Quantifying the training intensity distribution in middle-distance runners: the influence of different methods of training intensity quantification

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ABSTRACT

Purpose: The present study aimed to compare the training intensity distribution (TID) across an 8 week training period in a group of highly-trained middle-distance runners employing three different methods of training intensity quantification. **Methods:** Fourteen highly-trained middle-distance runners performed an incremental treadmill test to exhaustion to determine the heart rate and running speed corresponding to the ventilatory thresholds (gas exchange threshold and respiratory compensation threshold), as well as fixed rating of perceived exertion (RPE) values, which were used to demarcate three training intensity zones. During the following 8 weeks, the TID (total and percentage of time spent in each training zone) of all running training sessions (n=695) were quantified using continuous running speed and heart rate monitoring, and RPE. **Results:** Compared to the running speed derived TID (zone 1:79.9% $\pm$ 7.3%, zone 2:5.3% $\pm$ 4.9%, zone 3:14.7% $\pm$ 7.3%), heart rate demarcated TID (zone 1:79.6% $\pm$ 7.2%, zone 2:17.0% $\pm$ 6.3%, zone 3:3.4% $\pm$ 2.0%) resulted in a substantially higher training time in zone 2 (ES95%CI: -1.64 $\pm$ 0.53, p <0.001) and lower training time in zone 3 (-1.59 $\pm$ 0.51, p <0.001). RPE derived TID (zone 1:39.6% $\pm$ 8.4%, zone 2:31.9% $\pm$ 8.7%, zone 3:28.5% $\pm$ 11.6%) reduced time in zone 1 compared to both heart rate (-5.64 $\pm$ 1.40, p <0.001) and running speed (-5.69 $\pm$ 1.9, p <0.001), while time in RPE training zones 2 and 3 were substantially higher than both heart rate and running speed derived zones. **Conclusion:** Our results show that the method of training intensity quantification substantially affects the computation of the TID.

Keywords: TRAINING LOAD; TRAINING ZONE; EXTERNAL LOAD; INTERNAL LOAD.

INTRODUCTION

In order to induce performance improvements in well-trained athletes, modifications in training load are required, which typically arise from manipulations in the frequency, duration, and/or intensity of training. Of these training prescription variables, the way in which athletes distribute their training across the training intensity spectrum (i.e., training intensity distribution; TID) is considered to be a key determinant of training and performance adaptations.¹⁻⁵ Training intensity can be measured via external work rate (running speed or power output),^{6,7} an internal physiological response (i.e., heart rate or VO_2),^{8,9} or by how the training is perceived (i.e., rating of perceived exertion; RPE).¹⁰ To further guide training prescription and monitoring, training intensity zones have been employed, and while there is not yet a consensus on the most appropriate training zone model, models with up to 7 training zones have been described.^{1,11} Typically, the 3 zone model is demarcated by physiological thresholds such as the lactate thresholds (LT1 and LT2)¹² or ventilatory thresholds (VT1 and VT2),² forming 3 training zones (i.e., zone I: $<\text{VT1/LT1}$, zone II: between VT1/LT1 and VT2/LT2 and zone III: $>\text{LT2/VT2}$). There is strong evidence from experimental studies^{3-5,13} suggesting that the TID adopted by an athlete greatly affects the resultant performance and physiological adaptations. Furthermore, elite athletes aim to periodise their TID throughout different training phases within a season in order to peak for important competitions.¹⁴⁻¹⁶ As such, it is important to recognize the most appropriate methods of monitoring training intensity in order to precisely quantify the TID.

While there remains to be a consensus on the nomenclature and exact nature of the various TID approaches, a recent review¹ highlighted five patterns of TID; 1) high-volume, low-intensity training, which is composed of an extremely high training volume almost exclusively in zone 1 ($>90\%$); 2) polarized, whereby $\sim 80\%$ of total training volume is performed in zone 1, $\sim 20\%$ is performed in zone 3, with little or none in zone 2; 3) threshold training, whereby a much

higher volume of training is performed in zone 2 (>20%), with relatively little or none in zone 3, while the balance of training volume is accumulated in zone 1; 4) pyramidal, in which the majority of training volume is accumulated in zone 1 (~80%), and a decreasing proportion of training volume is accrued in zones 2 and 3; and 5) high-intensity training, whereby a high proportion of training includes high-intensity interval training in which a larger training volume is accumulated in zone 3 (~40%), while the balance of training volume is accumulated in zone 1 through low-intensity rest periods.

