telemetry (Accurex Plus, Polar Electro OY, Finland).

At the beginning and at the end of the training period, each subject performed a time trial, which constituted the simulated competition test (10.4-km cross-country race) on the same loop and under similar wind and environmental conditions. This time trial was used to (a) determine initial fitness level and ensure similar fitness levels in both groups before the start of the study (given that subjects were randomly assigned to either Z1 or Z2 group) and (b) compare the magnitude of changes in performance in both groups over the training period. The cross-country loop was similar to that of the target competition at the end of the season, and subjects were instructed to perform maximally. Verbal encouragement was given to the subjects, and all the tests were preceded by the typical precompetitive rest period (i.e., 2–3 days of easy training) to simulate actual competition conditions. Subjects wore a HR telemeter during pre- and post-training simulated competitions in order to compare the exercise intensity of both races.

Quantification of Exercise Load in Training. Because the initial 3-week mesocycle was the same for the 2 groups, for statistical comparisons we quantified data from the 4th to the 21st week (18 experimental weeks). For all the subjects, HR was measured (every 5 seconds) during each training session and preparatory competition (with no missing data) over the entire 21-week macrocycle. The following variables were quantified: (a) total time spent in each intensity zone (zone 1: HR below the HR at VT; zone 2: HR between HR at VT and HR at RCT; zone 3: HR above HR at RCT) and (b) total load (TRIMP score) as explained below. A total of ~2,000 training sessions were analyzed. Previous research on trained endurance athletes has shown that HR values at VT and RCT determined during laboratory testing remain stable over the season despite significant improvements in the workload eliciting both thresholds (22). Thus, a single test performed early during the training period (as used here) appears valid for training monitoring based solely on target HR values at VT and RCT (22).

We estimated total exercise load (i.e., intensity × volume) accumulated in each training session using a novel approach to calculating the TRIMP based on a method recently developed by Foster et al. (9). This method, which has been recently used to estimate total exercise load in 3-week professional cycling races (10, 23) and the training sessions of well-trained endurance runners of similar competition level to that of the present subjects (7), uses HR data during exercise to integrate both total volume and total intensity relative to 3 intensity zones. Briefly, the score for each zone is computed by multiplying the accumulated duration in this zone by an intensity-weighted multiplier (e.g., 1 minute in zone 1 is given a score of 1 TRIMP, 1 minute in zone 2 is given a score of 2 TRIMPs, and 1 minute in zone 3 is given a score of 3 TRIMPs). The total TRIMP score is then obtained by summing the results of the 3 zones.

Statistical Analyses

To ensure that the fitness and competition level of both groups was similar at baseline, mean values of all the variables indicative of fitness levels ($\dot{V}O_2$max, VT and RCT, etc.) and performance (10.4-km simulated race) obtained before the training period were compared between groups using the Mann-Whitney *U*-test. (Given the small population size, we selected the aforementioned nonparametric test instead of using an unpaired Student's *t*-test). We used a Wilcoxon test and Pearson's correlation coefficients to compare the intensity (through HR data) in all the subjects during both simulated competitions. This allowed us to confirm that the subjects performed a similar effort in both competitions, and thus the possible difference in the magnitude of improvement from pre- to post-training between both groups was attributable to the training intervention. To ensure that the total training loads (volume × intensity) and distribution in intensity zones was similar and different, respectively, in the 2 groups during the training period, mean values of total TRIMP score and total and % time spent in zones 1, 2, and 3 over the 18-week intervention period (weeks 4–21) were also compared in the 2 groups with the Mann-Whitney *U*-test. Finally, to evaluate the interactive effect of group and time on performance, mean improvement in performance over the training period in both Z1 and Z2 was compared using the Mann-Whitney *U*-test. The size of the change in performance and its precision were provided by reporting the change in mean values (± *SEM*) and the 95% confidence intervals (95% CI) for the change, respectively. The statistical power for all comparisons between groups Z1 ($N = 6$) and Z2 ($N = 6$) ranged between 0.06 and 1.00.

Descriptive data are reported as mean ± *SEM,* and the level of significance was set at $p \leq 0.05$ for all statistical analyses.

