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Abstract

Purpose: This study aims to evaluate training intensity distribution using different intensity measures based on session rating of perceived exertion (sRPE), heart rate (HR) and power output (PO) in well-trained cyclists. ***Methods:*** Fifteen road cyclists participated in the study. Training data was collected during a 10-week training period. Training intensity distribution was quantified using HR, PO and sRPE categorized in a 3-zone training intensity model. Three zones for HR and PO were based around a first and second lactate threshold. The three sRPE zones were defined using a 10-point scale: zone 1, sRPE scores 1-4; zone 2, sRPE scores 5-6; zone 3, sRPE scores 7-10. ***Results:*** Training intensity distribution as percentages of time spent in zone 1, zone 2 and zone 3 was moderate to very largely different for sRPE (44.9%, 29.9%, 25.2%) compared to HR (86.8%, 8.8%, 4.4%) and PO (79.5%, 9.0%, 11.5%). Time in zone 1 quantified using sRPE was large to very largely lower for sRPE compared to PO ($P < 0.001$) and HR ($P < 0.001$). Time in zone 2 and zone 3 was moderate to very largely higher when quantified using sRPE compared to intensity quantified using HR ($P < 0.001$) and PO ($P < 0.001$). ***Conclusions:*** Training intensity distribution quantified using sRPE demonstrates moderate to very large differences compared to intensity distributions quantified based on HR and PO. The choice of intensity measure impacts on the intensity distribution and has implications for training load quantification, training prescription and the evaluation of training characteristics.

Keywords: training impulse, cycling, rating of perceived exertion, heart rate, blood lactate

Introduction

The preparation of athletes requires the adjustment and manipulation of training variables such as intensity, duration and frequency in a training program as well as appropriate recovery.[1] To have an impact on performance, coaches must have an idea of the nature of the relationship between the training dose (or *training load*) and the training outcome or response.[2] Ultimately, it is the internal training load that will determine the training outcome.[3] In a training plan, the training load will be manipulated and this is most frequently done by adjusting the distribution of training intensity throughout the training plan. Even though there is a general agreement of physiological factors contributing to elite endurance performance[4-6], there is an ongoing debate on how to structure and organise the combination and distribution of intensity and duration for optimal performance.[7] The distribution of training intensity in elite athletes has featured prominently in this debate, receiving extensive reviews in recent years.[7,8] This has led to the adoption of a training model where training plans or characteristics are evaluated using a 3-zone training intensity model. Physiological thresholds based on blood lactate concentrations (LT_1, LT_2) or the first and second ventilatory thresholds (VT_1, VT_2) have been used as physiological markers to define the training intensity zones.[8-10] These physiological markers can be used to set individual-specific zones. Time spent in these zones is subsequently used to evaluate the training intensity distribution over a training period. Zones are defined as low intensity (zone 1, $<VT_1/LT_1$), moderate intensity (zone 2, between VT_1/LT_1 and VT_2/LT_2) and high intensity (zone 3, $> VT_2/LT_2$). Experimental research indicated that polarized training distribution with a large base of zone 1 endurance training combined with zone 3 training is optimal for endurance adaptations.[11,12] This seems to be reflected in the type of training engaged in by both elite and recreational endurance athletes whom seem to train at an intensity distribution that consists of ~80% of the training sessions performed at zone 1 and the remaining ~20% at zone 2 and 3.[7,8,13] Lucia et al.[14] quantified time spent in three heart rate (HR) zones during different training phases in professional cyclists showing a shift towards a higher proportion of moderate to high-intensity training when getting closer to the competitions. Along with monitoring HR, the availability of mobile power meters for cyclists has resulted in the widespread monitoring of power output (PO) in competitive cycling. This opens new avenues to individual performance analysis and to quantify percentage spent in different power-based intensity zones. This provides another objective measure of exercise intensity for cyclists, next to HR. Along with these objective intensity measures, the session rating of perceived exertion (sRPE) has been used as a more subjective rating of intensity for athletes (zone 1, sRPE scores 1-4; zone 2, sRPE scores 5-6; zone 3, sRPE scores 7-10).[8,15]