A host of studies^{2,11,17,18} have shown that elite endurance athletes tend to self-organize their training toward a polarized TID approach, while other observational studies show pyramidal,^{16,19} or high-volume low-intensity distributions.^{14,15} Indeed, there seems to be a non-uniform TID between endurance disciplines^{15-17,20} and even within endurance disciplines across different studies.^{7,17,18,21} These differences between studies may relate to the duration or phase of the training season that was monitored,¹ the method of establishing training zone demarcations (i.e., incremental test protocol and method of threshold determination),¹² or the training intensity quantification method itself.⁶ Indeed, comparisons between studies are problematic because some studies have employed RPE,¹⁸ fractions of the velocity at VO_{2max} ,²² heart rate,⁷ running velocity,¹⁷ or lactate,¹⁴ or ventilatory thresholds¹⁶ to demarcate the boundaries between training zones, and subsequently quantify the TID. Only one previous study⁶ has investigated how the TID is influenced by an internal, external and perceptual measure of training intensity quantification. Sanders et al.⁶ employed heart rate, power output and RPE demarcations to categorize the TID of fifteen well-trained road cyclists over a 10-week training period. The time spent in zone 1, zone 2 and zone 3 was moderate to very largely different for RPE (44.9%, 29.9%, 25.2%) compared to heart rate (86.8%, 8.8%, 4.4%) and power output (79.5%, 9.0%, 11.5%), while there was a higher proportion of time spent with the power output in zone 3 compared to heart rate in zone 3. Whether these findings would also

be apparent in other endurance sports, such as middle-distance running, where the type, content and duration of training sessions are very different, remains to be determined. Therefore, the aim of the present study was to compare the distribution of training intensity in a group of highly-trained middle-distance runners employing three different methods of training intensity quantification.

METHODOLY

Participants

Fourteen highly-trained middle distance runners participated in this study. Four runners were female (mean $\pm$ SD: age 19.5 $\pm$ 2.7 y, stature 170.9 $\pm$ 4.1 cm, body mass 52.4 $\pm$ 5.0 kg, VO_{2max} 64.6 $\pm$ 0.5 ml $\cdot$ kg $\cdot$ min⁻¹) and ten were male (age 20.2 $\pm$ 2.9 y, stature 182.1 $\pm$ 4.0 cm, body mass 71.3 $\pm$ 5.7 kg, VO_{2max} 72.0 $\pm$ 4.7 ml $\cdot$ kg $\cdot$ min⁻¹). The male runners had personal best running times for the 800 m and 1500 m of 116.6 $\pm$ 5.0 s (range: 111.2–126.1 s) and 237.1 $\pm$ 8.0 s (230.3–251.1 s), respectively, while the females had times of 132.8 $\pm$ 6.7 s (124.2–140.1 s) and 274.0 $\pm$ 12.1 s (257.1–284.2 s), respectively. All runners provided written informed consent prior to participating in this study which was approved by the Griffith University Human Research Ethics Committee.

Experimental design

Training data were collected for an 8 week period from October to December which was the general preparation phase for the upcoming competitive season. In the week prior to the beginning of the monitoring period, all runners performed an incremental treadmill run to establish three training intensity zones. The training zones were demarcated by the running speed and heart rate corresponding to the gas exchange threshold (GET) and the respiratory compensation threshold (RCT) and fixed RPE values (training zone 1: 0-4, training zone 2: 5-6, training zone 3: 7-10). The TID (total and percentage of time spent in each training zone) of

all running training sessions were quantified using continuous running speed and heart rate monitoring, and RPE.

Training zone determination

Each participant performed an incremental treadmill running test to volitional exhaustion starting at 12 km·h⁻¹ and 1% gradient with the speed increasing by 1 km·h⁻¹ until exhaustion. Heart rate (H10, Polar Electro, Oy, Finland) and respiratory variables (Cosmed Quark b²; Rome, Italy) were measured, while RPE was measured at the end of each stage. Exhaled air was analyzed to determine oxygen consumption (VO₂), carbon dioxide production (VCO₂) and minute ventilation (V_E). The GET was determined using the V-slope method described by Beaver et al.²³ while the RCT was determined using the V_E-versus-VCO₂ relationship also described by Beaver et al.²³ Two independent observers made threshold determinations. If there was disagreement between the two observers, a third was consulted. Heart rate and VO₂ values corresponding to GET and RCT were determined, as well as the maximal heart rate (HR_{max}) which was taken as the highest 10 s mean heart rate value during the test. VO_{2max} was determined as the highest 30-s VO₂ value.