RESULTS

Baseline Laboratory and Performance Tests

The average values of maximal running velocity attained during the treadmill tests (vmax), $\dot{V}O_2$max, running velocity at $\dot{V}O_2$max (v$\dot{V}O_2$max), HRmax, VT, RCT (both expressed as either running speed, %HRmax, or %$\dot{V}O_2$max), and performance time in the baseline competition test did not differ between the 2 groups (Table 1).

TABLE 1. Results (mean ± *SEM*) of laboratory and simulated competition tests at baseline (i.e., before the 18-week intervention period).*

	Group Z1 ($n = 6$)	Group Z2 ($n = 6$)
vmax (km·h^{-1})	21.5 ± 0.6	21.2 ± 0.7
v$\dot{V}O_2$max (km·h^{-1})	21.1 ± 0.7	20.5 ± 0.6
$\dot{V}O_2$max (ml·kg^{-1}·min^{-1})	68.6 ± 2.4	70.3 ± 2.6
HRmax (b·min^{-1})	191 ± 4	193 ± 3
VT (km·h^{-1})	13.7 ± 0.6	13.8 ± 0.5
VT (%$\dot{V}O_2$max)	67.0 ± 2.6	68.0 ± 3.6
VT (beats·min^{-1})	147 ± 4	151 ± 4
RCT (km·h^{-1})	17.8 ± 0.6	17.8 ± 0.6
RCT (%$\dot{V}O_2$max)	88.0 ± 2.3	87.3 ± 1.9
RCT (beats·min^{-1})	171 ± 4	173 ± 3
Performance time during 10.4-km simulated cross-country race (s)	2249 ± 51	2271 ± 61

* No significant differences existed between groups for any of the variables ($p > 0.05$). vmax = maximal running velocity attained during the treadmill tests; v$\dot{V}O_2$max = running velocity at $\dot{V}O_2$max; HRmax = maximal heart rate; VT = ventilatory threshold; RCT = respiratory compensation threshold.

TABLE 2. Comparison of exercise intensity in the pre- and post-training simulated competitions in all the subjects ($N = 12$)*

	Pre-training (n = 12)	Post-training (n = 12)
Mean HR (b·min^{-1})	175 ± 9	178 ± 9
Mean HR (%HRmax)	91.1 ± 2	92.5 ± 2
HRpeak (beats·min^{-1})	185 ± 12	186 ± 11

* Results are expressed as mean ± *SEM*. No significant differences existed between means ($p > 0.05$). HR = heart rate; HRmax = HRmax value of the laboratory tests (Table 1); HRpeak = peak HR value obtained during each simulated competition.

On the other hand, no significant difference was found between the exercise intensity (expressed as mean HR (beats·min^{-1}), mean HR (expressed as %HRmax), and peak HR attained during competition) of the pre- and post-training simulated competition, respectively (Table 2). Correlation coefficients between both competitions for the aforementioned variables were high and significant: $R = 0.86$ ($p < 0.001$) for mean HR (beats·min^{-1}), $R = 0.87$ ($p < 0.001$) for mean HR expressed as %HRmax, and $R = 0.82$ ($p < 0.05$) for peak HR obtained during competition.

Quantification of Training Load

None of the 12 subjects who completed the study became injured or sick during the training period or showed signs of chronic fatigue/overtraining (e.g., decreased peak values of HR, chronic muscle soreness). All were able to complete virtually ~100% of training sessions over the 5-month program as originally planned. The cumulative total duration of training sessions over the experimental period (weeks 4–21) averaged ~95–110 hours per runner (~100 hours in Z1 vs. ~75 hours in Z2) or ~5 to 6 hr·wk^{-1}. When expressed in total running distance, subjects completed a total of ~1,500 km (~85 km·wk^{-1}).

TABLE 3. Results (mean ± *SEM*) of training loads over the 18-week intervention period.

