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Otter, Tina Ardi

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CHAPTER 3

Monitoring training intensity, submaximal heart rate and running economy of competitive runners

(Submitted)

Ruby T.A. Otter

Michel S. Brink

Koen A. P. M. Lemmink

ABSTRACT

The purpose was to quantify training intensity and study its relation with submaximal heart rate (HR) and running economy (RE) of competitive runners over an entire training season. Eighteen middle- and long-distance runners (age: 23 ± 4 years) were monitored 46 weeks by daily training logs and seven submaximal performance tests. Training duration was recorded in minutes and intensity was measured by session Ratings of Perceived Exertion (sRPE). Training duration was divided into three intensity zones: Zone 1, sRPE ≤ 13 ; zone 2, sRPE 14–16; zone 3, sRPE ≥ 17 . HR and RE were measured by submaximal treadmill tests. 5229 training sessions/races and 73 tests were examined using multilevel analyses. Training duration was 8.2 ± 1.0 hours/week. Duration in zone 1, 2 and 3 was $45 \pm 21\%$, $42 \pm 23\%$ and $13 \pm 15\%$, respectively. Based on sRPE-zones, more training in zone 1 was related to lowered HR, but not to RE. Training in zone 2 was not associated to changes in HR and RE. Increasing training in zone 3 seemed to be disadvantageous to submaximal HR and RE. This research showed that there is large variation in training intensity and that it may be beneficial for HR and RE to change perceived high intense training to low intense training.

Keywords: Athletes; Submaximal test; Athletic training; Multilevel model; Training zones

INTRODUCTION

For high level coaches and athletes it is important to know how training intensity affects individual responses to training. However, there is an ongoing discussion about standardised tests that can be performed regularly to detect changes in training responses during a full season. Although race performance is the most important parameter of training adaptation, this parameter has its limitations since it is influenced by, for example, environmental conditions, terrain and head-to-head competition. The most frequently used standardised parameter to predict middle- and long distance race performance is maximal rate of oxygen consumption ($\dot{V}O_{2max}$). To determine $\dot{V}O_{2max}$ and race performance maximal effort of the runner is required, which may interfere with the training schedule if the runner is asked to perform regularly at maximal effort. Moreover, a reliable $\dot{V}O_{2max}$ can only be obtained if runners are highly motivated [2]. This may not be the case when performed several times. Yet, it is known that $\dot{V}O_{2max}$ is not the best measure to determine improvements in race performance of highly trained athletes [20,33]. Therefore, submaximal tests may be more suitable for monitoring purposes, as outcomes are not dependent on motivation, and there is no exceptional physical stress that may disturb the training program.

Commonly used submaximal test parameters to measure training responses are submaximal heart rate (HR) and running economy (RE) [7,30,36]. It is well-established that submaximal HR at a standardised exercise intensity is a marker of physical fitness when considered within the same subject. RE is an important factor of endurance running performance which is defined as the energy expenditure at a certain running speed below the anaerobic threshold [16]. Both submaximal HR and RE can be improved by low intensity training [3,24]. In addition, it is known that high intensity training induces improvements in submaximal HR and may improve RE [10]. Changes in these parameters should be put into individual perspective because of a large inter-individual variation [27].

To quantify low, middle and high intensity training, a classification of three intensity zones by thresholds derived from energy metabolism was proposed [23]. Several methods that were based on these thresholds have been used, such as zones derived from heart rate (HR) measures and from session Rating of Perceived Exertion (sRPE) [37].

The influence of training duration in three intensity zones on running performance has been monitored in a few studies [14,17,31]. Two of these studies observed how endurance runners actually train by monitoring their heart rate during training sessions [14,17]. According to Esteve-Lanao et al. (2005), only cumulative training duration in zone 1 and performance during actual short races (4.175 km) were related. Conversely, Galbraith et al. (2014) showed that total distance covered (training volume) and training above the lactate threshold (that is zone 2 and 3 combined) was related to critical speed calculated from maximal effort during a field test [17]. Both studies used group-level analyses, that is, correlational analyses in which individual development was not taken into account. Therefore, questions remain about the relationship between training intensity and training response when the individual component is taken into account.

