Group Training in Adolescent Runners: Influence on $\dot{V}O_2$max and 5-Km Race Performance

Paul D. Loprinzi,[1] Bradley J. Cardinal,[2] Jason R. Karp,[3] and Gary R. Brodowicz[4]

[1]*Bellarmine University, Department of Exercise Science, Louisville, Kentucky;* [2]*Department of Nutrition and Exercise Sciences, Oregon State University, Corvallis, Oregon;* [3]*RunCoachJason.com, REVO2LT Running Team, San Diego, California; and* [4]*Exercise Physiology Laboratory, School of Community Health, Portland State University, Portland, Oregon*

Abstract

Loprinzi, PD, Cardinal, BJ, Karp, JR, and Brodowicz, GR. Group training in adolescent runners: influence on $\dot{V}O_2$max and 5-km race performance. *J Strength Cond Res* 25(X): 000–000, 2011—The aims of this study were to (a) examine the interrelationships between training intensity, $\dot{V}O_2$max, and race performance in adolescent crosscountry runners and (b) determine if adolescent runners participating in a group crosscountry training program differ in the amount of training time at various intensities. In this study, 7 adolescent runners performed a laboratory-based $\dot{V}O_2$max test before and after a 9-week high-school crosscountry season. Heart rate (HR) and ventilatory threshold (VT) were used to identify 3 training zones for each runner based on the HR at ventilator threshold (HR_{VT}): zone 1: >15 b·min^{-1} below HR_{VT}; zone 2: between zone 1 and HR_{VT}; zone 3: $>HR_{VT}$. During each training session throughout the season, HR was measured to quantify the amount of training time in each of these 3 intensity zones. Results showed that the time in each of the 3 zones was not significantly associated with 5-km race performance. Zone 3 training time was positively associated with postseason $\dot{V}O_2$max ($r = 0.73$, $p = 0.06$); $\dot{V}O_2$max was significantly inversely associated with 5-km race performance ($r = -0.77$, $p = 0.04$). Each week, the amount of training time at, above, and below the VT was significantly different among the participants even though the training prescription for the group was standardized. The results suggest that, among adolescent crosscountry runners, training above the VT may be important in increasing $\dot{V}O_2$max and ultimately, race performance. Given the between-participant differences in the amount of training time in each HR zone, coaches should apply individual, rather than group, training programs.

Key Words crosscountry, running, heart rate

Address correspondence to Paul D. Loprinzi, loprinzp@onid.orst.edu.

0(0)/1–8

Journal of Strength and Conditioning Research

Introduction

To date, few studies have examined the effects of endurance training on endurance performance in adolescent runners (12,16). Most of the investigations examining the effect of training methods on endurance performance have been conducted in adults (1,3,4,6,10,11,15,21,22), with some in younger children (13,14). As a result, little is known about the role of training intensity on endurance performance (e.g., maximum oxygen consumption [$\dot{V}O_2$max]) and race performance (e.g., 5 km) in adolescent distance runners.

Of the few training studies conducted in adolescent runners, evidence shows that endurance training can improve physiological determinants of endurance performance (e.g., $\dot{V}O_2$max) and race performance (e.g., 5 km) in this population. Plank et al. (16) examined the physiological adaptations resulting from a season of crosscountry training in 9 male adolescent runners and showed that 13 weeks of training improved relative $\dot{V}O_2$max by 6%. More recently, Loprinzi and Brodowicz (12) also examined the physiological adaptations from a season of crosscountry training in adolescent crosscountry runners. Over a 9-week crosscountry training period, $\dot{V}O_2$max increases by 7%. In addition to improvements in $\dot{V}O_2$max, the 9-week crosscountry training period resulted in improvements in 5-km race time and 2-km time trial performance by approximately 4 and 11%, respectively.

Although these 2 studies show that endurance training can improve $\dot{V}O_2$max and race performance in adolescent crosscountry runners, it is unclear as to what extent that combinations of low-, moderate-, and high-intensity training optimize improvements in these parameters. If an ideal combination of intensities for eliciting improvements in $\dot{V}O_2$max and race performance can be established, coaches could use such knowledge to prescribe more effective training programs to improve the runner's performance. This knowledge of the ideal training intensity will be paramount in helping adolescent distance runners achieve their full potential in their current and future running. However, before such ideal training can be prescribed, it is important that coaches understand the individual profiles of their athletes. Although it may be expedient and convenient for running coaches to prescribe a single training program for a group of runners, it is possible that such programming will expose individual runners to a training stimulus that may not be appropriate. Consistent with the principle of individuality (18), individuals may respond differently to the same training program.

Providing some support to this assertion, an unpublished paper presented at the Annual Meeting of the Canadian Association of Sport Sciences (20) showed large individual differences in $\dot{V}O_2$max, ferritin, lactate, and hemoglobin concentrations resulting from a group swimming training program, suggesting that to provide an appropriate training stimulus, it is important for coaches to prescribe individual training programs based on each athlete's individual training response.

