How Do Endurance Runners Actually Train? Relationship with Competition Performance

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ABSTRACT

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.*, Vol. 37, No. 3, pp. 496–504, 2005. **Purpose:** To quantify the relationship between total training load and running performance during the most important competitions of the season (national cross-country championships, 4.175- and 10.130-km races). **Methods**: Eight well-trained, subelite endurance runners (age (mean ± SD): 23 ± 2 yr; $\dot{V}O_{2max}$: 70.0 ± 7.3 $mL \cdot kg^{-1} \cdot min^{-1}$) performed a maximal cardiorespiratory exercise test before the training period to determine ventilatory threshold (VT) and respiratory compensation threshold (RCT). Heart rate was continuously recorded using telemetry during each training session over a 6-month macrocycle, designed to achieve peak performance during the aforementioned cross-country races, lasting from late August to the time that these races were held, that is, mid-February. This allowed us to quantify the total cumulative time spent in three intensity zones calculated as zone 1 (low intensity, lower than the VT); zone 2 (moderate intensity, between VT and RCT); and zone 3 (high intensity, above the RCT). **Results**: Total training time in zone 1 (4581 ± 979 min) was significantly higher ($P < 0.001$) than that accumulated in zones 2 (1354 ± 583 min) and 3 (487 ± 154 min). Total time in zone 2 was significantly higher than time in zone 3 ($P < 0.05$). A correlation coefficient of $r = -0.79$ ($P = 0.06$) and $r = -0.97$ ($P = 0.008$) was found between the total training time spent in zone 1 and performance time during the short and long cross-country races, respectively. **Conclusions**: Our findings suggest that total training time spent at low intensities might be associated with improved performance during highly intense endurance events, especially if the event duration is ~35 min. Interventional studies (i.e., improving or reducing training time in zone 1) are needed to corroborate our findings and to elucidate the physiological mechanisms behind them.

Key Words: TRAINING, HEART RATE, VENTILATORY THRESHOLD, RESPIRATORY COMPENSATION THRESHOLD, TRAINING IMPULSE

Although extensive research has been conducted on the scientific basis (physiological, biomechanical, or genetic factors) underlying performance during endurance sports, surprisingly little research has focused on answering two of the basic questions in the field: What is the actual physiological load undertaken by competitive endurance athletes during training sessions, and how does this training load relate to competition performance?

In the past two decades, the use of portable heart rate (HR) telemeters has allowed scientists to estimate the exercise intensity of training sessions and competitions, based on the linear relationship that exists between HR and metabolic exercise intensity during dynamic exercise involving large muscle groups (e.g., running, cycling, swimming) (15). A method that can be used for examining physical exertion under competitive exercise conditions is obtained by partitioning intensity into different phases (or zones) according to reference HR values obtained during cardiorespiratory exercise testing. These include zone 1 (light intensity, below the ventilatory threshold (VT)), zone 2 (moderate intensity, between the VT and the respiratory compensation threshold (RCT)), and zone 3 (high intensity, above the RCT) (22,25). Although this simple and practical approach has been used to quantify exercise intensity during professional cycling races such as the Tour de France (22,25), only one report to date has examined the actual intensity of training sessions in competitive endurance athletes (34). This report has suggested that a high percentage of the training performed by elite athletes is at a comparatively low intensity (e.g., zone 1).

Another issue of widespread interest for athletes and coaches is the need for quantifying training and competition load by taking into account both exercise volume and in-

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Submitted for publication June 2004.
Accepted for publication November 2004.

0195-9131/05/3703-0496
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/01.MSS.0000155393.78744.86

tensity. Banister et al. (1,2) originally developed the concept of the training impulse (TRIMP) to integrate both intensity and volume into a single term. The original TRIMP algorithm is calculated by integrating total exercise time and each of basal, maximal, and mean exercise values of HR, respectively (2). Despite its advantages, the original TRIMP method does not take into account the aforementioned intensity zones based on reference HR values compared with various physiological thresholds, which denote changing physiological responses. To classify exercise intensity in a simple, practical manner, Foster et al. (13) recently proposed a novel approach to the original TRIMP concept by integrating total exercise volume, on the one hand, and total intensity relative to the aforementioned intensity zones, on the other.

The purpose of the current study was twofold: 1) to quantify variables indicative of total physiological load (time spent in each HR zone, TRIMP) during each training session over a long period of the season (i.e., several months) in a group of well-trained, competitive endurance runners; and 2) to determine the relationship between training load and performance during the most important competitions of the season (4.175- and 10.130-km cross-country races). For descriptive purposes only, subjects' HR were also recorded during the aforementioned competitions.

MATERIALS AND METHODS

Approach to the problem and experimental design. Several reports exist using the models of Banister et al. or Foster et al. for quantifying training or competition load in elite endurance athletes (25,28). To the best of our knowledge, no study has analyzed the possible relationship between actual training load and competition performance using either model. Foster et al. (10) demonstrated a quantitative relationship between total training load and performance changes in subelite and elite speed skaters. However, the technique of Foster et al. (13) is based on RPE, which is a relatively crude and subjective method to quantify training load. We propose that a more objective approach to the problem is to quantify relative work intensity based on laboratory-derived parameters associated with maximal exercise testing. Therefore, we have modified the schema of Foster et al. to reflect HR-defined zones associated with two simple reproducible values reflecting the VT and the RCT. Subsequently, we categorized our TRIMP model based on HR falling into one of three of the following categories: zone 1 (light intensity, below the VT), zone 2 (moderate intensity, between the VT and the RCT), and zone 3 (high intensity, above the RCT) (22,25).