Analysing multiple ways of measuring training intensity and how these may affect training intensity distributions provides valuable insight for coaches and practitioners working with these measures on a daily basis. Manzi et al.[15] and Seiler and Kjerland[8] both reported that training intensity distributions quantified using sRPE and HR provides similar results in recreational long distance runners and well-trained cross country skiers. Discrepancies observed between methods of measuring training intensity have implication for the evaluation of training characteristics and their potential relationship with training outcome.[12,16] Additionally, these differences may impact the quantification of training load, which involves the integration of training intensity and duration. Several training load measures have been reported in cycling integrating different measures of intensity. These vary from HR-based training impulse (TRIMP) methods to session-RPE training load (sRPE-TL) and the PO-based Training Stress Score™ (TSS).[9,17,18] The validity of training load measures has previously been evaluated by investigating the dose-response relationship of quantified training load and changes in aerobic fitness or performance, providing evidence that some methods are better suited to quantify training load in a specific sport.[19,20] Especially methods integrating individual physiological characteristics, such as the individualized TRIMP (iTRIMP) proposed by Manzi et al.[19] which integrates the individual's HR – blood lactate relationship to exponentially weigh exercise intensity and TSS™ which integrates the individuals functional threshold power, showed a high dose-response validity.[20] Potential differences in the dose-response relationship between training load and training outcome may be explained by differences observed in the measurement of exercise intensity. Previous research has shown similarities between intensity distributions when intensity is measured using sRPE and HR.[8,15] However, there is no research available evaluating or comparing these different measures of intensity in road cyclists. Furthermore, there is a limited amount of research available on training intensity distributions quantified using PO. Therefore, the aim of this study is to evaluate the training intensity distribution using different commonly used intensity measures in well-trained competitive cyclists.

Methods

Participants

Fifteen well-trained male competitive road cyclists (mean (SD): aged 22 (2.5) y, height 185.7 (4.1) cm, body mass 73.2 (4.6) kg) active in national and international competitions, competing for at least two years, with a mean of 10 (4) years of competitive experience (including youth competitions) participated in this study. Participants were informed about the procedures and written consent was obtained prior to participation. Institutional ethics approval was granted and in agreement with the Helsinki Declaration.

Research Design

Training data were collected during a 10-week pre-season training period (December to March). Before the training period, participants underwent a laboratory incremental exercise test with gas exchange and blood lactate measures. Riders were tracked and monitored using an online training diary (TrainingPeaks WKO+, Boulder, CO, USA). No training prescription or plan was provided to the participants, and the cyclists adhered to their own training plan or a plan provided by their coach.

Training intensity quantification

Training intensity was assessed using three different measures: HR, PO and sRPE. For every intensity measure, a 3-zone model was used to quantify the time spent in each intensity zone.[8] HR and PO zones were determined using a laboratory incremental cycling test with blood lactate measures conducted prior to the training period. The incremental test started at 100 W and increased 40 W every 4 min until volitional exhaustion or when the pedalling cadence fell below 70 rev·min^{-1} and the cyclist was not able to increase cadence. Each cyclist performed the test on their own bicycle, which was placed on an ergometer (Cyclus2 ergometer, RBM Electronics, Leipzig, Germany). All tests were performed under similar environmental conditions (17-18° C, 45–55% relative humidity). HR was recorded every 5 s using a portable HR monitor (Cyclus2; RBM Electronics, Leipzig, Germany). Capillary blood samples were taken from a fingertip at the end of every 4-min stage and directly analysed using a portable lactate analyser (Lactate Pro, Arkray KDK, Japan). PO and HR at different lactate thresholds were measured using publicly available software.[21] Three individual HR and PO zones were established around a first (LT_1) and second lactate threshold (LT_2) with LT_1 defined at an initial rise of 0.4 $mmol \cdot L^{-1}$ rise above baseline[10] and LT_2 defined using the modified D_{max} method.[22] HR and PO zones were proposed using previously established protocols[8]: zone 1, $\leq LT_1$; zone 2, $> LT_1$ and $< LT_2$; zone 3 $\geq LT_2$. The highest 30s mean HR obtained during the incremental test was used as a measure of HR_{max}. The last completed stage was used as the measure of maximum aerobic power output (W_{max}). If the stage was not completed W_{max} was calculated based on the fraction of the completed stage where volitional exhaustion occurred.[23] Gas exchange measures were obtained using an indirect calorimeter (Omnical, Maastricht Instruments, Maastricht, Netherlands) that was calibrated prior to testing according to the manufacturer's instructions. The test was performed until complete exhaustion to estimate $\dot{V}O_{2max}$. After the test, breath-by-breath values were visually inspected and $\dot{V}O_{2max}$ was defined as the highest 30s mean obtained during the test.