Previous research in which relationships between training intensity and training responses was determined has its limitations because of the short-term intervention designs. In addition, the longitudinal studies used group-level analyses in which individual changes in training intensities and training responses were not taken into account and/or used tests that require maximal effort. Thus, there is a need for studies that measure training intensity and assess changes in submaximal HR and RE in highly standardized conditions. Furthermore, these changes need to be analysed taking individual development into account. Therefore, the first goal of this study was to quantify training intensity distribution of competitive runners for an entire season. The second goal was to investigate the relationship between training duration in the intensity zones and submaximal HR and RE over an entire training season with an individual approach by using multilevel analyses with random intercepts.

METHODS

Participants

Eighteen Dutch competitive middle- and long-distance runners participated in this study, including athletes who compete regional, national and international. All runners (12 male, 6 female) trained within the same team led by the same coach who prescribed the training of each athlete including group sessions and

individual sessions. Age, height and body mass (mean \pm SD) were 23 ± 4 years, 1.82 ± 0.05 m and 66.2 ± 7.0 kg, respectively.

Design

During one training season (46 weeks) runners were monitored with a daily training log and 7 submaximal tests (ST1 - ST7). All runners performed a maximal incremental treadmill test one to two weeks before the first submaximal test to design individualized submaximal tests. Before participation, a sport physician medically cleared all runners according to the Lausanne recommendations [5] and a written informed consent was obtained. The study was approved by the local ethics committee and meets the ethical standards of the journal [18].

Training intensity

After each training session and race, all runners recorded duration (in minutes) and intensity (including warm up and cool down) in a training log. Intensity was measured using session Ratings of Perceived Exertion (sRPE) 30 minutes after the session. This procedure is known to be a valid method to determine global intensity [15]. Since in the Dutch education system grades are given on a scale from 1-10 (of which 1 means 'very bad' and 10 means 'excellent'), we used the original scale from 6-20 to avoid confusion of athletes [6]. This original scale was previously proposed for monitoring training [22] and was successfully used in several sports [8,32]. Three intensity zones were then calculated by dividing sRPE data based on the same intensity anchors (verbal expressions) at breakpoints, established by Seiler and Kjerland [37]. Zone 1 (TZ1) consists of sRPE \leq 13 (below and including somewhat hard), zone 2 (TZ2) consists of 1 sRPE 14 – 16 (between somewhat hard and very hard) and zone 3 (TZ3) consists of sRPE \geq 17 (very hard and above). Total training duration (TD) and time spent in each zone were calculated over 6 weeks before each submaximal test. TZ1, TZ2, TZ3 and TD were divided by 60 to transform minutes into hours.

Maximal incremental test

At the beginning of the running season, that is ~2 weeks before the initial submaximal test, all runners performed a maximal incremental treadmill test. Running speed during the warm-up phase was determined individually,

depending on the runner's maximal speed that was predicted by their coach, in order to finish the test in 8 to 12 minutes [25]. After five minutes, the speed continuously increased by 0.8 km/h per minute. The runners were instructed to run until exhaustion, whilst they were verbally encouraged continuously. $\dot{V}O_{2max}$ was defined as the highest 30 second rolling average of $\dot{V}O_2$ observed during the test. Peak speed (V_{peak}) was defined as the highest speed that was attained by the runner during the test. Maximal heart rate (HR_{max}) was determined as the highest HR during the test.

Submaximal test

All runners were familiarized with the testing equipment and to the submaximal test protocol. The total duration of the submaximal test was 15 minutes. Running speed was set for 6 minutes at 55% (00:00–06:00 min:s) and 70% V_{peak} (6:00–12:00 min:s), followed by 3 minutes at 85% V_{peak} (12:00–15:00 min:s) (Figure 1). Runners were asked for their Ratings of Perceived Exertion (RPE) 30 seconds before the end of each stage (after 5:30, 11:30 and 14:30 min:s, respectively).