The primary goal of this study is to provide running coaches with evidence-based strategies that they can used to improve the running performance of their adolescent distance runners. To determine which training intensity (i.e., low, moderate, high) is more important in eliciting improvements in endurance performance (i.e., $\dot{V}O_2$max) and race performance (i.e., 5 km), the first aim of this study is to examine the interrelationships between training intensity, $\dot{V}O_2$max, and race performance among adolescent distance runners over a season of crosscountry training. Once the optimal training intensity is established, coaches can use such information to prescribe appropriate workouts to elicit the desired training-induced adaptations. However, it is likely that individuals in a group will not all respond similarly to one general workout prescribed to the entire group, thus resulting in an inappropriate training stimuli at the individual level. Therefore, to determine if prescribing workouts at the group level produces different training responses at the individual level, the second aim of this study is to determine if adolescent runners participating in a group crosscountry training program differ in the amount of training time at various intensities during workouts at several points during the season. We hypothesize that high-intensity training will be positively associated with $\dot{V}O_2$max and inversely associated with 5-km race performance. Additionally, we hypothesize that standardized group training will result in individual differences with regard to the time spent at different intensities.

The practical implications of this study is that it will provide coaches with the ideal training intensity to improve endurance performance and inform coaches as to whether it is necessary to prescribe individualized training programs. Examples of how to individualize training will be discussed.

Methods

Experimental Approach to the Problem

To (a) examine the interrelationships between training intensity, $\dot{V}O_2$max, and race performance in adolescent crosscountry runners and (b) determine if adolescent runners participating in a group crosscountry training program differ in the amount of training time at various intensities during workouts at several points during the season, participants underwent a season of crosscountry training with $\dot{V}O_2$max measured before and after the season, with training intensity evaluated through heart rate (HR) monitoring during each training session. Assessment of HR monitoring on a daily basis will allow for the interrelationships between training intensity, $\dot{V}O_2$max, and race performance to be observed, and determine if adolescent distance runners respond differently to a group crosscountry training program.

Subjects

Seven male high-school crosscountry runners volunteered to participate in this study (M age = 16.3 ± 0.8 years; M height = 1.8 ± 0.1 m; M body mass = 69.3 ± 12.2 kg; sum of skinfolds = 34.1 ± 23.6 mm; and percent fat = 6.4 ± 7.6). The years of experience in crosscountry or track ranged from 0 to 3 years, with an average (SD) of 1.4 years (1.0). Each participant and his parents were required to provide written, informed consent before participation. All procedures of this study were approved by the Institutional Review Board of Portland State University. During the 7 weeks immediately preceding the start of the competitive season, each runner followed an unsupervised summer training program that involved light-intensity running approximating $<$10 miles·wk^{-1}. Details of the preseason training were obtained by self-report and included estimates of mileage and training intensity.

Procedures

Identical laboratory tests were conducted before and immediately after the 9-week crosscountry season. During the visits to the university's exercise physiology laboratory, participants completed a graded exercise test on a motorized treadmill to measure maximum oxygen consumption ($\dot{V}O_2$max). Details of the protocol are listed in the narrative that follows.

Anthropometric Measures. Height was measured to the nearest 0.65 cm using a calibrated, wall-mounted stadiometer, and bodyweight was measured to the nearest 0.11 kg using a calibrated physician's scale. Skinfold measurements (chest, abdomen, thigh) were measured in triplicate with a Lange skinfold caliper (Cambridge Scientific Industries, Cambridge, MD, USA), and all measurements were made according to the procedures of Jackson and Pollock (8). Gender- and age-specific equations were used to calculate percent fat from body density.

Graded Exercise Test. During the first laboratory tests performed before and immediately after the crosscountry season, each subject performed a maximal graded exercise test (Bruce protocol) on a motorized treadmill to determine $\dot{V}O_2$max, with $\dot{V}O_2$ and HR continuously monitored throughout the test. Heart rate was measured every minute using a portable HR monitor (Polar Vantage XL, Lake Success, NY, USA), and metabolic measurements were made every 30 seconds with an automated metabolic measurement system (ParvoMedics TrueOne 2400 Metabolic Measurement System, Sandy, UT, USA).

Analyzers were calibrated with medical-grade calibration gas (16.01% O_2; 3.97% CO_2); a Rudolph 3-L calibration syringe (Shawnee, OK, USA) was used for volume calibrations as per manufacturer specifications. Criteria used to define $\dot{V}O_2max$ were (a) a respiratory exchange ratio >1.10, (b) a plateau in $\dot{V}O_2$ (increase < 250 ml·min^{-1} with increase in treadmill speed or incline), (c) an HRmax within 10% of the age-predicted maximum (220 − age), and (d) a rating of perceived exertion > 8 on a 10-point scale. $\dot{V}O_2max$ was determined as the highest 30-second $\dot{V}O_2$ measured when at least 3 of the 4 criteria were satisfied; all 7 subjects demonstrated at least 3 of the criteria during pre and postseason testing.