HR and PO data were collected during every training session using portable power meters of different brands owned by the cyclists: SRM system (n = 3) (SRM, Jülich, Welldorf, Germany), Power2max (n = 6) (Power2max, Chemnitz, Germany), PowerTap[24] (n = 2) (CycleOps, Madison, USA), SRAM Quarq (n = 1) (SRAM, Chicago, Illinois, USA), Rotor (n = 1) (Rotor bike components, Madrid, Spain), Stages powermeter (n =1) (Stages Cycling, Saddleback LTd., UK) and Pioneer power meter (n = 1) (Pioneer, Kawasaki, Kanagawa, Japan). Validity of all the crank based mobile power meters was assessed by comparing the measured power output by the mobile power output to the set power output by the ergometer (Cyclus2 ergometer, RBM Electronics, Leipzig, Germany) during every stage of the incremental test. The power meters were calibrated prior to testing according to the manufacturer's instructions. Mean and percentage difference, standard error estimate (SEE), Bland Altman 95% Limits of Agreement (LOA) and Intraclass Correlations (ICC) were measured. Stages power meter (mean difference 3.4% or 7 W, SEE 8 W, LOA 15 W, ICC 1.00), Power2max (mean difference 4.2% or 6 W, SEE 3 W, LOA ±8 W, ICC 0.99), SRAM Quarq (mean difference 3.9% or 9 W, SEE 2 W, LOA ±17 W, ICC 0.99), SRM system (mean difference 4.3% or 9 W, SEE 3 W, LOA ±8 W, ICC 0.99), Rotor (mean difference 2.7% or 6 W, SEE 2 W, LOA ±6 W, ICC 1.00) and Pioneer power meter (mean difference 2.8% or 7 W, SEE 6 W, LOA ±13 W, ICC 0.99) all showed high concurrent validity. HR and PO training intensity distribution as minutes and percentages spent in each training zone were calculated using training analysis software (TrainingPeaks WKO+, Boulder, CO, USA). Session rating of perceived exertion (sRPE) was determined of every training session. The sRPE was obtained 30 min after the training session based on the question: "How hard was your workout?" [18] Session-RPE data were divided into three intensity zones based on a previous study by Seiler and Kjerland[8]. The three zones defined were: zone 1, sRPE scores 1-4; zone 2, sRPE scores 5-6; zone 3, sRPE scores 7-10.

Statistical analysis

Descriptive results are presented as mean (standard deviation). Prior to analysis the assumption of normality was verified by using Shapiro-Wilk W test. Training intensity distributions assessed using sRPE, HR and PO were compared to each other using a multilevel random intercept model in R (R: A Language and environment for statistical computing, Vienna, Austria) using Tukey's method for pairwise comparisons. This model was used over a traditional repeated measures ANOVA as it offered a better fit, is able to account for missing data, and better handles any uneven spacing of repeated measurements.[25] Minutes spent training were fitted as a normal response variable with sRPE, HR and PO training zones included as categorical fixed effects. Random effect variability was modelled using a random intercept for each participant, accounting for individual differences in time spent in each zone. Standardised effect size is reported as Cohen’s *d*, using the pooled standard deviation as the denominator. Qualitative interpretation of *d* was based on the guidelines provided by Hopkins[26]: 0 - 0.19 trivial; 0.20 – 0.59 small; 0.6 – 1.19 moderate; 1.20 – 1.99 large; ≥ 2.00 very large.

Results

Physiological variables assessed with the laboratory incremental cycling test are presented in Table 1. HR and PO at LT_1 and LT_2 were observed at 83 (4)% and 90 (2)% of HR_{max}. A total of 689 training sessions have been collected and analysed with each athlete averaging 46 (9) training sessions over the 10-week monitoring period. The cyclists trained a mean of 134.5 (26) hours during the 10-week monitoring period.