HR and RE were calculated as training responses. HR during stage 1 (HR1) (3:00–6:00 min:s) and stage 2 (HR2) (9:00–12:00 min:s) was calculated as an average of HR over the last 3 minutes of both stages. Due to the slow half-life of heart rate [1], the first minute of stage 3 was excluded from the analysis, which means that heart rate in stage 3 (HR3) was calculated over the last 2 minutes (13:00 - 15:00 min:s). HR1, HR2 and HR3 are expressed as a percentage of individual HR_{max} which was determined by the maximal incremental treadmill test. RE is defined as steady state $\dot{V}O_2$ during submaximal running [35]. Three minutes of exercise after an intensity change is required to reach steady state $\dot{V}O_2$ [21]. Therefore, $\dot{V}O_2$ is only calculated for stage 1 and stage 2 of the submaximal test. $\dot{V}O_2$ during stage 1 and 2 ($\dot{V}O_{2-1}$ and $\dot{V}O_{2-2}$, respectively) was averaged over the same intervals as HR1 and HR2. $\dot{V}O_{2-1}$ and $\dot{V}O_{2-2}$ are expressed as a percentage of individual $\dot{V}O_{2max}$ in order to cope with a possible effect of initial individual differences in capacities.

A preliminary study in our laboratory showed that the day-to-day variation of HR and $\dot{V}O_2$ during the submaximal treadmill test is 1-2% and 3%, respectively. These day-to-day variations are in line with previously measured variations [1,36]. All tests were performed in similar environmental conditions (temperature: $18.8 \pm$

0.9; relative humidity: 39.7 ± 11.6) on the same treadmill (Lode Valiant, Groningen, the Netherlands). During all tests, the slope of the treadmill was set at 2%. Gas exchange data were measured using an automated breath-by-breath analyser (Cortex Metalyzer 3b, Leipzig, Germany) and heart rate was recorded every second (Polar, Kempele, Finland). Each morning before testing, the equipment was calibrated according to the manufacturer's guidelines. Runners refrained from strenuous exercise and drinking alcohol the day before each test and consuming caffeine in the last three hours before each test.

In total, data of 5229 training sessions and races were collected. Thirty-seven sRPE values and 68 duration values were missing, that is 0.7% and 1.3%, respectively. In total, 73 submaximal running tests were conducted.

Statistical analyses

Descriptive statistics were determined for all parameters and represented as mean \pm SD. The data were analysed using the multilevel modelling program MLwiN [34]. The advantage of MLwiN is that the number of repeated measurements per participant is allowed to vary (e.g. because of missing data), which was the case in the longitudinal design of this study. Multilevel modelling is an extension of multiple regression analysis developed for analysing clustered data. Clustered data are, for example, repeated measurements (level 1) of participants (level 2). By clustering the data, the opportunity is provided to determine if the effect of a predictor (e.g. training load) on the test variable (e.g. running economy) is larger than within-individual variation. First, intercept-only models (i.e. empty models) with two levels (level 1: measurement, level 2: participant) were created for all training responses (HR1, HR2, HR3, $\dot{V}O_{2-1}$ and $\dot{V}O_{2-2}$) using random intercept models. Random intercepts are used to make the analysis more specified to the individual so that the data of each participant is can have another intercept. Second, 6 predictor variables were added separately to the intercept-only model to investigate explained variance of the training responses by constant variables (sex and age at the start of the study) and training parameters (i.e. TD, TZ1, TZ2 and TZ3). Since longitudinal monitoring of high level competition runners limits sample size, all parameters were added separately to ensure sufficient power. Significance (set at 0.05) of explained variance of training responses by all variables was evaluated by comparing the -2

log likelihood of the intercept-only model with the models that included a predictor variable.

RESULTS

Training intensity

On average, each athlete performed 291 ± 58 training sessions over 46 weeks, ranging from 201 to 419 training sessions over the course of the study. Average training duration was 8.2 ± 1.0 hours per week, ranging from 5.6 to 10.7 hours per week. Average TZ1, TZ2 and TZ3 over the entire period was $45 \pm 21\%$, $42 \pm 23\%$ and $13 \pm 15\%$, respectively. However, the large SD's show a wide variation in training intensity distribution between runners. Average sRPE in TZ1, TZ2 and TZ3 was 12 ± 1 , 15 ± 1 and 18 ± 1 , respectively. Figure 1 shows descriptive statistics of training parameters calculated for every 6-week period prior to the submaximal tests.