Ventilatory threshold (VT) was determined by visual inspection of scatterplots of minute ventilation (V_E) vs. time by 2 independent investigators (5,23). Scatterplots of the ventilatory equivalent for oxygen ($V_E/\dot{V}O_2$) vs. time were used to confirm the identification of VT. Evaluators were not blinded to subject or trial; 1 evaluator was involved in all testing, and the other was not. The HR at VT (VT_{HR}) was used to identify 3 training zones: zone 1 = HR > 15 b·min^{-1} below VT_{HR}; zone 2 = HR between zone 1 and VT_{HR}; zone 3 = HR > VT_{HR}.

Training. During the 9-week crosscountry season (mid-August to mid-October), runners performed standardized training sessions prescribed by the coach, with training occurring 5 d·wk^{-1}. Traditional workouts were prescribed, including supervised workouts (e.g., intervals and hill repeats), and unsupervised training sessions (e.g., easy short runs, easy long runs, tempo runs, and fartleks).

Heart rate was monitored during every training session using downloadable, frequency-coded HR watches (Acumen, TZ-Max 100, Sterling, VA, USA) with 30-second registration intervals. Athletes were provided with an HR monitor before each training session. After each training session, data were downloaded to a computer and imported into an Excel spreadsheet. The content of each training session was evaluated according to the time in each of the 3 HR zones. Over the training period, 203 observations were possible. In total, 168 observations were recorded, resulting in an overall response rate of 83%. Nonobserved days were a result of the participant forgetting to start the HR monitor watch or failing to attend the crosscountry practice.

Five-kilometer Race Performances. The crosscountry season consisted of 9 high-school crosscountry meets (5-km races). All race performances were recorded, but the race time of the most important competition of the season (i.e., district championship meet) was used to evaluate training-induced performance effects that occurred throughout the crosscountry season.

Statistical Analyses

For the first aim of this study, pairwise correlation coefficients were calculated to examine the interrelationships between training intensity, endurance performance (5-km race time), and $\dot{V}O_2max$. The significance of the pairwise correlation coefficients was tested using the pairwise significance option. To make comparisons between participants (aim 2), analyses were restricted to the training sessions during which HR data were present for all 7 participants. Training sessions were excluded if the HR monitoring time varied substantially (>20 minutes) across participants for a particular training day. Data are presented for 4 training sessions (1 session in weeks 1, 2, 3, and 8), because these were the only training sessions in which HR data were present for all 7 participants with minimal between-participant variation in HR monitoring time. Time training per session and percentage of training time in each HR zone were calculated. To statistically compare the time spent in each training zone between participants, data were analyzed using a 7 (participants) × 3 (zones) chi-square (χ^2) analysis for each of the 4 weeks of training. Beyond probability testing, the magnitude of each χ^2 value was estimated using the contingency coefficient (CC), with values ≥0.30 thought to be large and meaningful (7). Significance was established as $p \leq 0.05$.

Results

Over the course of the 9-week season, there were no statistically significant changes in height ($t_{(6)} = -0.09$; $p > 0.05$), bodyweight

Table 1. Correlation coefficients (*p* value) among the study variables assessed at pre and postseasons.

	Zone 1	Zone 2	Zone 3	5-km Race	Preseason $\dot{V}O_2max$	Postseason $\dot{V}O_2max$
Zone 1	1.0					
Zone 2	−0.05 (0.92)	1.0				
Zone 3	−0.69 (0.09)	0.37 (0.42)	1.0			
5-km Race	−0.12 (0.79)	0.16 (0.74)	−0.29 (0.53)	1.0		
Preseason $\dot{V}O_2max$	−0.31 (0.51)	−0.14 (0.76)	0.64 (0.12)	−0.80 (0.03)	1.0	
Postseason $\dot{V}O_2max$	−0.40 (0.37)	0.15 (0.74)	0.73 (0.06)	−0.77 (0.04)	0.81 (0.03)	1.0