Subjects. Eight competitive (national and regional (Madrid area) level, competition experience ≥5 yr) Spanish runners participated in the study. The mean (±SD) age, mass, and height were 23 ± 2 yr, 64.6 ± 3.3 kg, and 172.9 ± 4.7 cm, respectively. Their best performance in 1500- and 5000-m track races averaged 85.8 and 82.1%, respectively, of the world record. All of them were born, live, and train in the area around Madrid, Spain (~600-m altitude). The institutional research ethics committee approved the study, and the subjects provided informed consent before participation.

Main characteristics of training periodization and competition goals. We quantified the total physiological load of each training session (outlined below) from the start to the end of a 6-month period (24-wk macrocycle, lasting from late August to the time the national (Spanish) championships of cross-country races were held, in mid-February). This 6-month interval was composed of eight 3-wk mesocycles, each of which had a 2:1 load structure (i.e., 2 wk of high load followed by an "easy" week), and was divided in three main periods: preparatory (first four mesocycles (weeks 1–12)), specific (next two mesocycles (weeks 13–18)), and competitive (last two mesocycles (weeks 19–24)). The preparatory period was used for basic or foundation training (including mostly low- to moderate-intensity running and strength-training sessions). In the specific period, strength-training sessions were performed specifically during actual running (see below), and running intensity was progressively increased. The purpose of the competition period was to convert basic fitness built during the previous months to competition performance. Running volume ($km \cdot wk^{-1}$) increased through the preparatory period (to reach a maximum of 90–100 $km \cdot wk^{-1}$ in week 11), decreased during the specific period but increased again in weeks 18 and 19 (90 $km \cdot wk^{-1}$), and finally decreased during the competition period (mean of 40–50 $km \cdot wk^{-1}$). Overall, running intensity followed the opposite pattern. During the preparatory period, special emphasis was placed on zone 1 training and on workouts at RCT of gradually increasing duration (to complete a continuous 30-min bout at RCT by the end of the period). The specific period was focused on short (~1 min) interval workouts at $\dot{V}O_{2max}$, whereas in the competitive period, longer interval sessions (few bouts of several minutes each) were performed mostly in zone 3. Although considerable variations existed depending on the aforementioned periods of the macrocycle and the hard or easy weeks of each mesocycle, the runners' usual training schema for the 6-month period included 1–3 training sessions per week of low intensity (zone 1), 1–3 sessions per week of low to moderate intensity (zone 1 and zones 1–2), 1–2 sessions per week with a core part in zone 2, and 2 hard sessions per week including interval workouts at high intensities (zones 2–3 and zone 3). Training usually included 1–2 strength-training sessions per week, consisting of weight lifting and circuit weight training during the preparatory period, and specific strength sessions during the specific period (i.e., short running intervals on steep hills or muddy terrain or using weight vests). In the competition period, subjects performed one easy session per week of weight lifting.

At the end of the preparatory period and during the specific period and during the competition period, the runners participated in six and two cross-country races (distances ranging between 5 and 10 km), respectively (excluding the two target competitions that are described below). HR was continuously monitored during these preparatory races and included in the quantification of training loads (i.e., total training time in the three intensity zones, total training volume, and TRIMP score) (see section on quantification of exercise load in training and competition). Although these competitions were not the target ones, since the subjects had not yet reached their peak performance level, these races were used as an important part of their training schedule and runners were required to perform as well as possible. A schematic representation of the training load on a week-by-week basis over the period of the study is presented in Figure 1.

The 6-month macrocycle was aimed at achieving peak competition performance during the national (Spanish) championships of cross-country races (short distance (4.175 km) or long distance (10.130 km)) held in mid-February, at the end of the 6-month period (with 5 d of rest between races). Both races were held over a hilly terrain (i.e., ~1 and ~2.5 km with ~8% upgrade for the short- and long-distance races, respectively).

Laboratory testing. The subjects reported to the laboratory (~600-m altitude) at the start of the 6-month 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 $km \cdot h^{-1}$, running velocity was increased by 0.5 $km \cdot h^{-1}$ every 30 s 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 ($\dot{V}E$), ventilatory equivalents for oxygen ($\dot{V}E \cdot \dot{V}O_2^{-1}$) and carbon dioxide ($\dot{V}E \cdot CO_2^{-1}$), and end-tidal partial pressure of oxygen ($P_{ET}O_2$) and carbon dioxide ($P_{ET}CO_2$).