Training intensity distribution analyses

Rating of perceived exertion

Participants were provided with a training diary which instructed them to rate the global intensity of all training sessions and races using a modified category ratio scale going from 0 to 10.¹⁰ The scale was graduated unit by unit and with the following correspondence: 0 = rest, 1 = very weak, 2 = weak, 3 = moderate, 4 = somewhat hard, 5 = hard, 7 = very hard, 10 = maximal. Participants were instructed to complete their RPE training diary 30 min after completion of each training session. The 10-point scale was divided into three training zones based on fixed RPE values with training zone 1 = RPE of 1–4, training zone 2 = RPE of 5–6;

and training zone 3 = RPE of 7-10 which is in line with previous research.^{2,6} The total training time spent with an RPE within each one of these RPE derived training zones was determined.

Heart rate

All participants wore a heart rate chest strap (H10, Polar, Kempele, Finland) and wrist watch (M430, Polar, Kempele, Finland) for all running training sessions. Continuous heart rate data was downloaded from each running session and was used to determine the TID by quantifying the time spent with a heart rate in each training zone using the manufacturer software (Polar Flow, Polar Inc., Kempele, Finland). Training zones were quantified according to the reference heart rate values obtained during the incremental treadmill running test: zone I (<GET), zone II (between GET and the RCT) and zone III (>RCT).

GPS

As a measure of external training intensity, the training time spent within each of three training zones was derived from the running speed data that was collected during each training session from a GPS running watch (M430, Polar, Kempele, Finland). The three training zones were derived from the reference running speed values that corresponded to the GET and RCT values obtained during the incremental treadmill running test: zone I (<GET), zone II (between GET and the RCT) and zone III (>RCT). The total training time spent within each one of these speed-based training zones was determined.

Statistical analysis

Results are expressed as mean $\pm$ SD unless stated otherwise. A two-way analysis of variance with Bonferroni pairwise comparisons was used to identify differences between TIDs assessed using RPE, heart rate and running speed. The effect size (*d*) statistic with upper and lower 95% confidence intervals (CI) were also calculated to assess the magnitude of difference between TID. The magnitude of difference was classified as trivial <0.2, small 0.2 to 0.6, moderate 0.6

to 1.2, large 1.2 to 2.0, and very large 2.0 to 4.0. All statistical analyses were performed using SPSS 25.0 (SPSS Inc, Chicago, IL, USA), with statistical significance accepted as $P < .05$.

RESULTS

Table 1 shows the physiological and performance characteristics from the incremental running test of the male and female subjects. A total of 721 running training sessions were completed by the subjects in the 8-week study period according to training diaries, with 695 training sessions being included in the final analysis as these were accompanied by a complete GPS and heart rate data set. Table 2 shows the total training time spent in each training zone for each training intensity quantification method.

Figure 1 shows the TID for all training sessions where heart rate, RPE and running speed were recorded. RPE training zone demarcations resulted in $39.6\% \pm 8.4\%$ of running training time being performed at an intensity of ≤ 4 on the RPE scale, $31.9\% \pm 8.7\%$ of running training time in the middle of the scale (4.5 to 6.5) and $28.5\% \pm 11.6\%$ of running training time being rated as ≥ 7 . Heart rate derived time in zone resulted in a pyramidal TID with $79.6\% \pm 7.2\%$ of total training time in zone 1, $17.0\% \pm 6.3\%$ in zone 2 and $3.4\% \pm 2.0\%$ in zone 3. Heart rate derived time in zone 1 was substantially higher than RPE time in zone 1 ($ES \pm 95\%CI$ 5.64 ± 1.40 , *very large*, $p < 0.001$) while time in heart rate zone 2 and 3 were substantially lower than RPE time in zone 2 (-2.11 ± 0.54 , *very large*, $p < 0.001$) and 3 (-3.53 ± 0.9 , *very large*, $p < 0.001$). Running speed training zone demarcations resulted in a polarized distribution of $79.9\% \pm 7.3\%$, $5.3\% \pm 4.9\%$ and $14.7\% \pm 7.3\%$ of total training time spent in training zone 1, 2 and 3, respectively. Time in running speed training zone 1 was similar to heart rate zone 1 (0.04 ± 0.25 ; *trivial*, $p = 0.78$), but differed from RPE training zone 1 (5.69 ± 1.9 ; *very large*, $p < 0.001$). Time in running speed zone 2 was substantially lower than heart rate zone 2 (-1.64 ± 0.53 ; *large*, $p < 0.001$), while heart rate time in zone 3 was lower compared to running speed (-1.59 ± 0.51 ;

large, $p<0.001$). Time in running speed zone 2 and 3 was substantially lower than RPE derived training time in zone 2 (-3.75 ± 1.20 ; *very large*, $p<0.001$) and 3 (-1.94 ± 0.62 ; *large*, $p<0.001$).