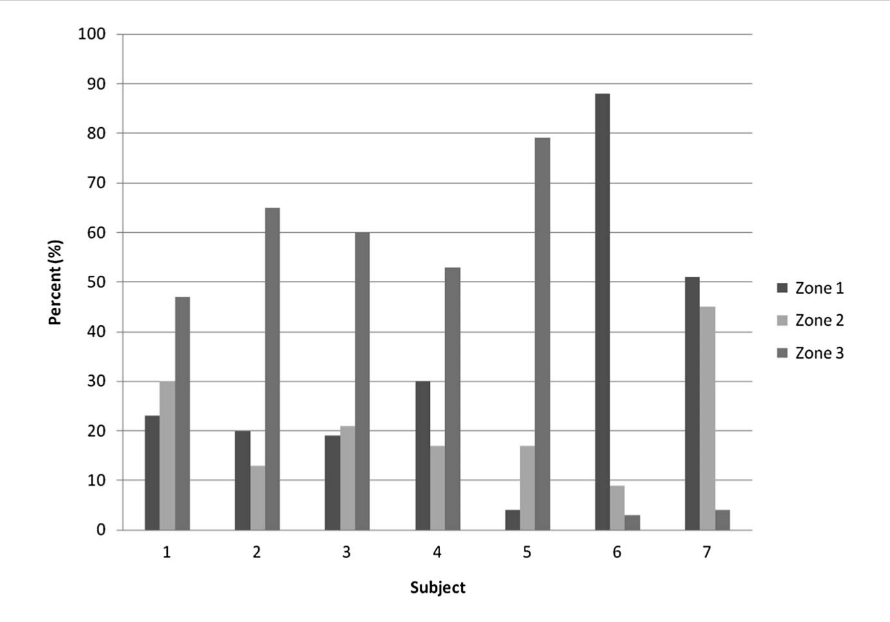

Figure 1. Time (%) in each heart rate zone for the analyzed workout in week 1.

($t_{(6)} = 0.15$; $p > 0.05$), percent body fat ($t_{(6)} = 0.11$; $p > 0.05$), or sum of skinfolds ($t_{(6)} = 1.57$; $p > 0.05$). With regard to physiological responses from the tests, absolute $\dot{V}O_2max$ increased by 5.8% (3.9 ± 0.6 vs. 4.1 ± 0.6) and relative $\dot{V}O_2max$ increased by 7.1% (56.3 ± 5 vs. 60.6 ± 3.3) over the 9-week training period ($p < 0.05$).

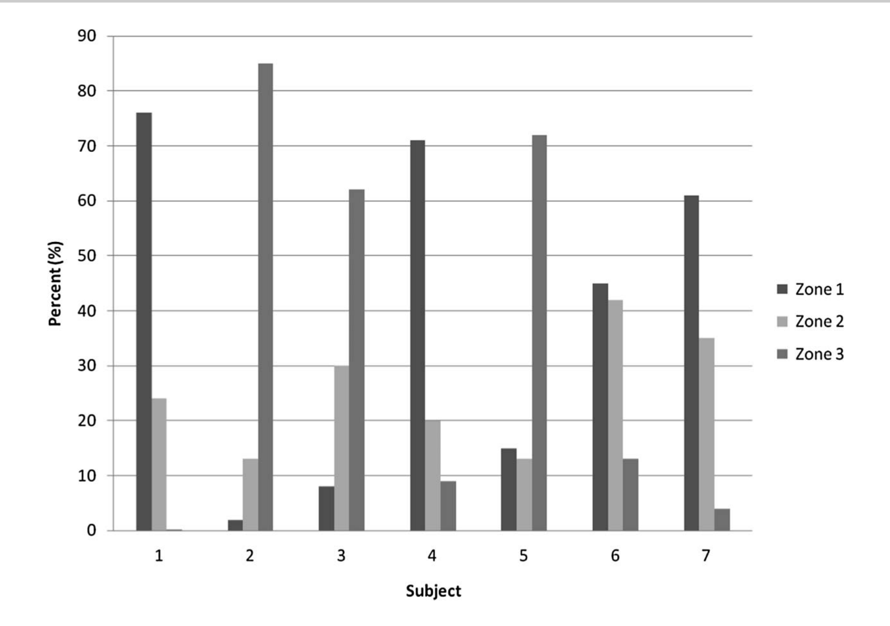

Figure 2. Time (%) in each heart rate zone for the analyzed workout in week 2.

Aim 1: Interrelationships between Training Intensity, $\dot{V}O_2max$, and Race Performance

Total training time in zone 1 (418 ± 99 minutes) was significantly higher ($p < 0.01$) than that accumulated in zone 2 (224 ± 58 minutes) but was not significantly different ($p = 0.19$) than total time in zone 3 (287 ± 156 minutes). Total time in zone 3 was not significantly higher than time in zone 2 ($p = 0.29$).

No statistically significant relationships were noted between training time in each training zone and 5-km championship race time (zone 1: $r = -0.12$, $p = 0.79$; zone 2: $r = 0.16$, $p = 0.74$; zone 3: $r = -0.29$, $p = 0.53$). Similarly, there was no statistically significant correlation between either training time in zone 1 ($r = -0.40$, $p = 0.37$) or time in zone 2 ($r = 0.15$, $p = 0.74$) with postseason $\dot{V}O_2max$. However, there was a nonsignificant trend between time in zone 3 ($r = 0.73$, $p = 0.06$) and postseason $\dot{V}O_2max$. There was a significant inverse relationship between postseason $\dot{V}O_2max$ and the 5-km championship race ($r = -0.77$, $p = 0.04$). A correlation matrix between the variables assessed at pre and postseasons is displayed in Table 1.