	Group Z1 ($n = 6$) goal distribution in zones 1, 2, and 3: ~80/10/10	Group Z2 ($n = 6$) goal distribution in zones 1, 2, and 3: ~65/25/10
Total TRIMPs	8134 ± 408	8277 ± 463
Mean TRIMP·wk^{-1}	452 ± 23	460 ± 26
Total time in zone 1 (min)	5246 ± 396	3830 ± 215*
Total time in zone 2 (min)	779 ± 116	1411 ± 95*
Total time in zone 3 (min)	502 ± 78	485 ± 65
Total % in zone 1	80.5 ± 1.8	66.8 ± 1.1
Total % in zone 2	11.8 ± 2.0	24.7 ± 1.5*
Total % in zone 3	8.3 ± 0.7	8.5 ± 1.0*

* $p < 0.01$ for Z1 vs. Z2. See text for explanation of TRIMP and zones 1, 2, and 3.

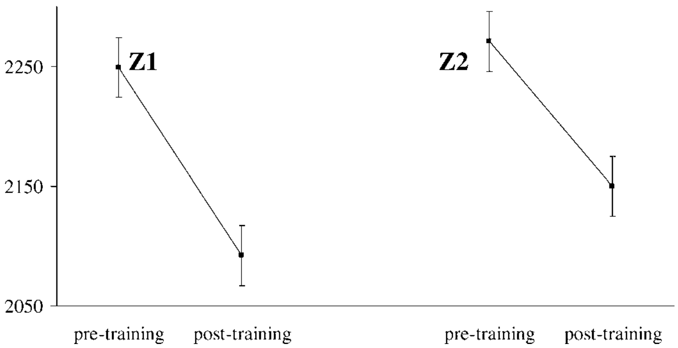

FIGURE 1. Change in performance after the training period during the simulated 10.4-km cross-country race in both groups.

As designed, no significant differences were found in total TRIMP score or in mean weekly TRIMP score between groups, indicating that the total training load (intensity × volume) of both groups was similar over the intervention period (Table 3). However, as designed, significant differences were found between groups for total and percent training time in zones 1 and 2 ($p < 0.01$), but no significant differences were found for total and percent training time in zone 3 ($p > 0.05$).

Although performance time was significantly improved in both groups after training ($p = 0.03$ in both cases) (Figure 1), the magnitude of the improvement was significantly ($p = 0.03$; statistical power = 0.60) higher in Z1 than in Z2 (-157 ± 13 seconds vs. -121.5 ± 7.1 seconds, respectively; difference in mean improvement between Z1 and Z2: -35.5 ± 14.6 seconds; 95% CI: -68.4 seconds; -3.3 seconds).

DISCUSSION

The key finding of this study was that in a well-trained athletes training over a 5-month period, a distribution of HR-based training intensity of 80% zone 1, 12% zone 2, and 8% zone 3 elicited significantly greater performance enhancement than a program in which the time spent at or around the lactate threshold intensity was doubled to ~25% while holding time in zone 3 constant.

This is the first randomized, controlled training study that has experimentally assessed, through quantification of actual training loads, the effects of increasing or decreasing the contribution of relatively low intensity (zone 1) training on the performance of well-trained endurance athletes. To the best of our knowledge, only 2 recent descriptive studies have continuously monitored actual daily training loads using objective methods (HR recordings) during short- (32 days) (27) to long-duration (6 months) training periods in competitive endurance athletes (7). Although our results do not necessarily challenge the classic principle of training specificity, our data, together with those of previous research (2, 7, 20, 21, 23, 26), support the notion that in well-trained athletes, only a comparatively small amount of training needs to be performed at moderate to high intensities (zones 2 and 3) in order to achieve top performance and prevent overtraining. In other words, it seems that relatively low-intensity training (zone 1) is an essential part of any competitive endurance training program.