Maximal oxygen uptake ($\dot{V}O_{2max}$) was recorded as the highest $\dot{V}O_2$ value obtained for any continuous 1-min period during the tests. At least two of the following criteria were also required for the attainment of $\dot{V}O_{2max}$: a plateau in $\dot{V}O_2$ values despite increasing velocity, a respiratory exchange ratio ≥1.15, or the attainment of a maximal HR value (HR_{max}) above 95% of the age-predicted maximum. The VT was determined using the criteria of an increase in both $\dot{V}E \cdot \dot{V}O_2^{-1}$ and $P_{ET}O_2$ with no increase in $\dot{V}E \cdot VCO_2^{-1}$, whereas the RCT was determined using the criteria of an increase in both $\dot{V}E \cdot \dot{V}O_2^{-1}$ and $\dot{V}E \cdot VCO_2^{-1}$ and a decrease in $P_{ET}CO_2$ (24). Two independent observers detected VT and RCT. If there was disagreement, the opinion of a third investigator was obtained (24). HR ($beats \cdot min^{-1}$) was continuously monitored during the tests using a telemeter (Xtrainer Plus; Polar Electro OY, Kempele, Finland).

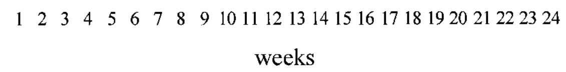

FIGURE 1—Schematic representation of the average training impulse (TRIMP) of all the subjects ($N = 8$) on a week-by-week basis over the 6-month period of the study (24-wk macrocycle, lasting from late August to the time that the national (Spanish) championships of cross-country races were held (i.e., mid-February)). See text for explanation of TRIMP.

Quantification of exercise load in training. For all the subjects, HR was continuously measured (every 5 s) during each training session (with no missing data) and preparatory competitions (as mentioned above) over the 6-month macrocycle to quantify the following variables: 1) total time spent in each of the three intensity zones (zone 1: HR below the HR at VT; zone 2: HR between the HR at VT and the HR at RCT; zone 3: HR above the HR at RCT); and 2) total load (TRIMP score) as explained below. (A total of ~1000 training sessions were analyzed.) As mentioned above, in six and five runners of the total of eight subjects who participated in this study, we also recorded performance time and HR during the target short and long cross-country races, respectively, which were held at the end of the 6-month period. (Three subjects participated in both races). Previous research on trained endurance athletes has shown that HR values at VT and RCT determined during previous laboratory testing remain stable over the season despite significant improvements in the workload eliciting both thresholds (24). Thus, a single test early during the training period might suffice for training monitoring based solely on target HR values at VT and RCT (24).

We estimated total exercise load (i.e., intensity × volume) accumulated in each training session using a novel approach to the TRIMP based on a method recently developed by Foster et al. (13). This method, which has been recently reported to estimate total exercise load in 3-wk professional cycling races (25), uses HR data during exercise to integrate both total volume, on the one hand, and total intensity relative to three intensity zones, on the other. Briefly, the score for each zone is computed by multiplying the accumulated duration in this zone by a multiplier for this particular zone (e.g., 1 min in zone 1 is given a score of 1 TRIMP, 1 min in zone 2 is given a score of 2 TRIMP, and 1 min in zone 3 is given a score of 3 TRIMP). The total TRIMP score is then obtained by adding the results of the three zones.

Performance tests during the training period. To assess improvements in subjects' endurance fitness during the 6-month macrocycle, the runners performed the following test on a flat grass running loop at weeks 7 and 20, respectively. (The distance of the loop was calculated using a measuring wheel (Trumeter Measure Meter, Manchester, UK) (measurement error < 0.5 m per each 100-m interval). The test consisted of three running bouts of 15 min, each performed on a different day, during which subjects were instructed to maintain the running speed eliciting a HR value of 5 $beats \cdot min^{-1}$ below the HR at VT (running speed in zone 1), equidistant between the HR at VT and RCT (running speed in zone 2), and 1 beat·min^{-1} above the HR at RCT (running speed in zone 3). This allowed us to determine whether the mean running speed in the three intensity zones improved over the training period. In weeks 7, 20, and 24, the subjects performed a 20-m speed test and a 300-m test to determine their ability to generate maximal running velocities and both maximal vertical squat jump (SJ), from a starting position of 90° for the knee angle, and countermovement jump (CMJ) tests to assess the dynamic explosive force characteristics of their leg muscles. In each testing battery, the subjects performed the 20-m speed test twice, and the better trial was taken for analysis, whereas they performed the 300-m test only once. Both tests were performed on a 400-m running track. The 20-m running times were measured by two photocell gates (Telemechanique, France) connected to an electronic timer, and the 300-m performance time was measured with a digital timer (Oregon Scientific SL928M, Portland, OR). The jump tests were performed on a force platform (Bosco System Devices, Ano Glyfada, Greece), and subjects' hands were kept on the hips during each jump. The rise of the center of gravity (cm) was calculated from the flight time. Two maximal jumps were recorded for both SJ and CMJ, and the maximum in terms of height was taken. In all tests, external verbal encouragement was given to each subject.