Aim 2: Individual Responses to Group Training

For the training session for week 1, the total minutes of HR monitoring ranged from 53.5 to 64 minutes. Five of the 7 participants spent 47-79% of their training in zone 3, whereas for 2 of the participants, very little time was in this zone. (range: 3–4%) (Figure 1). Training time in each zone was statistically different among the participants ($\chi^2_{(12,818)} = 337.16$, $p < 0.001$). The CC indicated that the effect was large (CC = 0.54).

For the training session for week 2, the total minutes of HR monitoring ranged from 22.5 to 25 minutes. Three

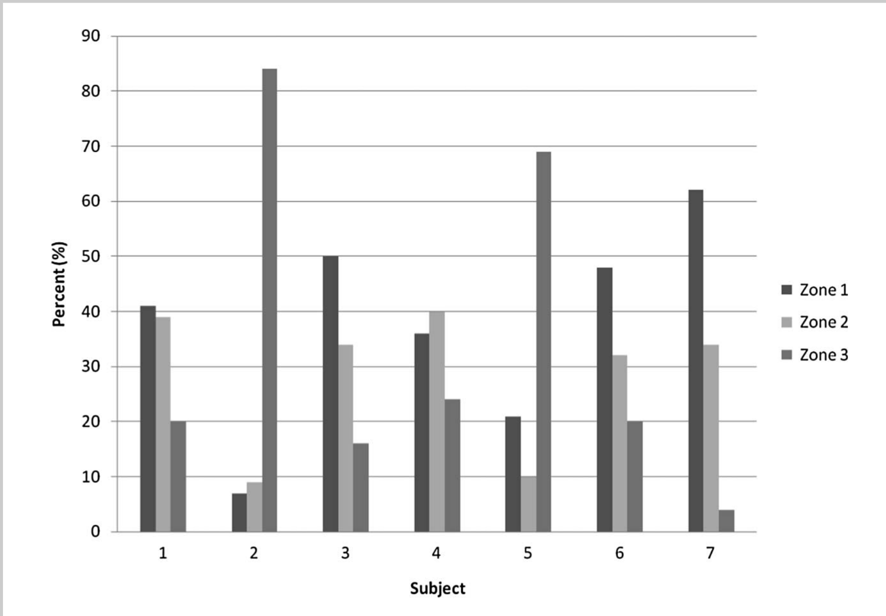

Figure 3. Time (%) in each heart rate zone for the analyzed workout in week 3.

participants occupied the majority of the training session in zone 3 (range: 62–85%), whereas for the remaining 4 participants, only 0–13% of the training time was in this zone (Figure 2). Training time in each zone was statistically different among the participants ($\chi^2_{(12,329)} = 190.15$, $p < 0.001$). The CC indicated that the effect was large (CC = 0.61).

For the training session for week 3, the total minutes of HR monitoring ranged from 24.5 to 40.5 minutes. Only 2 participants occupied the majority of the training session in zone 3 (range: 69–84%); the training time in this zone by the other 5 participants ranged from 4 to 24% (Figure 3). Training time spent in each zone was statistically different among the participants ($\chi^2_{(12,422)} = 145.11$, $p < 0.001$). The effect was large (CC = 0.51).

For the training session for week 8, the total minutes of HR monitoring ranged from 15 to 26 minutes. Only 1 participant occupied the majority of this training session in zone 3 (61%). Only 2–33% of the session training time was occupied in this zone by the other 6 participants (Figure 4). Training time in each zone was statistically different among the participants ($\chi^2_{(12,301)} = 98.66$, $p < 0.001$). Once again, the effect was large (CC = 0.50).