For the reader familiar with the substantial literature involving the training of untrained subjects at intensities approximating their lactate threshold, the now robust observation (2, 7, 8, 22, 26–28) that successful endurance athletes spend comparatively little training time in zone 2 may seem surprising. Previously, one of us synthesized these observations by proposing that elite endurance athletes tend to self-organize their training in a polarized fashion, with most of their training performed clearly below or above the zone 2 intensity range but relatively little training in this middle zone (8, 27). One point of discussion that remains uncertain is how best to quantify training intensity distribution. In the present study, we have used the HR-based time in zone approach. This approach registers all HRs from the start to the finish of every training session without taking into account the nature of the training sessions performed. The strength of this approach is that every training minute is incorporated into the quantification. A weakness of this approach may be that the impact of high-intensity sessions, such as interval training on the distribution of daily stress load, is diluted by the considerable zone 1 and 2 HR contribution to even a very hard high-intensity interval session (warm-up, recovery between intervals, cool down). In response to this problem, another quantification approach that focuses more on the predominant intensity of each training session or session goal approach has also been described (27). When applied to the current study, we found that in the Z1 group 74% of all sessions were performed in zone 1, 11% were performed primarily in zone 2, and 15% of all sessions involved interval training or training races in zone 3. This distribution approximates the polarized intensity distribution observed previously (2, 27, 29) in highly trained athletes during a hard preparation period.

The current study adds significantly to these previous descriptive reports by subjecting the hypothesis that a focus on low-intensity volume is actually important in maximizing performance gains to an experimental trial. The tight control of total volume and training load in the present study allows us to conclude that the distribution of training load across intensity and not only total training load or average intensity of training is a critical factor in optimizing performance gains.

In the competition model chosen here (simulated 10-km cross-country race), the contribution of zone 3 (i.e., ≥90% of HRmax) is predominant (≥85% of total competition time). Despite this fact, low-intensity training accounts for the great majority of training time. In pilot studies with the same subjects, we originally aimed to assess the effects of increasing the contribution of zone 3 training, i.e., accounting for up to 15% of total time in zone (i.e., significant volumes of zone 3 training incorporated into ~25–30% of all training sessions). This training model was found to be too demanding for the subjects to be followed for more than 2 to 3 weeks. Afterwards, signs of overreaching/overtraining (altered sleeping patterns, insufficient recovery between daily workouts, increased muscle soreness or inability to reach zone 3, and target running pace during intense workouts) were evident in most of the runners. Similarly, the relative contribution of zone 3 during highly demanding endurance events, such as the Tour de France, does not surpass 10% of exercise time (20). On the other hand, although moderate-intensity training (~55–85% HRmax) for 20 to 60 minutes (at least 3 days·wk^{-1}) is usually recommended for improving and maintaining cardiorespiratory fitness in nonathletes (1), the upper part of this general intensity zone (i.e., zone 2, corresponding to ~70–90% HRmax in our subjects) seems too demanding for endurance athletes (i.e., with a mean weekly training time ≥6 hours). When a certain threshold is reached (>20% of total training time), this intensity zone does not seem to induce further beneficial adaptations as opposed to increasing time in zone 1.

Seiler and Kjerland (27) have proposed that there are 2 basic patterns of training intensity distribution emerging from the research literature. They called one of them the "threshold-training" model, in which a special emphasis is placed on training sessions at intensities around the maximal lactate steady state i.e., ~zone 2. This model has been shown to induce significant improvements in untrained subjects (5, 11, 14, 18). The other pattern proposed by Seiler and Kjerland is the so-called "polarized-training" model. This pattern emerges from a limited number of published observations in elite endurance athletes, including international class rowers (8, 28, 29), cross-country skiers (27), gold medal–winning time trial cyclists (26), and internationally elite marathoners (2). Although differing in sport discipline, all of these studies involved athletes training ≥10 to 12 hours per week. They suggest that high-performance athletes generally train either in zone 1 (accounting for ~75% of the total training volume) or above the RCT (~10% of HR based time in zone or perhaps 15% of training sessions) but surprisingly little time at threshold intensity (zone 2). For example, Billat and colleagues (2) reported that elite French and Portuguese marathoners (best times of 2:06–2:10) only performed 4% of their training kilometers at marathon pace, which is essentially identical with the first lactate threshold.

Thus, the threshold-training model (mainly focused in zone 2) seems more adequate for untrained or moderately fit populations, whereas in endurance athletes, spending too much training time in zone 2 (>20%) at the expense of zone 1 may impair competitive performance, perhaps through its impact on the autonomic nervous system. Our experimental data support the hypothesis that a polarized-training model may be optimal in competitive athletes, provided the contribution of zone 3 approximates 10% of total training time (or 15% of total training sessions i.e. 1 to 2 zone 3 sessions per week) during mid- to long-term training periods (>1 month).