Statistical analysis. The Kolmogorov–Smirnov test was applied to ensure a Gaussian distribution of the data. We report mean (±SD, 95% confidence intervals (95%CI) and coefficient of variation (CV)) data for total time spent in each of the three intensity zones and total TRIMP score, respectively, accumulated over the total 6-month period. Repeated-measures ANOVA was also used to compare the total time spent in each of the three zones over the 6-month training period and the results of the performance tests (300-m test, 20-m speed test, SJ, and CMJ) held in weeks 7, 20, and 24. The Tukey test was used as a *post hoc* test. The results of the fitness running tests in zones 1, 2, and 3, held in weeks 7 and 20, were compared with a Wilcoxon's test. Pearson product–moment correlation coefficients (and the corresponding SEE and 95%CI) were calculated to determine whether there was a significant relationship between total training time, total time, and total training distance (km) in each of the three intensity zones over the 6-month macrocycle, on one hand, and performance time in short- and long-distance cross-country races (i.e., total time to complete each race). Independent variables were the variables indicative of training loads, whereas performance time was the dependent variable. We also calculated the relationship between accumulated TRIMP score from the start to the end of the 6-month period and competition performance time, with a Spearman's rho test. The level of significance was set at $P \leq 0.05$ for all statistical analyses.

RESULTS

Laboratory tests. The average $\dot{V}O_{2max}$ of the subjects was 70.0 ± 7.3 mL·kg^{-1}·min^{-1} (95%CI: 62.8–75.1; CV: 10.4%). The VT and the RCT occurred at 61.1 ± 4.2% (95%CI: 55.2–69.1; CV: 6.9%) and 85.1 ± 4.2% (95%CI: 81.6–88.7; CV: 4.9%) of $\dot{V}O_{2max}$, respectively. HR at VT and RCT averaged 140 ± 15 beats·min^{-1} (95%CI: 126–154; CV: 10.7%) and 171 ± 9 beats·min^{-1} (95%CI: 163–179; CV: 5.3%), respectively, or ~71 and ~87% of HR$_{max}$ (197 ± 4 beats·min^{-1}; 95%CI: 183–200; CV: 2.0%) obtained during the tests.

Quantification of training load. None of the subjects were injured or sick during the training period and showed no signs of chronic fatigue/overtraining (e.g., decreased maximal HR or chronic muscle soreness). All the subjects were able to complete the majority of the training sessions over the 6-month program as originally planned. The cumulative total duration of training sessions over the 6-month period in which we recorded HR data amounted to ~110 h, during which athletes completed a total of ~1600 km (i.e., ~70 km·wk^{-1}). Mean total and percent total time spent in each of the three intensity zones over the 6-month period are shown in Figure 2. Significant differences were found between total time in zone 1 and total time in both zones 2 ($P < 0.001$; statistical power: 0.98) and 3 ($P < 0.001$; statistical power: 0.99) and between total time in zone 2 and total time in zone 3 ($P < 0.05$; statistical power: 0.79).

Total TRIMP score accumulated over the 6-month period averaged 8750 ± 1398 TRIMP (95%CI: 7581–9919; CV: 16.0%) (i.e., ~365 TRIMP·wk^{-1}).

Performance tests. The running speed in zones 2 and 3 significantly improved in week 20 compared with week 7 ($P < 0.05$) (Table 1), which indicated an increase in endurance fitness over the training period. No changes were found in the other tests (20-m speed test, 300-m test, SJ, and CMJ), except for a lower performance in the SJ test in week 24 compared with the start of the training period.

Quantification of performance during competition. Performance time averaged 788 ± 33 s (95%CI: 755–823; CV: 4.2%) (mean running pace of 3 min 10 s·km^{-1})

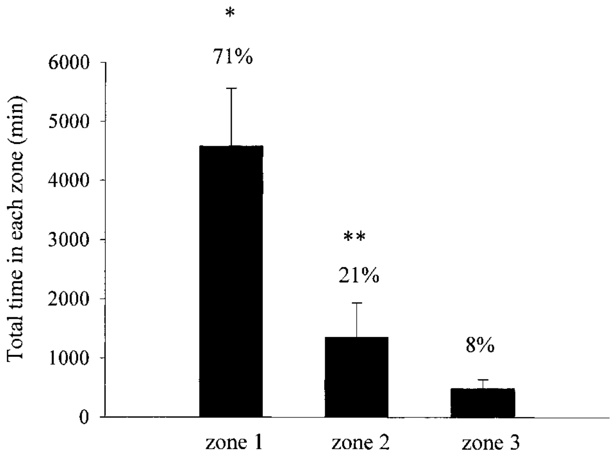

FIGURE 2—Mean ± SD values of total time spent in each intensity zone by all the subjects ($N = 8$) over the 6-month period of the study based on heart rate (HR) data. Percentage time spent in each zone is also showed on top of bars. Zone 1 (low intensity): HR below HR value eliciting the ventilatory threshold (VT); zone 2 (moderate intensity): HR between HR value eliciting the VT and the respiratory compensation threshold (RCT), respectively; zone 3 (high intensity): HR above HR value eliciting the RCT. *$P < 0.001$ for zone 1 vs both zones 2 and 3; **$P < 0.05$ for zone 2 vs zone 3. 95%CI and CV for zones 1, 2, and 3 are 3763–5399 min, 21.4%; 866–1841 min, 43.1%; and 359–616 min, 31.6%, respectively.

TABLE 1. Results of the performance tests.