Training intensity distribution

The quantification of training intensity distribution using the three different methods as time spent in the zones is presented in Table 1 and as percentage time presented in Figure 1. Pairwise comparisons between the total time spent in each zone with the different methods is presented in Table 3. Percentage of total time spent in zone 1 was 86.8 (5.9)% for HR, 79.5 (7.3)% for PO and 44.9 (27.4)% for sRPE. Time spent at HR in zone 1 was moderately higher ($P = 0.0277$, ES = 1.10) than time spent at PO in zone 1. The time spent in zone 1 was large to very largely lower for sRPE compared to PO ($P < 0.001$, ES = 1.80) and HR ($P < 0.001$, ES = 2.52) in zone 1. Percentage of total time spent in zone 2 was 8.8 (4.7)% for HR, 9.0 (5.6)% for PO and 29.9 (12.8)% for sRPE. Training time quantified using the sRPE scale in zone 2 was very largely higher compared to time spent in zone 2 quantified using HR ($P < 0.001$, ES = 2.41) and PO ($P < 0.001$, ES = 2.30). Percentage of total time spent in zone 3 was 4.4 (2.0)% for HR, 11.5 (2.5)% for PO and 25.2 (24.9)% for sRPE. Time spent at HR in zone 3 was very largely lower compared to time spent in zone 3 quantified using PO ($P = 0.0159$, ES = 2.99). Time spent in zone 3 quantified using the sRPE scale was moderate to largely higher compared to time spent in zone 3 quantified using PO ($P < 0.001$, ES = 1.00) and HR ($P < 0.001$, ES = 1.55).

Discussion

The main finding of this study is that training intensity distribution quantified using a sRPE scale provided moderate to very large differences compared to intensity distributions quantified using methods based on time spent in pre-defined HR or PO zones. Discrepancies observed between methods of measuring training intensity distribution may have implications for the evaluation of training and therefore potential future training prescription. The potential relationship between time spent in different training zones and training outcome could also be affected. Previous research has indicated the importance of a large base of zone 1 training in endurance athletes[7,27], substantiated by research showing the positive relationship between time spent in zone 1 and improvements in performance.[12,16] The large to very large differences observed between time spent in zone 1 quantified using sRPE compared to objective measures as HR and PO suggests that sRPE underestimates the time spent in zone 1 and thereby may not reflect actual training characterises of these athletes. The relationship between time spent in different training intensity zones and performance outcome may be misinterpreted when training intensity distribution is quantified using a subjective measure as sRPE in road cyclists. The moderate to very large differences observed for training quantified in zone 2 and zone 3 between sRPE and HR or PO further questions the use of sRPE to evaluate training intensity distribution in cyclists.

The between-method differences in quantifying training intensity distribution are not in line with previous research. Seiler and Kjerland[8] showed an intensity distribution of 76%, 6% and 18% in zone 1, 2 and 3 using the sRPE scale in cross-country skiers which is substantially different to the sRPE distribution observed in this study: 42.7%, 29.7% and 27.5%, respectively. Manzi et al.[15] also showed substantially different training intensity distribution in runners using the sRPE scale compared to our results with 69.6%, 27.8% and 2.6% for zone 1, 2 and 3, respectively. Differences in training duration and type of the workouts performed by cyclists may explain the differences observed with previous research. For instance, the training duration mentioned by Manzi et al.[15] varied between ~50 and ~130mins which is substantially lower than the average training duration of the cyclists in this study (~175 min). Since the cyclists in this study mainly focused on low-intensity endurance sessions (~3-6 hours), the duration and not the intensity of the training will mainly influence the perceived exertion of the riders. For example, a 5 hour cycling training session can be subjectively perceived as hard (e.g. sRPE score of 7) despite the low-intensity (i.e. low HR) nature of training. Additionally, in running or cross-country skiing it is common to perform multiple sessions a day, especially during phases with high training load. A consequence of this could be that the sessions become more specific with one intensity zone/goal in focus. In cycling it is common to include specific moderate to high intensity intervals during low intensity long duration sessions, performing mainly one session a day. These 'mixed' sessions may explain the differences observed in training intensity distribution quantified using sRPE compared to HR or PO. Especially because sRPE is a categorization of the entire training session in one of the three zones, while HR and PO intensity distributions are non-categorical and based on minute by minute data of the training session. These methodological differences can contribute to the large differences observed between training intensity quantified using HR/PO and sRPE. Sylta et al.[28] further suggests that a time in zone approach may underestimate training performed in the high-intensity range. Previous studies have used the 'Session Goal' approach which assigns an entire training session to one of the three HR zones based on the predominant goal of that session.[28] However, the 'mixed' type of training done by cycling makes this approach less usable since specific intervals/blocks are performed within low-intensity long duration sessions making it difficult to define one predominant session goal. Nevertheless, these results suggest that the long-duration type and training organization of cyclists may contribute to why time spent in zone 1 is underestimated by sRPE, but time spent in zone 2 and zone 3 is overestimated by sRPE compared to the objective measures based on HR and PO. This potentially suggests that sRPE may be less applicable as a measure of training intensity in road cycling. However, the use of sRPE in addition to measures of HR or PO may provide insights in to the fatigue state of the athletes.[29]