DISCUSSION

The results from the present study suggest that the method of training intensity quantification affects the computation of the TID in highly-trained middle-distance runners. In particular, the total training time spent in three pre-defined training zones demarcated by RPE provided significantly greater training time in training zones two and three compared to heart rate and running speed time in zone calculations. Furthermore, a greater training time was spent with a heart rate in zone 2 compared to running speed despite a similar training time in zone 1, while heart rate tended to accumulate less time in training time in zone 3 compared to running speed. These findings are important for athletes, coaches and sport science practitioners who monitor the TID of their training programs. They should acknowledge that the method of training intensity quantification can substantially influence the TID.

Only one previous study has investigated the influence of an external, internal and perceptual measure of training intensity on the resultant TID quantification.⁶ Sanders et al.⁶ showed that in well-trained male competitive road cyclists the RPE responses (percentage of time in zone; 1: 44.9%, 2: 29.9%, 3: 25.2%) provided moderate to very large differences in the time spent in zone 2 and 3 compared to heart rate (86.8%, 8.8%, 4.4%) and power output (79.5%, 9.0%, 11.5%) over a 10 week general preparation training period. This finding is in agreement with the present study as we also demonstrated that the RPE derived TID resulted in a substantially larger amount of training time in training zones 2 and 3 compared to heart rate (ES $\pm$ 95%CI; zone 2: 2.11 ± 0.54 , $p<0.001$, zone 3: 3.53 ± 0.9 , $p<0.001$) and running speed zone 2 (3.75 ± 1.20 , $p<0.001$) and 3 (1.94 ± 0.62 , $p<0.001$). In further support of the disparity between RPE and heart rate derived TID quantification using the time in zone approach, Seiler et al.² reported that male

cross-country skiers spent 91%, 6.4% and 2.6% of total training time with a heart rate in zone 1, 2 and 3, respectively, compared to 76%, 6% and 18% using the RPE time in zone approach. While there are no doubt differences in the type, duration and content of training sessions between endurance cyclists,¹⁶ cross-country skiers,¹⁵ and middle- and long-distance runners²¹ which may explain the differences in the TID across studies, it is clear that within each study there is a disconnect in the TID derived from RPE and both heart rate² and external measures of training intensity.⁶ The reasons for this likely relate to the computation of the time in zone approach from each method as well as the contextual factors influencing RPE. Given that an entire training session is categorized in one of the three RPE demarcated training zones compared to the second by second heart rate and running speed registration, it may not be surprising that there are large differences in the TID derived by the different training intensity quantification methods in the present study and that of others.^{2,6} Furthermore, it is clear that RPE is not only a function of perceived training intensity, but it is also affected by exercise duration,²⁴ as well as the residual fatigue from a previous training session and non-training stress.²⁵ If an endurance athlete was to complete a relatively long training session accumulating time in training zone 1 (based on heart rate or external measures of training intensity), whilst still recovering from a previous training session, this session may be rated as exclusively a zone 2 or 3 RPE session despite the possibility of heart rate and a given external measure of training intensity indicating a predominant zone 1 session. While this does not discredit the use of RPE as a measure of training intensity and for the computation of training load, it is clear that RPE derived TID using a time in zone approach is substantially different than both heart rate² and power output⁶ or running speed derived TID calculations. In order, to improve the precision of the RPE derived TID, RPE scores could be collected following each major component of a given training session to better reflect the nature of that session, although this needs to be experimentally tested.

In the present study, there was a greater time spent with a heart rate in zone 2 compared to running speed in zone 2. This led to heart rate producing a pyramidal TID (79.6%, 17.0%, 3.4%), while running speed represented more of a polarized TID (79.9%, 5.3%, 14.7%). The reasons for this likely relate to the slower kinetics of heart rate increase compared to the ability to accelerate to reach a given running speed. This resulted in a lower training time accumulated with a heart rate in zone 3 and greater training time in zone 2 which would effectively provide a more pyramidal TID. While there are limited studies available that detail the TID of top level middle-distance runners, the heart rate derived pyramidal TID in the highly-trained middle-distance runners from the present study is in agreement with other literature that has characterised the heart rate derived TID of middle- and long-distance runners.^{7,8,26} Tjelta et al.⁸ reported that top level junior European middle- and long-distance runners accumulated 78.3% of their weekly training distance in zone 1 (65-82% of HRmax), 19.5 ± 5.4 % in zone 2 (82-92% of HRmax) and only 2.2% in zone 3 (92-97% of HRmax) across a full calendar year. Manzi et al.²⁶ showed that long-distance recreational male runners accumulate 76.3%, 17.3% and 6.3% of total training time in training zone 1, 2 and 3, respectively, using heart rate demarcations (heart rate at 2.0 and 4.0 mmol/L and maximal heart rate) to anchor each training zone. Esteve-lanao et al.⁷ also reported that well-trained Spanish middle- and long-distance runners accumulated 71%, 21% and 8% of total training time with a heart rate in zone 1, 2 and 3, respectively, which were anchored by the ventilatory thresholds. These observational studies are also supported by an experimental study²⁷ that showed a heart rate derived pyramidal TID resulted in larger improvements in a simulated 10.4-km cross-country race compared to a threshold TID.