	Week 7	Week 20	Week 24
Running speed in zone 1 ($km \cdot h^{-1}$)	14.0 ± 0.4	14.3 ± 0.6	—
Running speed in zone 2 ($km \cdot h^{-1}$)	15.3 ± 0.9	16.3 ± 0.8*	—
Running speed in zone 3 ($km \cdot h^{-1}$)	16.7 ± 1.2	18.4 ± 0.5*	—
300-m test (s)	42.8 ± 2.2	42.9 ± 1.8	43.1 ± 2.3
20-m speed test (s)	2.47 ± 0.09	2.51 ± 0.08	2.47 ± 0.07
SJ (cm)	32.5 ± 5.1	33.2 ± 4.4	30.8 ± 5.2†
CMJ (cm)	33.4 ± 7.0	34.0 ± 4.4	33.0 ± 6.3

Data are shown as mean ± SD. Running speed in zone 1 (running speed eliciting a heart rate (HR) value 5 $beats \cdot min^{-1}$ below the HR at the ventilatory threshold (VT)); running speed in zone 2 (running speed eliciting a HR value equidistant to the HR at VT and respiratory compensation threshold (RCT)); running speed in zone 3 (running speed eliciting a HR value 1 $beat \cdot min^{-1}$ above the HR at RCT); SJ, squat jump; CMJ, countermovement jump.
* $P < 0.05$ for week 7 vs week 20.
† $P < 0.05$ for week 7 vs week 24.

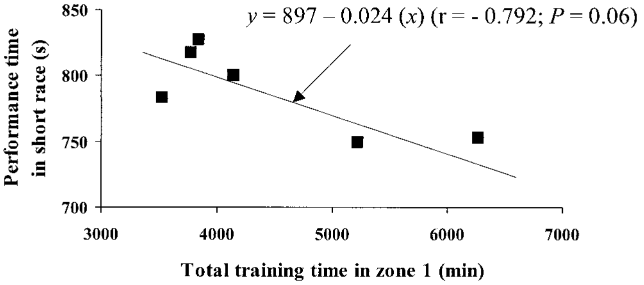

FIGURE 4—Relationship between total time accumulated in zone 1 (low intensity) during training sessions and performance time during the short (4.175 km) cross-country race. See Figure 2 for quantification of zone 1. Both training and competition data are only from the six subjects who participated in the short race (three of them also participated in the long race).

during the short-distance (4.175 km) cross-country race and 2114 ± 78 s (95%CI: 2017–2212; CV: 3.7%) (mean running pace of 3 min 32 $s \cdot km^{-1}$) during the long-distance (10.130 km) cross-country race. Runners started both races at 140–150 $beats \cdot min^{-1}$ (~75% HR_{max}) due to both competition stress and previous active warm-up, and usually reached zone 3 in less than 1–2 min (see Fig. 3 for an example). Mean HR during the short- and long-distance race averaged 95 ± 2% (95%CI: 92–97; CV: 2.1%) and 92 ± 2% (95%CI: 89–94; CV: 2.2%) of the subjects' HR_{max}, respectively.

Relationship between training load and competition performance. We observed a negative correlation coefficient of $r = -0.79$ ($P = 0.06$; SEE: 22 s; 95%CI: −0.98 to 0.06) for the relationship between the total training time spent in zone 1 and performance time during the short-distance cross-country race (Fig. 4). A significant correlation of $r = -0.79$ was also found for the total training distance (km) covered in zone 1 during training and performance time during the same event ($P = 0.06$; SEE: 22 s; 95%CI: −0.98 to 0.06).

We observed a significant negative correlation between total training time ($r = -0.97$; $P = 0.008$; SEE: 23 s; 95%CI: −1.00 to −0.56) and total training distance (km) covered in zone 1 ($r = -0.97$; $P = 0.006$; SEE: 22 s; 95%CI: −1.00 to −0.56) and performance time during the long-distance cross-country race (Fig. 5). No other significant correlations were found.

DISCUSSION

The main findings of our study were twofold. First, these regional/national class endurance runners spent the majority (71%) of their training time at low intensities (zone 1 (i.e., below ~60% $\dot{V}O_{2max}$ or ~70% HR_{max})). The proportion of moderate (60–85% $\dot{V}O_{2max}$) and high-intensity training (>85% $\dot{V}O_{2max}$) was significantly lower (i.e., 21 and 8%, respectively). On the other hand, there was a relationship between cumulative training time at low intensities (zone 1) and endurance performance during events, which are completed at very high intensities (i.e., 30 min of continuous exercise in zone 3 or >85% $\dot{V}O_{2max}$). Performance during such events does not seem to be associated with total training time spent at medium or high intensities (zones 2 and 3, respectively).