The average values that were attained during the maximal incremental treadmill test were for male runners ($n=12$): $\dot{V}O_{2max}$, 64.3 ± 5.1 mL \cdot kg⁻¹ \cdot min⁻¹; V_{peak} , 5.9 ± 0.2 m/s and HR_{max} , 190 ± 9 bpm. For female runners ($n=6$) these values were: $\dot{V}O_{2max}$, 57.0 ± 4.5 mL \cdot kg⁻¹ \cdot min⁻¹; V_{peak} , 5.1 ± 0.2 m/s and HR_{max} , 187 ± 11 bpm. Averages of HR, $\dot{V}O_2$ and RPE during the submaximal running test are shown in Table 1.

Sex and age did not significantly explain any of the variance of the training responses. Table 2 shows fixed (intercept and estimate) and random (level 1 and 2) effects, $-2\log$ -likelihood and significance values of the training response models. In Table 3, only the estimates that significantly explain variance of training responses are shown.

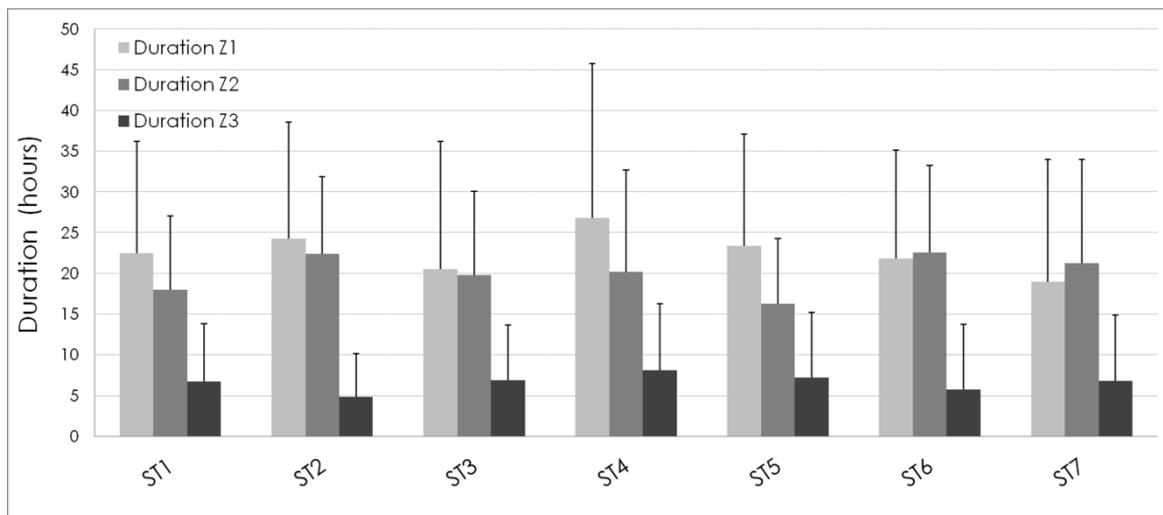


Figure 1. Training intensity distribution over each 6-week period before submaximal running tests. ST1 – ST7 indicate the moments of the submaximal running tests. Total training duration in hours over 6 weeks was ST1, 47.2 ± 14.9 ; ST2, 51.6 ± 12.2 ; ST3, 47.2 ± 17.7 ; ST4, 55.2 ± 19.9 ; ST5, 46.9 ± 15.7 ; ST6, 50.1 ± 14.2 ; ST7, 47.1 ± 16.4

Table 1. Physiological and subjective responses to the submaximal running test (ST) (mean \pm SD)