In contrast to the heart rate derived pyramidal TID in the highly-trained middle-distance runners from the present study, the external measure of training intensity (running speed) represented more of a polarized TID (79.9%, 5.3%, 14.7%). There is also evidence from

observational studies^{17,28} to support the use of a polarized TID in trained middle- and long-distance runners. Interestingly, these supporting studies also employed external measures of training intensity with Billat et al.¹⁷ demarcating training zones by marathon race pace: zone I (<marathon pace), zone II (marathon pace) and zone III (>marathon pace), while Ingham et al.²⁸ categorized the training intensity of an international 1500-m runner according to the respective speed expressed as a percentage of velocity at VO_{2max} . Ingham et al.²⁸ did not provide the exact TID values from their case study, but it was noted that the elite 1500-m runner altered their TID from year 1 to year 2 of the observation period to a more polarized TID by accumulating more low-intensity, less threshold-intensity, and an increase in the amount of high-intensity training. Billat et al.¹⁷ reported that National level French and Portuguese marathon runners accumulated 78% of total weekly distance at less than marathon pace, while 4% and 18% of total distance was run at marathon pace and above marathon pace, respectively. The differences in the TID approach adopted by the runners in these studies^{7,8,17,26,28} likely relates to the method of establishing training zone demarcations (i.e., graded exercise test protocol and method of physiological threshold determination),¹² the duration and time of the season that the observations were made,¹ or the training status of the runners and the event(s) that each runner specialises in (i.e., middle- or long-distance). Furthermore, it is clear from the results of the present study that the method of training intensity quantification is another factor that may contribute to the non-uniform TID of endurance athletes within the same discipline across different studies.^{7,17,18,21,27,28,30}

PRACTICAL APPLICATION

Endurance runners are likely to periodise their TID during different training phases so we would suggest that both internal (heart rate) and external (running speed) measures of training intensity are used to monitor the TID. In order to improve the precision of the RPE time in zone approach, RPE scores could be collected following each major component of a given

training session (i.e., following the warmup, main session and cool down) to better reflect the nature of that session. Running speed training zone demarcations may be more suitable for training sessions involving frequent changes of running speed and short, high-intensity intervals as heart rate may not precisely reflect the frequent changes of running speed during these training sessions. However, monitoring heart rate may be an important method of training intensity quantification during steady-state, long-distance runs or longer interval sessions. Furthermore, the integration of all three measures of training intensity employed in the current study could be used to quantify ratios of different intensity measures²⁹ or to monitor the responses to a standardized warmup³⁰ in order to identify fatigue and/or quantify changes in fitness without the need to undertake additional performance tests.

CONCLUSION

This study investigated the effects of three different methods of training intensity quantification on TID using a time in zone approach in a group of highly-trained middle-distance runners. We found that the total training time spent in three pre-defined training zones demarcated by RPE provided significantly greater training time in training zones two and three compared to heart rate and running speed time in zone calculations. When comparing heart rate with running speed time in zone, a greater training time was spent with a heart rate in zone 2, and lower training time spent in zone 3. Our results show that the method of training intensity quantification substantially affects the computation of the TID.

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LIST OF FIGURES

Figure 1. Training intensity distribution (percentage of total training time spent in each training zone) for all training sessions where heart rate, RPE and running speed/distance were recorded.

^aSignificantly different from heart rate and running speed relative training time in corresponding training zone

^bSignificantly different from running speed relative training time in corresponding training zone

LIST OF TABLES

Table 1. Physiological and performance characteristics from the incremental running test and training characteristics of the male and female subjects.

Abbreviations: GET, gas exchange threshold; HR, heart rate; RCT, respiratory compensation threshold; VO_{2max}, maximal oxygen uptake; MHR, maximal heart rate.

Table 2. Total training time spent in each training zone for all training sessions where heart rate, RPE and running speed/distance were recorded.

^aSignificantly different from heart rate and running speed training time in corresponding training zone

^bSignificantly different from running speed training time in corresponding training zone