Our descriptive study is not without methodological limitations. The novelty of our study, especially the fact that we

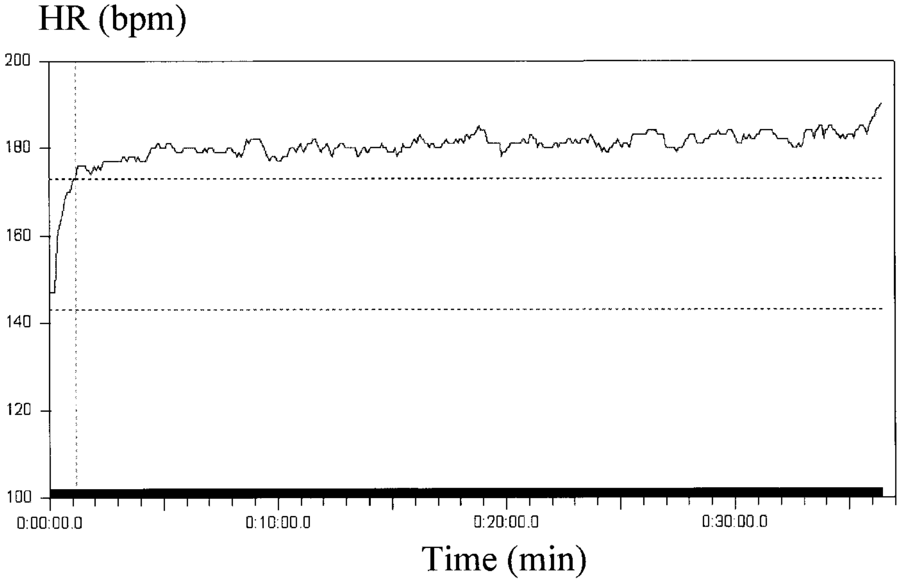

FIGURE 3—Example of the heart rate (HR) response in one study subject during the long (10.130 km) cross-country race. This figure was obtained from the HR telemeter software been used (Xtrainer Plus; Polar Electro OY, Kempele, Finland). Horizontal dashed lines represent HR limits between zones 1 and 2 and 2 and 3, respectively, and the vertical dashed line represents the time point at which the subjects reached zone 3.

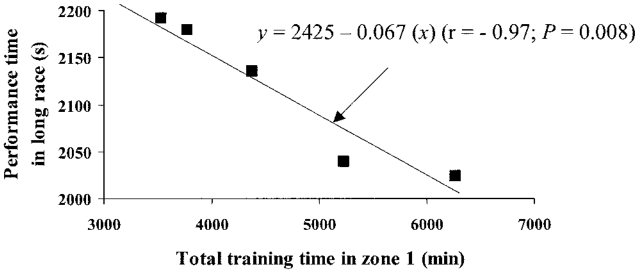

FIGURE 5—Relationship between total time accumulated in zone 1 (low intensity) during training sessions and performance time during the long (10.130 km) cross-country race. See Figure 2 for quantification of zone 1. Both training and competition data are only from the five subjects who participated in the long race (three of them also participated in the short race).

collected actual HR data to quantify training loads during a whole season, would overcome, at least partly, the limitations described. First, caution is indeed needed when interpreting our correlation results, as a cause-and-effect relationship cannot be inferred from this statistical approach. Further, interventional studies are needed to corroborate our findings and to prove the existence of an actual cause-and-effect relationship between total training time spent in zone 1 and performance during endurance running events (i.e., increasing or decreasing the total time spent in the three intensity zones in different groups of athletes with similar training background and competitive level). On the other hand, estimation of exercise intensity with HR data is not without limitations itself. The major criticism would be the phenomenon of cardiac drift (i.e., the slow rise in HR that occurs during moderate to high constant workloads, when exercise duration is prolonged for >20 min (15)). The cardiac drift is especially evident if environmental heat stress is high. In this regard, the current study was conducted during fall and winter months, and temperatures were not high in any of the training sessions over the study period (i.e., consistently <15°C). Nonetheless, an upward HR drift inevitably indicates additional stress to the body, whether this stress is due to dehydration or mild heat stress (15). In addition, cardiac drift would bias HR recordings toward a higher percentage of time in zones 2 and 3, which is opposite from the findings of this study. Finally, despite the limitations of HR records, no other means of continuously and nonintrusively examining the exercise intensity in athletes during both running training and competition are currently available.

In our study, HR was measured during specific races for descriptive purposes only (i.e., to corroborate that the subjects were performing at sufficient intensity in both events). This is an important consideration for a research design such as ours, which seeks to examine the relationship between training loads and actual competition performance. However, a potential methodological drawback still comes from the fact that we did not record HR data during the minutes before both races, when anticipatory increases in HR before competition could inflate the response of this variable during competition, especially during its first minutes and thus might potentially result in an overestimation of actual exercise race intensity (27). Our runners started both target races with high HR values (i.e., 140–150 beats·min^{-1} or ~75% HR$_{\max}$ (Fig. 3). These increased values are attributable, at least partly, to previous active warm-up, a common practice before all competition events that accelerates $\dot{V}O_2$ and HR kinetics at the onset of exercise (5). They might be also explained by the mental stress of competition, as it is known that sympathetic activity is usually enhanced in response to emotional stress (26).