	ST1 (n = 13)	ST2 (n = 14)	ST3 (n = 11)	ST4 (n = 12)	ST5 (n = 9)	ST6 (n = 9)	ST7 (n = 5)
Stage 1							
HR1 (%)	73.9 ± 3.6	72.7 ± 3.9	72.9 ± 3.6	73.2 ± 3.2	74.2 ± 5.5	73.6 ± 5.0	69.5 ± 3.0
$\dot{V}O_{2-1}$ (%)	66.0 ± 4.1	64.6 ± 4.1	69.6 ± 5.7	70.2 ± 5.5	74.7 ± 5.1	71.9 ± 6.5	69.1 ± 4.8
RPE (units)	10 ± 2	10 ± 2	9 ± 2	10 ± 2	10 ± 1	10 ± 2	9 ± 2
Stage 2							
HR2 (%)	86.4 ± 3.1	86.1 ± 3.0	85.1 ± 2.6	85.6 ± 3.4	86.6 ± 4.5	85.4 ± 4.0	82.5 ± 2.3
$\dot{V}O_{2-2}$ (%)	82.9 ± 5.5	81.0 ± 4.8	87.5 ± 5.0	88.9 ± 5.8	94.5 ± 6.3	91.2 ± 8.2	89.6 ± 7.1
RPE (units)	13 ± 2	13 ± 2	13 ± 2	12 ± 2	13 ± 2	14 ± 2	12 ± 2
Stage 3							
HR3 (%)	93.1 ± 2.6	93.6 ± 2.3	92.7 ± 2.1	92.9 ± 2.7	93.5 ± 2.9	92.3 ± 2.6	90.8 ± 1.7
RPE (units)	16 ± 1	15 ± 1	16 ± 2	15 ± 1	16 ± 2	16 ± 2	15 ± 2

All included runners are from the same group of 18 runners. Heart rate (HR) is expressed as a percentage of individual maximal HR. Running economy ($\dot{V}O_2$) is expressed as a percentage of individual $\dot{V}O_{2max}$. RPE = Rating of Perceived Exertion

Table 2. Multilevel models of submaximal performance parameters

n = 73		<i>Fixed</i>		<i>Random</i>		-2*	p
		Intercept (constant)	Estimate	Level 2 (between runners)	Level 1 (within runners)		
HR1	Empty model	73.19 (0.82)		10.60 (4.06)	5.64 (1.08)	371.3	-
	TZ3	71.99 (0.93)	0.15 (0.07)	9.15 (3.56)	5.37 (1.02)	366.2	0.024
HR2	Empty model	85.70 (0.68)		7.05 (2.75)	4.24 (0.81)	348.6	-
	TD	90.79 (1.84)	-0.10 (0.03)	5.27 (2.13)	4.00 (0.76)	340.8	0.005
	TZ1	87.47 (0.98)	-0.07 (0.03)	5.32 (2.16)	4.21 (0.80)	343.9	0.030
HR3	Empty model	92.95 (0.49)		3.51 (1.42)	2.67 (0.51)	311.3	-
	TD	96.55 (1.43)	-0.07 (0.03)	2.99 (1.23)	2.48 (0.47)	304.6	0.010
$\dot{V}O_{2-1}$	Empty model	68.31 (1.13)		18.74 (7.60)	14.69 (2.80)	435.3	-
$\dot{V}O_{2-2}$	Empty model	86.41 (1.36)		26.04 (11.04)	25.56 (4.87)	472.4	-
	TZ3	83.99 (1.75)	0.30 (0.13)	29.96 (12.10)	22.70 (4.33)	467.5	0.027

Multilevel models for heart rate during the three stages of the submaximal running test (HR1, HR2 and HR3) and running economy during two stages of the submaximal running test ($\dot{V}O_{2-1}$ and $\dot{V}O_{2-2}$). For all test parameters empty models are shown in which these parameters are estimated according to one fixed factor (intercept). Next to the empty models, the models for HR and RE including training parameters which add to the model significantly are displayed. The estimate is average change in predicted HR or RE when training increases with 1 hour (either of total duration (TD), duration in zone 1 (TZ1), duration in zone 2 (TZ2) or duration in zone 3 (TZ3)) in 6 weeks prior to the test. All values are given as estimates and standard errors (SE).

Table 3. Estimated changes in test parameter

	HR1	HR2	HR3	$\dot{V}O_{2-1}$	$\dot{V}O_{2-2}$
TD	.	- 0.60%	-0.42%	.	.
TZ1	.	- 0.42%	.	.	.
TZ2
TZ3	+ 0.9%	.	.	.	+ 1.8%

Estimated changes in submaximal test parameters if runners train one hour per week more over 6 weeks in total duration (TD), zone 1 (TZ1), zone 2 (TZ2) and zone 3 (TZ3). For example, if an athlete increases TD with 1 hour each week over 6 weeks, the predicted HR2 decreases with 0.60% of individual maximal HR. These values are calculated from estimates that are derived from the multilevel models. Heart rate (HR) is expressed as a percentage of individual maximal HR. Running economy ($\dot{V}O_2$) is expressed as a percentage of individual $\dot{V}O_{2max}$. RPE = Rating of Perceived Exertion. Only significant variables are included.