Studies from both Australia (15) and South Africa (30) in high-level cyclists have demonstrated that training performance responds positively to short-term increases in the amount of high-intensity training performed. Common to both of these studies was the fact that at baseline the subjects were performing very little zone 2 or 3 and were presumably therefore quite responsive to a short-term increase in intensity loading. These same studies do not support a clear advantage of one type of intensified training over another, suggesting that the impact of intensified training may be quite general, mirroring earlier findings from Daniels et al. (4), who demonstrated a very general response to intensified training. The implication of these findings is that adaptations to high-intensity training occur quite rapidly and that the dose-response characteristics of high-intensity training may saturate at fairly low volumes of training. It seems reasonable to hypothesize that central circulatory performance might respond (and saturate) rapidly to increases in training intensity, whereas changes in skeletal muscle mitochondrial volume, capillary density, and other skeletal muscle adaptations may take weeks or months to saturate (24). Thus, from the perspective of adaptation induction, substantial volumes of low-intensity training coupled with small volumes of high-intensity training may provide an effective combination of stimuli for both peripheral and central adaptation. It is important to point out here that low-intensity exercise for the well-trained athlete is directly comparable to low-intensity exercise for the untrained to moderately active. Intensity is quantified relative to the maximal oxygen consumption, which is in turn limited by cardiovascular performance. Therefore, in well-trained athletes with typically high maximal oxygen consumption, a given relative intensity corresponds to a greater degree of muscle activation and oxidative flux in working muscle. We suspect that this difference is of importance in understanding the way training intensity self-organizes towards a polarized model in highly trained endurance athletes.

Training induces adaptation but also induces stress responses. Controlling the training intensity distribution may provide a mechanism for balancing these 2 effects. An alternative explanation for the comparatively small amount of moderate-to-high intensity (zones 2–3) training performed by serious athletes has to do with the likelihood of down-regulation of the sympathetic nervous system in response to a large volume of high-intensity exercise. There is evidence that the activity of the sympathetic nervous system is reduced after severe and prolonged training and competition in athletes, consistent with a hormonal exhaustion syndrome (19). Lehmann et al. (16) reported decreases in catecholamine secretion in overtrained athletes. Although beta receptor density and catecholamine sensitivity are generally higher in athletes than sedentary individuals (17), heavy training produces evidence of catecholamine depletion (16). This pattern may also be consistent with a reduced sensitivity to catecholamines, as demonstrated in chronic over-stimulation or exhaustive stress (3, 31). Because one consequence of a reduced sensitivity to catecholamines might be reductions in maximal cardiac output and the ability to selectively divert blood flow to the active musculature and because down-regulation of beta receptors would only be expected in the presence of chronic elevations of catecholamines, it is possible that there is an upper limit to the amount of high-intensity training that can be tolerated over any period. Evidence supporting this concept may be found in the fixed TRIMP values and minutes of zone 3 exercise in the relatively longer Tour de France cycling race and the relatively shorter Vuelta a España (10, 23). As previously mentioned, pilot research from our group with these same runners has shown very poor tolerance to a training program with a contribution of zone 3 exceeding 10% of total training time.

PRACTICAL APPLICATIONS

In summary, we observed that an intensification of training to include significantly more training at and around the lactate threshold was actually associated with relatively smaller performance gains over a 5-month training period compared with a group of athletes whose training organization was more focused on low-intensity zone 1 training volume coupled with moderate volumes (~10%) of zone 3 training.

Our results do not necessarily challenge the classic principle of training specificity, and it should be kept in mind that the present data provide no evidence that highly specific workouts (zone 3) simulating competition speed are not crucial to achieve top-level performance. Rather, our data suggest that an older coaching concept of "junk miles" applies not to relatively low-intensity training but to moderately high-intensity training. Large volumes of zone 2 or threshold training in already well-trained athletes may be inadequate to stimulate further cardiorespiratory adaptation but may contribute to fatigue, potentially via down-regulation of the sympathetic nervous system.