Nevertheless, previous research with simulated laboratory competitions (i.e., without the mental stress of real competitive situations) has shown that the HR of trained endurance athletes increases quickly from the start of exercise (e.g., from 93 to 175 beats·min^{-1} (or 95% HR$_{\max}$)) in less than 90 s (14). Moreover, a fast time response of HR during the first minutes of a highly demanding exercise bout is to be expected in athletes, as this is a typical adaptation to endurance training (29), and the cardiac pump must match the increase in blood flow that occurs in endurance-adapted working muscles at the onset (first 1–2 min) of exercise (16). On the other hand, the high mean HR values that we found during specified competitions (means of 95 and 92% of HR$_{\max}$ for the short- and long-distance race, respectively, or zone 3 during most competition duration) are in agreement with previous research on simulated, noncompetitive trials lasting from a few minutes to ~1 h (3,35,37,40). To sustain race pace during these types of efforts, trained endurance athletes must maintain very high HR values (≥90% HR$_{\max}$), similar to those reported in our target competitions. Finally, a recent study by Iellamo et al. (17) with elite athletes has shown that, although the stress of competition activates central structures, leading to the stimulation of some hormonal systems as the hypothalamic–pituitary–suprarenal axis, this enhanced response is dissociated with autonomic cardiac regulation, which seems to remain unchanged. As a result, HR response would not differ much between simulated or actual competitions, at least in well-trained athletes like our subjects. In any case, future research in the field should include prerace HR data to account for any potential influence of stress-related anticipatory HR response. Regardless of these observations, this phenomenon does not affect our study findings in that our study demonstrates a strong relationship between zone 1/baseline training and race time.

Although several excellent reports are available in the literature on the training characteristics of elite endurance runners, particularly African athletes (4,7,33), to the best of our knowledge, despite the simplicity of HR data collection, there is only one other study that has described the training load for a group of competitive athletes by using three intensity zones that are delimited by target HR values (34). Our results are in substantial agreement with those of the study on elite Norwegian junior skiers (over the duration of a month) in which 91% of all training was completed in zone 1. Although Robinson et al. (31) reported the HR data of each training session over a 6- to 8-wk period in endurance runners with a competitive/training level similar to that of our subjects, training intensity was not partitioned into different zones. Instead, HR data were averaged, and mean training intensity was estimated as a percentage of the $\dot{V}O_{2max}$ obtained in a previous laboratory test. The results showed a mean training intensity of 64% $\dot{V}O_{2max}$. To date, most studies have described training characteristics using running speed data reported in daily training logs or questionnaires instead of quantifying actual HR data. We believe that these techniques introduce several complications. First, reporting exercise intensity in terms of running speed could potentially underestimate exercise intensity due to the so-called slow component, that is, the gradual increase in $\dot{V}O_2$ occurring after the third minute of exercise bouts performed above the VT, despite power output or running speed remaining constant (41). In addition, the validity of training logs or questionnaires for estimating actual training intensity has not been clearly documented.

Several reports are available regarding the training intensity of endurance athletes using training logs or questionnaires. With some exceptions (mostly African runners), the current findings and those of previous research seem to indicate that low-intensity training accounts for the majority of training time in endurance athletes. Coetzer et al. (7) estimated the training intensity of black and white South African male runners with a higher competition level than that of our subjects (i.e., best 10-km time <30 min). The training volume of white runners was slightly higher than that of our subjects (~80 km·wk^{-1} vs 70 km·wk^{-1}, respectively) and the training intensity (estimated by interview) was comparable (i.e., nearly 85% of total training performed at intensities <80% $\dot{V}O_{2max}$). Black runners, however, spent nearly 36% of their total training (90 km·wk^{-1}) at intensities >80% of $\dot{V}O_{2max}$. Billat et al. (4) recently estimated that ~10–16% of training volume (~130–170 km·wk^{-1}) for male and female Kenyan runners was performed at intensities at or above the lactate threshold (i.e., ≥VT). This is less than the time for the runners in our study (29% (zones 2 and 3) above VT). However, the total volume of high-intensity training (~20 km·wk^{-1}) is in the same general range as observed in the current study. In a previous report, Saltin et al. (33) described (from training logs/questionnaires) that the training programs of several Kenyan elite runners (~100 km·wk^{-1}) included very little low-intensity work and was characterized mostly by high-intensity sessions. As mentioned above, however, no actual training HR data using the triphasic model are available in endurance runners. Seiler and Kjerland (34) observed that in elite Norwegian junior cross-country skiers, 91, 6, and 3% of the training time was performed in zones 1, 2, and 3, respectively. However, when the HR records were analyzed by the session-goal approach, which corrects for the extensive period of low HR during recovery intervals of high-intensity days, 75, 8, and 17% of workouts were conducted nominally in zones 1, 2, and 3, respectively. This is very similar to our results. Foster et al. (10) also evaluated training load using the session RPE method and the pattern of lactate accumulation. These results also suggested that the general pattern of training approximates 75% low-intensity training. This general pattern of a high percentage of low-intensity training is also reflected in a retrospective analysis of the training of elite Norwegian rowers over the past three decades of the 20th century (9). The training intensity of professional cyclists obtained during the main part of the season (November–May) has been described with training logs using the three HR zones reported here (23). Interestingly, the percentage of total training time (~25 h·wk^{-1}) spent by cyclists in zones 1, 2, and 3 was similar (~75, ~15, and ~10%, respectively) during winter-spring months to the values we report here (71, 21, and 8%, respectively). Similarly, the percentage of time spent in zones 1, 2, and 3 during 3-wk races as the Tour de France (total duration ~100 h) approaches 70, 23, and 7%, respectively (22). Thus, the current data and those of previous research (9,22,34) suggest that well-trained endurance athletes tend to spontaneously pace themselves in a manner such that they spend most training time (or competition time, in the case of continuous long-term competitions such as 3-wk tour races) in zone 1, with a considerably lower contribution of zone 2 and especially zone 3.