There was a higher proportion of time spent in PO in zone 3 compared to HR in zone 3. This can be explained by the 'physiological lag' inherent with HR while PO provides a more direct measure of exercise intensity.[17] Short high-intensity bursts or accelerations, because of the stochastic nature of cycling, will be reflected as time spent in zone 3 quantified using PO but due to the lag in physiological response measured with HR this will not be reflected in the time spent in zone 3 using HR. This would suggest that differences in training intensity distribution between HR and PO would differentiate when more high-intensity training sessions are performed (e.g. competitive season). Subsequently, this could potentially mean that the intensity distributions of HR may not reflect the neuromuscular demand of these short-duration efforts[30], while this is reflected in the intensity distributions quantified using PO as a higher percentage in zone 3. Even though the neuromuscular demand may be less prone in endurance sports such as competitive cycling, this may have an impact on quantified load during short-duration high-intensity interval training sessions.[30]

The measurement of training intensity is an important aspect of training load, which integrates both intensity and duration. Training load measures in cycling are based on intensity measures including HR, sRPE and PO. This study provides evidence of between-method differences in training intensity quantification which could potentially impact training load quantification integrating these intensity measures. A recent study suggests training load measures such as the HR-based individualized training impulse (iTRIMP) (r = 0.77, 0.81) and the PO-based Training Stress Score™ (TSS) (r = 0.75, 0.79) to be the most valid tools to inform a dose-response relationship between training load and fitness (PO at 2 and 4 $mmol \cdot L^{-1}$) in a group of cyclists as the relationships were stronger compared to sRPE-based training load (r = 0.54, 0.60).[20] Explanations for the stronger dose-response relationship of iTRIMP and TSS are possibly a more valid quantification of training intensity since the results of this study shows high agreement between intensity quantified using HR and PO, but less for HR/PO and sRPE. As the study by Sanders et al.[20] is the only study evaluating different training load quantification methods in cycling, these results should be substantiated by future research.

Practical applications

The moderate to very large differences observed between training intensity distribution quantified using sRPE compared to HR and PO questions the use of this subjective measure to reflect training characteristics and the relationship between training intensity distributions and training outcome in road cycling. More specifically, time in zone 1 appears to be underestimated while time in zone 2 and zone 3 are overestimated by sRPE compared to objective measures as HR and PO. Additionally, the results of this study show that time spent in the high-intensity domain is higher when quantified using PO compared to HR. As previously stated, this can be explained by the lag inherent with HR while PO provides a direct and immediate measure.[17] This could potentially mean that HR may not reflect the neuromuscular demand of short-duration efforts, while this is represented in the greater proportion of time spent in zone 3 quantified using PO. Therefore, intensity distributions during a period with a great proportion of high-intensity training can be substantially different between PO and HR. This information can be seen as valuable for practitioners working with HR and PO data on a daily basis. Furthermore, this data shows the differences between subjective (sRPE) and objective (HR, PO) assessment of intensity and the possible implications this may have for training load quantification.

Conclusion

This study shows that training intensity distribution as time spent in three pre-defined zones quantified using a subjective measure as sRPE provided moderate to very largely different results compared to intensity distribution based on objective measures such as HR or PO. Differences in training intensity quantification can have a possible impact on the accuracy of training load quantification and the evaluation of training characteristics.