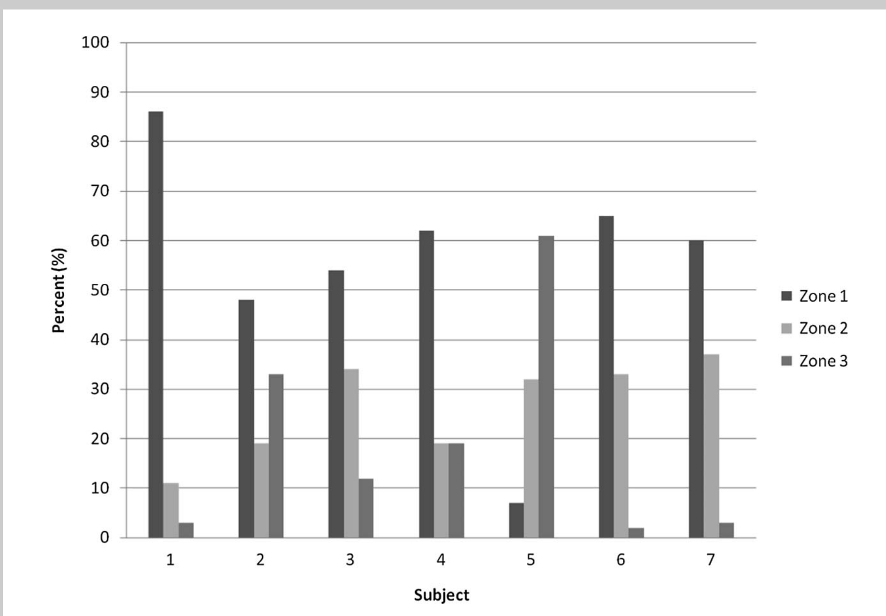

Figure 4. Time (%) in each heart rate zone for the analyzed workout in week 8.

Discussion

The aims of this study were to (a) examine the interrelationships between training intensity, $\dot{V}O_2$max, and race performance in adolescent crosscountry runners and (b) determine if adolescent runners participating in a group cross-country training program differ in the amount of training time at various intensities during workouts at several points during the season. With respect to the first aim, and in contrast to our hypothesis, the results demonstrate that the time in each intensity zone was not significantly related to 5-km race performance. In accordance with our hypothesis, training time in zone 3 (i.e., high intensity) was related to $\dot{V}O_2$max, with postseason $\dot{V}O_2$max significantly inversely related to 5-km race performance. These results suggest that, among adolescent crosscountry runners, training above the VT may be important for increasing $\dot{V}O_2max$, with increased levels of $\dot{V}O_2max$ serving as an important influence on 5-km race performance. Although not measured in this study, possible physiological factors causing increases in $\dot{V}O_2max$ can be attributed to improvements in maximal cardiac output stroke volume, a-$\dot{V}O_2$ difference, muscle blood flow, capillarization, preload, left ventricle size, venous return, and myocardial contractility (17). With regard to the second aim, we found that for the same workouts prescribed by their coach, the training time at various intensities relative to the VT HR was significantly different among adolescent distance runners, suggesting that the runners were experiencing different physiological responses to the workouts.

Given the lack of published research that has examined the effect of different training intensities on race performance or $\dot{V}O_2max$ in adolescent crosscountry runners, it is difficult to compare the results of this study with others. However, the results of this study are similar to a cycling study conducted in a younger population (13,14). In a sample of 84 children aged 10–11 years, 2 groups were involved in a 13-week endurance training program. In experimental group 1 (n = 36), subjects trained 3 $d \cdot wk^{-1}$ at a high intensity (>80% HRmax), with each training session being 25–35 minutes in duration. Similarly, in experimental group 2 (n = 20), subjects trained at the same intensity, but for 15–20 minutes per session, 2 $d \cdot wk^{-1}$. Results showed that after the 13-week training program, only the subjects in experimental group 1 significantly improved $\dot{V}O_2max$ from pre to posttraining. These results suggest that high-intensity training of at least 25 minutes, 3 $d \cdot wk^{-1}$ is necessary to improve $\dot{V}O_2max$ among young cyclists.

In contrast to the findings in young cyclists and the results reported in this study, Esteve-Lanao et al. (6) showed that low-intensity training may be more important for improving endurance performance than high-intensity training. In this study, 8 subelite endurance runners (mean age: 23 ± 2 years) competed in both a short (4.175 km) and a long (10.130 km) distance crosscountry race after a 6-month training period. During each training session, HR was continuously measured to quantify the amount of time training at 3 different intensities: below the VT (low-intensity, zone 1), between the VT and respiratory compensation (moderate intensity, zone 2), and above the respiratory compensation (high intensity, zone 3). Total training time in zone 1 (4,581 ± 979 minutes) was significantly higher than total training time in zones 2 (1,354 ± 583 minutes) and zones 3 (487 ± 154 minutes). Results showed that only the time in zone 1 was related to endurance performance. The correlation between the total training time in zone 1 and performance time during the short crosscountry race ($r = -0.79$; $p = 0.06$) and long crosscountry race ($r = -0.97$; $p = 0.008$) suggest that total training at low intensities is associated with improved performance during crosscountry races. Divergent results between this study and the present study may be attributable to differences in the population, training duration, race distance, and method used to classify training intensity.

With regard to the second aim, the effects of group training on individual training responses, it is difficult to compare the results of the present study to other studies, because no studies to date have examined individual training responses to a group training program in adolescent crosscountry runners. Providing some support to the results of the present study, an unpublished paper presented at the Annual Meeting of the Canadian Association of Sport Sciences (20) showed large individual differences in $\dot{V}O_2max$, ferritin, lactate, and hemoglobin concentrations resulting from a group swimming training program. It is unknown whether the differences were statistically significant. However, the results of that study, together with those of the present study, suggest that to provide an appropriate training stimulus, it is important for coaches to prescribe individual training programs based on each athlete's individual training response.