One of the main training questions for coaches and athletes involved in medium-to-long distance running events is whether it is better to train moderately faster for a shorter time or to train longer at light intensities. The main finding of this study is that if experienced runners accumulate more time at moderately high intensities (zone 2), they do not necessarily develop a faster racing pace. The present data suggest that if the runner can dedicate more time to daily training sessions, it seems better to design an "easy-hard" distribution of load (increasing the amount of low-intensity training) than a "moderately high–hard" training approach (large zone 2 contribution).

These findings add the first direct experimental support of several descriptive studies reporting a polarized training organization among elite endurance athletes. For the conditioning coach, a take-home message may be that sport training sessions should also attempt to avoid making every session the same intensity to avoid stagnation and staleness. Longer training sessions at more moderate intensity should be balanced against highly demanding training bouts, either on the field or in the weight room. Both intensity levels in proper combination seem to be important for long-term development, although the proper combination seems to include relatively more low-intensity, nonspecific training than might have been anticipated.

REFERENCES

1. AMERICAN COLLEGE OF SPORTS MEDICINE. Position stand on the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med. Sci. Sports Exerc.* 30:975–991. 1998.
2. BILLAT, V.L., A. DEMARLE, J. SLAWINSKI, M. PAIVA, AND J.P. KORALSZTEIN. Physical and training characteristics of top-class marathon runners. *Med. Sci. Sports Exerc.* 33:2089–2097. 2001.
3. BRODDE, O.E., A. DAUL, AND N. O'HARA. Beta adrenoreceptor changes in human lymphoctes induced by dynamic exercise. *Naunyn Schmiedebergs Arch. Pharmacol.* 325:190–192. 1984.
4. DANIELS, J.T., R.A. YARBOUGH, AND C. FOSTER. Changes in VO_{2max} and running performance with training. *Eur. J. Appl. Physiol.* 39:249–254. 1978.
5. DENIS, C., D. DORMOIS, AND J.R. LACOUR. Endurance training, VO2max, and OBLA: A longitudinal study of two different age groups. *Int. J. Sports Med.* 5:167–173. 1984.
6. DOHERTY, M., L. NOBBS, AND T.D. NOAKES. Low frequency of the "plateau phenomenon" during maximal exercise in elite British athletes. *Eur. J. Appl. Physiol.* 89:619–623. 2003.
7. ESTEVE-LANAO, J., A.F. SAN JUAN, C.P. EARNEST, C. FOSTER, AND A. LUCIA. How do endurance runners actually train? Relationship with competition performance. *Med. Sci. Sports Exerc.* 37:496–504. 2005.
8. FISKESTRAND, A., AND K.S. SEILER. Training and performance characteristics among Norwegian international elite rowers 1970–2001. *Scand. J. Med. Sci. Sports* 14:303–310. 2004.
9. FOSTER, C., J.A. FLORHAUG, J. FRANKLIN, L. GOTTSCHALL, L.A. HROVATIN, S. PARKER, P. DOLESHAL, AND C. DODGE. A new approach to monitoring exercise training. *J. Strength Cond. Res.* 15:109–115. 2001.
10. FOSTER, C., J. HOYOS, C.P. EARNEST, AND A. LUCIA. Regulation of energy expenditure during prolonged athletic competition. *Med. Sci. Sports Exerc.* 37:670–675. 2005.
11. GASKILL, S.E., A.J. WALKER, R.A. SERFASS, C. BOUCHARD, J. GAGNON, D.C. RAO, J.S. SKINNER, J.H. WILMORE, AND A.S. LEON. Changes in ventilatory threshold with exercise training in a sedentary population: The HERITAGE Family Study. *Int. J. Sports Med.* 22:586–592. 2001.
12. GILMAN, M.B. The use of heart rate to monitor the intensity of endurance training. *Sports Med.* 21:73–79. 1996.