Submaximal heart rate

Variance of HR1 (Table 2) was significantly explained by TZ3 with an increase of one hour of TZ3 per week over six weeks that was related to an increased HR1 by 0.9% (Table 3). Variance of HR1 was not explained by TD, TZ1 and TZ2.

The models for HR2 and HR3 showed that TD significantly explained variance (Table 2). One extra hour TZ1 per week over six weeks decreased HR2 and HR3 with 0.60% and 0.53% of individual HR_{max} , respectively. Variance of HR2 was also significantly explained by TZ1. It was shown that HR2 decreased by 0.42% when TZ1 would be increased by 1 hour per week over 6 weeks (Table 3).

Running economy

Variance of $\dot{V}O_{2-1}$ was not explained by training parameters. However, increased $\dot{V}O_{2-2}$ was significantly explained by increased TZ3 (Table 2 and Table 3). That is, if runners trained one hour per week more in zone 3 over a period of six weeks, their predicted $\dot{V}O_{2-2}$ would be 1.8% (of $\dot{V}O_{2max}$) higher (Table 3).

DISCUSSION

The design of this study enabled quantifying training intensity of competitive runners and took a first step to investigate its relationship to submaximal HR and RE over the course of an entire training season. The key findings of this study were that 1) the runners showed a large variation of training duration at 3 intensity

zones; 2) increased duration of perceived low intensity training and decreased duration of perceived high intensity training seems to be related to improved submaximal HR and RE. These findings may sound counter intuitive; therefore, we will put these into perspective in the following discussion.

The current results show that average TZ1, TZ2 and TZ3 over the entire 46-week period was 45%, 42% and 13%, respectively. These results differ from observations in previous studies which show substantially more TZ1 and less in TZ2, but they are comparable with regard to TZ3 [14,17,26,31,37,38]. The discrepancies between training intensity distribution in the current study and previous studies can be due to varying measurement methods or they can be caused by differences in training regimen. We determined training duration in the three intensity zones by self-reported duration and sRPE scores. However, some of the previous studies quantified training intensity distribution according to HR measurements. These differences may explain our finding of a remarkably lower percentage of TZ1 and higher TZ2 compared to other observations. However, our observed training intensity distribution is also not consistent with that of other studies using comparable methods [26,37,38]. Although we have used the exact same anchors as were proposed by Seiler & Kjerland (2006), we have used the 15-point scale [6] instead of the 10-point scale to rate perceived exertion [15]. Because of the concise anchors, it is unlikely that the differences can be explained by our method [11]. Therefore, the explanation for the discrepancy is probably that training regimens of the runners in our study differed from training regimens of runners [14], cross-country skiers [26,37] and triathletes [31].

Results of the current study showed that one hour of TZ3 predicted a 0.9% higher HR1 (Table 3). So to decrease HR1 more than the day-to-day variation (i.e. $\sim 1\text{-}2\%$ of HR_{\max} [1]), TZ3 should be decreased by at least 1:07 h:min per week over 6 weeks. Predicted HR2 was reduced by more TZ1 with an increase of one hour per week in TZ1 over a 6-week period predicting a decrease in HR2 by 0.42% (Table 3). Therefore, an increase of at least 2:23 h:min per week in TZ1 over 6 weeks was contributing to a meaningful decrease in HR2. For positive changes beyond day-to-day variation in HR2 and HR3, total training duration should be increased by at least 1:40 h:min and 2:23 h:min per week over 6 weeks, respectively. That is, because a difference of one hour in total training duration contributed -0.60% and -0.42% to predicted HR2 and HR3, respectively (Table 3).

An increase in total training duration of at least 1:40 h:min per week (i.e. ~28% increase) is not always feasible. Therefore, total training duration does only contribute to a meaningful changes in predicted submaximal HR if that kind of increase is possible for the athlete.