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Figures and tables

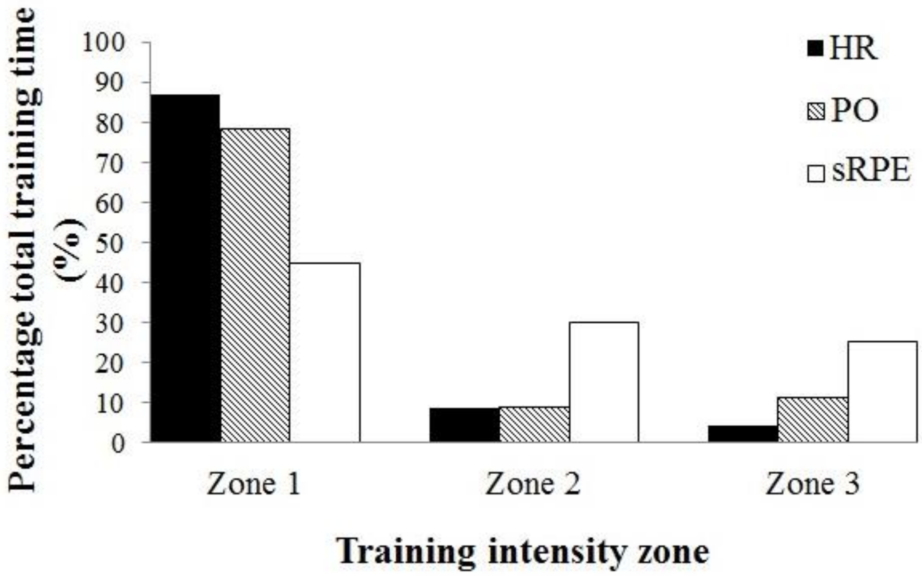

Figure 1. Training intensity distribution (%) over the 10-week training period quantified using heart rate (HR), session RPE (sRPE) and power output (PO).

Table 1. Physiological measures obtained from the laboratory incremental cycling test prior to the training period.

N=15	**Mean (SD)**	**Range**
$\dot{V}O_{2max}$ (mL·min·kg^{-1})	62 (4)	55 – 69
$\dot{V}O_{2max}$ (L·kg^{-1})	4.5 (0.3)	3.9 – 5.3
W_{max} (W)	381 (29)	335 – 460
PO at 0.4 mmol·L^{-1} rise above baseline (W)	275 (34)	196 – 342
PO at modified D_{max} (W)	320 (28)	279 – 383
HR_{max} (beats·min^{-1})	189 (8)	177 – 212
HR at 0.4 mmol·L^{-1} rise above baseline (beats·min^{-1})	157 (10)	136 – 171
HR at modified D_{max} (beats·min^{-1})	171 (9)	155 – 192

Abbreviations: VO_{2max}, maximal oxygen uptake; W_{max}, peak power output; PO, power output; HR, heart rate; HR_{max}, maximal heart rate.

Table 2. Time spent in each intensity zone and training load over the 10-week monitoring period quantified using session RPE, heart rate or power output.

Intensity distribution	**sRPE**	**HR**	**PO**
Total training duration (min)		8066 (1556)	
Total time in zone 1 (min)	3451 (2112)[1,2]	6985 (1390)[1]	6356 (1110)
Total time in zone 2 (min)	2397 (1076)[1,2]	731 (444)	772 (551)
Total time in zone 3 (min)	2218 (2284)[1,2]	350 (164)[1]	933 (292)

Abbreviations: sRPE, session rating of perceived exertion; HR, heart rate; PO, power output.

[1]Significantly different from total time spent in intensity zone quantified using PO

[2]Sigificantly different from total time spent in intensity zone quantified using HR

Table 3. Pairwise comparisons between total time spent in zones using different measures of quantifying exercise intensity

Pairwise Comparison Total time spent in zones (min)	Absolute difference (min)	95% Confidence Interval Lower	Upper	*P*	Cohen's *d*	Qualitative outcome
HR zone 1- sRPE zone 1	3534	2159	4909	<0.0001	2.52	Very large
PO zone 1 - sRPE zone 1	1606	1186	2026	<0.0001	1.80	Large
HR zone 1 - PO zone 1	629	358	899	0.0277	1.10	Moderate
sRPE zone 2 - HR zone 2	1666	1245	2087	<0.0001	2.42	Very large
sRPE zone 2 - PO zone 2	1625	1221	2030	<0.0001	2.30	Very large
HR zone 2 - PO zone 2	41	-119	200	1	0.02	Trivial
sRPE zone 3 - HR zone 3	1868	700	3036	<0.0001	1.54	Large
sRPE zone 3 - PO zone 3	1284	185	2383	<0.0001	1.00	Moderate
HR zone 3 - PO zone 3	584	448	720	0.0159	2.99	Very large

Abbreviations: sRPE, session rating of perceived exertion; HR, heart rate; PO, power output.