The actual training data presented here in endurance athletes showing that 1) low-intensity training accounts for the majority of training time and 2) there is an association between total cumulative training time at low intensities (zone 1) and endurance performance during events held at very high intensities (i.e., 30 min at >85% $\dot{V}O_{2max}$) are in apparent disagreement with some classic studies showing that physiological or performance improvements are associated with high-intensity training sessions (8,39). Steady-pace sessions at an intensity of at least 80–90% $\dot{V}O_{2max}$ (i.e., approximately RCT) have traditionally been considered to be the optimal intensity based on the results from previous studies (30,39). Furthermore, one distinguishable feature of the best endurance runners of the modern era (i.e., East Africans) is the high intensity of their training sessions, as mentioned above, although this trend is not evident in the data from Billat et al. (4). In contemporary times, many Kenyan runners are trained by former Kenyan champions, who recommend interval workouts at velocities slightly higher than in competitions (4). Such interval training runs at intensities of $\dot{V}O_{2max}$ and higher could improve the aerobic potential of type IIA muscle fibers, which in turn could become more fatigue resistant. Thus, training speed ensures that the cardiovascular demand is at its maximum, but it also determines the generation of muscular force that is important for performance, especially during the last 10–20% of races (4). Although our subjects performed some interval workouts in zone 3 (i.e., at velocities eliciting maximal HR and possibly $\dot{V}O_{2max}$), we found no relationship between total training time spent at this workload and performance during actual competition (which was performed mostly in zone 3, at near-maximal intensities). In line with our findings, most of the training data available on white endurance athletes using HR as a marker of training intensity has shown that the preferred average intensity of training sessions is below the theoretical optimal intensity (9,23,31,34). The reasons for our findings are not immediately apparent.

We found no relationship between total training load (i.e., volume × intensity computed as TRIMP score) and competition performance, in contrast to the results of Foster et al. (10), who found a saturation curve between training load and cycle time trial performance, which emphasizes the somewhat surprising importance of low-intensity training background in competition performance.

The observation that the better runners performed relatively more of their training at lower intensities must be taken in context, since it does not necessarily imply that the best way to improve performance is to train at low intensities. It might be suggested that in a group of runners training together, the better runners will be less challenged while performing the same training bouts and thus have lower percentages of time in the higher HR zones. However, although the runners in this study were all coached by the same person, they did not perform their training as a group. Therefore, the explanation that the same training was easier for the better runners does not seem likely in this case. Studies from both Australia (18) and South Africa (36) in high-level cyclists have demonstrated that training performance responds positively to short-term increases in training intensity. These same studies do not support great amount of importance of one type of intensified training over another, suggesting that the impact of intensified training may be quite general. These data support earlier findings from Daniels et al. (8), who demonstrated a very general [illegible]tensified training. The implication of these [illegible] adaptations to high-intensity training occur [illegible]nd that the dose-response characteristics of [illegible]raining may saturate at fairly low volumes of [illegible] training. To our knowledge, there are few data addressing how short-term training adaptations to high-intensity training might occur. It would be most reasonable to suggest that central circulatory changes might be able to respond rapidly to changes in training load, because changes in mitochondrial number or capillary density in type II muscle fibers may take some weeks to occur (32).

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We believe that the most likely explanation for the comparatively small amount of high-intensity training performed by serious athletes has to do with the likelihood of downregulation of their 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 (21,25). Lehmann et al. (19) reported decreases in catecholamine secretion in overtrained athletes. Although beta-receptor density and catecholamine sensitivity are generally higher in athletes than in sedentary individuals (20), heavy training produces evidence of catecholamine depletion (19). This pattern may be consistent with a reduced sensitivity to catecholamines, as demonstrated in chronic overstimulation or exhaustive stress (6,38). Since one consequence of a reduced sensitivity to catecholamines might be reductions in cardiac output and the ability to selectively divert blood flow to the active musculature and since a drive to downregulate beta receptors would be expected only 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 of time without risking downregulation of the sympathetic nervous system. This concept awaits experimental verification. However, evidence in support of this concept may be found in the fixed TRIMP values and minutes of zone 3 exercise in the relatively longer Tour de France and the relatively shorter Vuelta a España (25).

In summary, competitive runners spent most of their training at low intensities. Our findings suggest that total training time spent at low intensities might be associated with improved performance during highly intense endurance events, at least if the event duration is ~35 min. Interventional studies (i.e., increasing or reducing athletes' total training time in zone 1) are needed to corroborate our findings. On the whole, we believe that the results from this study provided evidence that athletes might engage in a form of pacing that occurs over a very long period of time. Just as athletes must distribute their energetic resources within a competition (11,12,25) to prevent substrate depletion or metabolite accumulation, it appears that they must also perform a certain level of pacing over long periods of time, so that the balance of the training stress and training adaptations remains favorable.

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