Previously it has been shown that submaximal HR of runners decreased after a period of endurance training [4,9]. By adding high intensity training, submaximal HR can show a further decrease [4]. It has also been reported that HR measures would not change after a period of exhaustive endurance training, which induced a status of overtraining [39]. It was suggested that athletes who cope well with the training volume and/or intensity show a lowered submaximal HR and athletes who are training too much do not show the improvement. Therefore, our finding of increasing submaximal HR with increasing TZ3 infers that the runners in our study may train too much and/or too intense and cannot cope with additional TZ3.

Results of the current study showed that runner's predicted $\dot{V}O_{2-2}$ increased by 1.8% (of individual $\dot{V}O_{2max}$) if TZ3 was increased by one hour per week in a 6-week period (Table 3). However, to reach a larger decrease in predicted $\dot{V}O_2$ (i.e. a decreased submaximal $\dot{V}O_2$ is an improved RE) than the intra-individual variation (1.5 – 5% [36]), TZ3 should be decreased by at least 50 minutes per week over 6 weeks to reach a meaningful decrease in predicted $\dot{V}O_{2-2}$. Decreasing TZ3 by that amount was not possible for all runners, as some runners did not spend that much time in TZ3. This means that changes in TZ3 cannot elicit a meaningful change in predicted $\dot{V}O_{2-2}$ for all runners. However, it illustrates that TZ3 may have a negative effect on RE.

In a recent review it was described that training at comparable intensities to TZ2 and TZ3 can improve RE [3]. Our findings suggest that TZ2 is not related to improvements in RE and that an increase in TZ3 is related to a decrease in RE. These contradictory findings may be explained by the relatively high training load and relatively low capacities of our runners (e.g. $\dot{V}O_{2max}$). For example, a previous study reported 7 hours of training per week in runners with a $\dot{V}O_{2max}$ of 70 mL·kg⁻¹·min⁻¹ [4]. In contrast, our runners trained over 8.2 hours with lower physical capacities ($\dot{V}O_{2max}$ female: 57.0 mL·kg⁻¹·min⁻¹ and male: 64.3 mL·kg⁻¹·min⁻¹). This may explain the negative contribution of TZ3 to training responses of runners in our study. Moreover, the training intensity in our study is measured by sRPE, which

means that athletes rate the intensity of their own training. Accumulated fatigue may have resulted in a higher perception of training intensity leading to a larger proportion of time spent in TZ3. The relationship between more TZ3 and decreased RE may thus be a result of overtraining. It has been shown in previous research that mental fatigue increases sRPE [28]. Therefore, for future research, it may be helpful to include psychological measures as well.

A limitation of this study may be the heterogeneity of the runners in terms of sex, age, and physical capacities (i.e. $\dot{V}O_{2max}$). However, there was no significant contribution of sex and age to submaximal HR and $\dot{V}O_2$. Moreover, corrections were made for physical capacities since submaximal HR and $\dot{V}O_2$ are calculated as a percentage of individual HR_{max} and $\dot{V}O_{2max}$, respectively. This also explains why no significant influence was found of sex and age on the prediction of most training responses. Finally, since a multi-level structure was used, individual patterns of development were taken into account. Therefore, it is also justified that male and female athletes of different capacities and age were included in this study.

In the current study, we used advanced statistical modelling to analyse complex longitudinal data. This type of analysis has been used previously in sport sciences, for example, to investigate dribbling development [19], training and performance of soccer players [8,12,13,40]. Major advantages are that these models take individual differences into account and are able to handle missing values in an accurate way. Similar to correlation and regression, these models assume linearity. However, from a theoretical training perspective, this may not be realistic. Runners cannot train at an infinite volume because a ceiling effect occurs following the law of the diminishing returns. Even a downward curve in performance after too large training volumes may be observed [29]. Also, it is likely that training characteristics interact and that the sole contributions that are observed in the current study are dependent on overall training distribution. Therefore, care should be taken when interpreting these results.

Conclusions

Monitoring training intensity with the sRPE method is a practical method which can lead to relevant information for coaches. While the associations we observed do not prove causation, it was shown that an increase in TZ1 may be beneficial,

TZ2 may be neutral and an increase in TZ3 may be disadvantageous to training responses of middle- and long distance runners if the training load may not match the training status. However, future research should focus on establishing the cause-and-effect relationship between sRPE based training intensity and the interaction of training intensities and performance by means of long term intervention studies.

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