A plausible explanation for the drastic between-participant differences in the amount of training time in each HR zone may be attributable to a social-psychology phenomenon referred to as social loafing. Social loafing suggests that individuals within a group are less likely to put forth 100% effort because of lower levels of motivation and accountability (24). Unfortunately, group settings often provide an optimal environment to loaf. As a result, the minimal personal accountability from being in a group training program may influence an individual's level of motivation. Clearly, social loafing has important implications for team performance. If it is not feasible to individualize training, running coaches are encouraged to visually monitor group training sessions to minimize any possibility of social loafing.

In summary, training time in each of the 3 intensity zones was not associated with 5-km race performance. High-intensity training time was positively associated with $\dot{V}O_2max$, and $\dot{V}O_2max$ was significantly negatively associated with 5-km race time, suggesting that high-intensity training is needed to enhance $\dot{V}O_2max$ in adolescent crosscountry runners. For the same prescribed training sessions, there was a wide range in the amount of time within specific ranges of prescribed intensities, suggesting that the runners in the group experienced different training effects. Given the paucity of studies examining the interrelationships between training intensity, $\dot{V}O_2max$, and race performance in adolescent crosscountry runners, and individual differences in a group crosscountry training program, additional studies, employing a larger sample size, are needed to confirm our results.

Practical Applications

Our results show that high-intensity training is important for improving $\dot{V}O_2max$ among adolescent distance runners. Additionally, our results indicate that adolescent distance runners with a higher $\dot{V}O_2max$ perform better at the 5-km race distance during crosscountry. Therefore, to improve endurance performance among adolescent distance runners, high-school running coaches should, at appropriate times throughout the season, prescribe training sessions at a relatively high intensity (i.e., above the VT). Examples of long aerobic intervals that coaches can use to improve $\dot{V}O_2max$ include runs lasting 2–5 minutes at the speed associated with $\dot{V}O_2max$. The recovery periods should be equal to or slightly shorter than the duration of the aerobic interval. Another evidence-based strategy to improve $\dot{V}O_2max$ is to improve the speed at which the VT occurs (9). To do so, runners should perform various forms of training (e.g., intervals, fartleks, tempos) at moderate to high intensities (equivalent to ca. 30 seconds slower per mile than the runner's current 5-km race pace). Examples of workouts to elicit improvements in the VT include continuous runs up to 10 miles at VT pace and long aerobic intervals (e.g., mile repeats) at VT pace with short recovery (e.g., 1 minute) between intervals (2).

In addition to showing the importance of high-intensity training in improving $\dot{V}O_2max$, our results showed that for the same prescribed training sessions, there was a wide range in the amount of time within specific ranges of prescribed intensities, suggesting that the runners in the group experienced different training effects. Consequently, to minimize these interindividual differences in training responses among runners in a group setting, coaches, when feasible, should tailor the training to each individual runner. Heart rate monitoring is a feasible method for coaches to individualize training programs. For easy comfortable distance runs, coaches should have their runners train at approximately 70–75% of maximum HR. For training sessions that aim to increase the speed at which the VT occurs, coaches should prescribe a training HR range approximating 85–90% of maximum HR (9). Lastly, for longer aerobic intervals of 2–5 minutes in duration, coaches should prescribe a training HR range nearing 95–100% of maximum HR (2). In addition to using HR monitoring to individualize training programs, other factors such as the runner's tolerance of the training load, responsiveness to training, training needs, recovery response, and training preferences need to be considered (19). A runner's ability to tolerate and respond to a training stimulus is influenced by multiple factors, such as age and maturation, running experience, fitness level, and muscle fiber type. It is important that some of these factors be taken into consideration when designing an individualized training program. To allow for gradual training adaptations to occur, coaches should use training periodization strategies to adjust training volume and intensity. The coach should carefully monitor the runner's signs and symptoms for evidence of overtraining and make adjustments when necessary. With any training program, the coach should aim to develop a balanced profile of attributes for each athlete. Through objective assessments, coaches can determine the strengths and weaknesses in the profile of each athlete and then prescribe training accordingly. Another important factor to consider when prescribing individualized training is to understand the individual's ability to recover. Runners with different physiological profiles will require different recovery and tapering protocols. Coaches should monitor their runners' abilities to recover from workouts to determine the appropriate recovery protocol. Finally, to develop and maintain a positive attitude toward training, and to improve adherence to a training schedule, coaches should attempt to consider their runners' training preferences (e.g., types of workouts, location of training). Notably, if individualizing training programs is not feasible, coaches are encouraged to visually monitor training sessions to ensure social loafing does not occur.