13. JUNG, A.P. The impact of resistance training on distance running performance. *Sports Med.* 33:539–552. 2003.
14. KINDERMANN, W., G. SIMON, AND J. KEUL. The significance of the aerobic-anaerobic transition for the determination of work load intensities during endurance training. *Eur. J. Appl. Physiol. Occup. Physiol.* 42:25–34. 1979.
15. LAURSEN, P.B., C.M. SHING, J.M. PEAKE, J.S. COOMBES, AND D.G. JENKINS. Interval training program optimization in highly trained endurance cyclists. *Med. Sci. Sports Exerc.* 34:1801–1897. 2002.
16. LEHMANN, M., P. BAUMGARTL, C. WIESANACK, A. SEIDEL, H. BAUMANN, S. FISCHER, U. SPORI, G. GENDRISCH, R. KAMINSKI, AND J. KEUL. Training-overtraining: Influence of a defined increase in training volume vs training intensity on performance, catecholamines and some metabolic parameters in experienced middle and long-distance runners. *Eur. J. Appl. Physiol.* 64:169–177. 1992.
17. LEHMANN, M., H.H. DICKHUTH, P. SCHMID, H. PORZIG, AND J. KEUL. Plasma catecholamines, beta adrenergic receptors, and isoproterenol sensitivity in endurance trained and non-endurance trained volunteers. *Eur. J. Appl. Physiol.* 52:362–369. 1984.
18. LONDEREE, B.R. Effect of training on lactate/ventilatory thresholds: A meta-analysis. *Med. Sci. Sports Exerc.* 29:837–843. 1997.
19. LUCIA, A., B. DIAZ, J. HOYOS, C. FERNANDEZ, G. VILLA, F. BANDRES, AND J.L. CHICHARRO. Hormone levels of world class cyclists during the Tour of Spain stage race. *Br. J. Sports Med.* 35:424–430. 2001.
20. LUCIA, A., J. HOYOS, A. CARVAJAL, AND J.L. CHICHARRO. Heart rate response to professional road cycling: The Tour de France. *Int. J. Sports Med.* 20:167–172. 1999.
21. LUCIA, A., J. HOYOS, J. PARDO, AND J.L. CHICHARRO. Metabolic and neuromuscular adaptations to endurance training in professional cyclists: A longitudinal study. *Jpn. J. Physiol.* 50:381–388. 2000.
22. LUCIA, A., J. HOYOS, M. PEREZ, AND J.L. CHICHARRO. Heart rate and performance parameters in elite cyclists: A longitudinal study. *Med. Sci. Sports Exerc.* 32:1777–1782. 2000.
23. LUCIA, A., J. HOYOS, A. SANTALLA, C. EARNEST, AND J.L. CHICHARRO. Tour de France vs Vuelta a España: Which is harder? *Med. Sci. Sports Exerc.* 35:872–878. 2003.
24. SALTIN, B., AND P.D. GOLLNICK. Skeletal muscle adaptability: Significance for metabolism and performance. In: *Handbook of Physiology*. L.D. Peachy, ed. Baltimore: Williams and Wilkins, 1983. pp. 555–631.
25. SAUNDERS, P.U., D.B. PYNE, R.D. TELFORD, AND J.A. HAWLEY. Factors affecting running economy in trained distance runners. *Sports Med.* 34: 465–485. 2004.
26. SCHUMACKER, Y.O., AND P. MUELLER. The 4000-m team pursuit cycling world record: Theoretical and practical aspects. *Med. Sci. Sports Exerc.* 34:1029–1036. 2002.
27. SEILER, K.S., AND G.O. KJERLAND. Quantifying training intensity distribution in elite endurance athletes: Is there evidence for an 'optimal' distribution? *Scand. J. Med. Sci. Sports* 16:49–56. 2006.
28. STEINACKER, J.M. Physiological aspects of training in rowing. *Int. J. Sports Med.* 14Suppl 1:S3–S10. 19993.
29. STEINACKER, J.M., W. LORMES, M. LEHMANN, AND D. ALTENBURG. Training of rowers before world championships. *Med Sci Sports Exerc.* 30: 1158–1163. 1998.
30. STEPTO, N.K., J.A. HAWLEY, S. C. DENNIS, AND W.G. HOPKINS. Effects of different interval training programs on cycling time-trial performance. *Med. Sci. Sports Exerc.* 31:736–741. 1998.
31. TOHMEH, J.F., AND P.E. CRYER. Biphasic adrenergic modulation of beta receptors in man. *J. Clin. Invest.* 65:836–849. 1980.

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