References

1. Acevedo, EO and Goldfarb, AH. Increased training intensity effects on plasma lactate, ventilatory threshold, and endurance. *Med Sci Sports Exerc* 21: 563–568, 1989.
2. Billat, LV. Interval training for performance: A scientific and empirical practice. Special recommendations for middle- and long-distance running. Part I: Aerobic interval training. *Sports Med* 31: 13–31, 2001.
3. Billat, V, Demarle, A, Paiva, M, and Koralsztein, JP. Effect of training on the physiological factors of performance in elite marathon runners (males and females). *Int J Sports Med* 23: 336–341, 2002.
4. Billat, VL, Flechet, B, Petit, B, Muriaux, G, and Koralsztein, JP. Interval training at $\dot{V}O_2max$: Effects on aerobic performance and overtraining markers. *Med Sci Sports Exerc* 31: 156–163, 1999.
5. Caiozzo, VJ, Davis, JA, Ellis, JF, Azus, JL, Vandagriff, R, Prietto, CA, and McMaster, WC. A comparison of gas exchange indices used to detect the anaerobic threshold. *J Appl Physiol* 53: 1184–1189, 1982.
6. Esteve-Lanao, J, San Juan, AF, Earnest, CP, Foster, C, and Lucia, A. How do endurance runners actually train? Relationship with competition performance. *Med Sci Sports Exerc* 37: 496–504, 2005.
7. Fleiss, JL. *Statistical Methods for Rates and Proportions*. New York, NY: John Wiley & Sons, 1981.
8. Jackson, AS and Pollock, ML. Generalized equations for predicting body density of men. *Br J Nutr* 40: 497–504, 1978.
9. Janssen, P. *Lactate Threshold Training*. Champaign, IL: Human Kinetics, 2001.
10. Kemi, OJ, Haram, PM, Loennechen, JP, Osnes, JB, Skomedal, T, Wisloff, U, and Ellingsen, O. Moderate vs. high exercise intensity: Differential effects on aerobic fitness, cardiomyocyte contractility, and endothelial function. *Cardiovasc Res* 67: 161–172, 2005.
11. Laffite, LP, Mille-Hamard, I, and Koralstein, JP. The effect of interval training on oxygen pulse and performance in supra-threshold runs. *Arch Physiol Biochem* 111: 202–210, 2003.
12. Loprinzi, PD and Brodowicz, GR. Physiological adaptations and analysis of training content in high school cross-country runners. *Res Sports Med* 16: 189–202, 2008.
13. Mahon, A and Vaccaro, P. Cardiovascular adaptations in 8 to 12 year old boys following a 14-week running program. *Can J Appl Physiol* 19: 139–150, 1994.
14. Mandigout, S, Melin, A, Lecoq, AM, Courteix, D, and Obert, P. Effect of two aerobic training regimens on the cardiorespiratory response of prepubertal boys and girls. *Acta Paediatr* 91: 403–408, 2002.
15. Mikesell, KA and Dudley, GA. Influence of intense endurance training on aerobic power of competitive distance runners. *Med Sci Sports Exerc* 16: 371–375, 1984.

16. Plank, DM, Hipp, MJ, and Mahon, AD. Aerobic exercise adaptations in trained adolescent runners following a season of cross-country training. *Res Sports Med* 13: 273–286, 2005.

17. Powers, SK and Howley, ET. *Exercise Physiology: Theory and Application to Fitness and Performance*. New York, NY: McGraw-Hill Humanities Social, 2008.

18. Rushall, B. Coaches and sport psychology. *Int J Sport Psychol* 10: 164–167, 1979.

19. Rushall, B and Pyke, F. *Training for Sports and Fitness*. New York, NY: Macmillan, 1990. pp. 84–95.

20. Savage, M, Brown, S, and Savage, P. *Physiological and Performance Correlates of Training in Swimmers*. Annual Meeting of the Canadian Association of Sport Sciences, Halifax, Canada. 1981.

21. Smith, TP, Coombes, JS, and Geraghty, DP. Optimising high-intensity treadmill training using the running speed at maximal O(2) uptake and the time for which this can be maintained. *Eur J Appl Physiol* 89: 337–343, 2003.

22. Smith, TP, McNaughton, LR, and Marshall, KJ. Effects of 4-wk training using *V*max/*T*max on $\dot{V}O_2max$ and performance in athletes. *Med Sci Sports Exerc* 31: 892–896, 1999.

23. Wasserman, K, Whipp, BJ, Koyl, SN, and Beaver, WL. Anaerobic threshold and respiratory gas exchange during exercise. *J Appl Physiol* 35: 236–243, 1973.

24. Widmeyer, WN, Brawley, LR, and Carron, AV. Group dynamics in sport. In: *Advances in Sport Psychology*. T. Horn, ed. Champaign, IL: Human Kinetics, 2002. pp. 285–308.