Section: Original Investigation

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Journal: *International Journal of Sports Physiology and Performance*

Acceptance Date: August 9, 2018

DOI: https://doi.org/10.1123/ijspp.2018-0120

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Preferred Running Head: Perceived Exertion in Adolescent Distance Running

Abstract Word Count: 241

Text-Only Word Count: 3,428

Number of Figures and Tables: 5

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ABSTRACT

Purpose: To investigate the effect of measurement timing and concurrent validity of session (sRPE) and differential (dRPE) ratings of perceived exertion as measures of internal training load (ITL) in adolescent distance runners. **Methods:** Fifteen adolescent distance runners (15.2 ± 1.6 y) performed a two-step incremental treadmill test for the assessment of maximal oxygen uptake, heart rate and the blood lactate responses. Participants were familiarised with RPE and dRPE during the treadmill test using Foster's modified CR-10 Borg scale. Subsequently, each participant completed a regular two-week mesocycle of training. Participants wore a heart rate monitor for each exercise session and recorded their training in a logbook, including sRPE, dRPE leg exertion (dRPE-L) and breathlessness (dRPE-B) following session completion (0 min), 15 min post-session and 30 min post-session. **Results:** sRPE, dRPE-L and dRPE-B scores were all *most likely lower* when reported 30 min post-session, compared to scores 0 min post-session (% change ±90% confidence limits; sRPE, -26.5% ±5.5%; dRPE-L, -20.5% ±5.6%, dRPE-B, -38.9% ±7.4%). sRPE, dRPE-L and dRPE-B all maintained their largest correlations (r = 0.74 to 0.89) when reported at session completion (0 min), in comparison to each of the HR-based criteria measures. **Conclusion:** sRPE, whether reported 0 min, 15 min or 30 min post-session, provides a valid measure of ITL in adolescent distance runners. Also, dRPE-L and dRPE-B can be used in conjunction with sRPE, across all time-points (0, 15 and 30 min), in order to discriminate between central and peripheral exertion.

Key Words: RPE, heart rate, internal training load, youth, endurance training

INTRODUCTION

The ability to measure accurately the internal training load (ITL) of an athlete is essential when trying to optimise athletic performance[1] and prevent adverse training outcomes, such as injury or overtraining[2]. This is important for coaches and practitioners who prescribe training loads for adolescent athletes[3], whereby early sports specialisation has become more popular and is complicated by growth and maturational issues[4]. Traditionally, ITL has been measured using heart rate (HR), due to the almost linear relationship between HR and oxygen uptake ($\dot{V}O_2$), a measure of energy expenditure, across multiple steady-state submaximal exercise intensities[5]. However, while HR is still regarded as the ‘gold standard’ for non-invasive measurement of ITL[6], it is often unfeasible within youth sport, requiring the use of expensive telemetric HR monitors and technical expertise. Consequently, the session rating of perceived exertion (sRPE), an athlete’s subjective rating of perceived exertion multiplied by session duration (minutes), has been established as a simple and valid measure of ITL[7].

Based on the formative research of Foster et al.[8], sRPE is typically reported 30 minutes following session completion. They argued that this approach reduces the effect of the final section of an exercise session on the reported sRPE. However, few studies have investigated the effect of measurement timing on sRPE, especially within youth sport. Therefore, the most suitable time-point to report sRPE remains unclear and is largely dependent on the inclusion (or exclusion) of a cool-down[9]. It has also been argued that sRPE may oversimplify the psychophysiological construct of exertion[10], potentially lacking sensitivity during high intensity exercise. However, through the application of differential ratings of perceived exertion, such as leg-exertion (dRPE-L) and breathlessness (dRPE-B), it has been shown that it is possible to discriminate between central and peripheral exertion[11], possibly resulting in a more perceptive estimation of ITL. Nonetheless, the validity of sRPE and dRPE measures, in terms of measuring ITL, has yet to be established within adolescent distance running.

sRPE has been validated within many different sports and study populations[12]. However, less is known about dRPE-L and dRPE-B, in addition to whether these measures of ITL are valid in adolescent populations. While previous research has validated sRPE within many youth sport contexts (e.g. water polo and taekwondo), no studies have validated sRPE, dRPE-L and dRPE-B in adolescent distance runners. This needs addressing due to the popularity of distance running, throughout adolescence, whereby these measures cannot be applied based on the research conducted in adult populations[13] and dissimilar youth sport contexts. Considering that distance running employs a variety of exercise intensities, typically prescribed via external training loads[14] (i.e. number of intervals), it is essential that the ITL imposed on an adolescent athlete can be effectively monitored by coaches and practitioners.

Therefore, in a population of adolescent distance runners, the purpose of this study was to (1) investigate the effect of measurement timing on sRPE, dRPE-L and dRPE-B following exercise session completion, across three time-points (0, 15 and 30 min), and (2) to examine the concurrent validity of sRPE, dRPE-L and dRPE-B, as measures of ITL, when compared to three individualised HR-based criterion measures.

METHODS

Participants

Fifteen (three girls) adolescent distance runners (age 15.2 ± 1.6 y) volunteered to participate in this study. Each participant had to be a member of an England Athletics affiliated athletics club, aged 13 to 18 years and training for a specific middle distance running event, ranging from the 800 m through to the 3,000 m (including Steeplechase). A convenience-based sampling procedure was used, with each participant receiving verbal and written information of the study procedures. Parental consent and participant assent were obtained. Ethical approval was granted by the institutional ethics committee (170315/B/03), in agreement with the Declaration of Helsinki.

Experimental Design

This study used a prospective observational research design where each participant completed one laboratory visit, followed by a two-week mesocycle of training. Data collection took place between May and September 2017.

Laboratory Visit

On arrival to the laboratory, participants were familiarised with study procedures, the concept of RPE and Foster's modified CR-10 Borg scale[8]. Anthropometric measures, a baseline capillary blood sample and resting heart rate (HR_{rest}) were collected, followed by the completion of a two-part incremental treadmill test for the assessment of VO_{2max}, maximum heart rate (HR_{max}), the blood lactate threshold (LT) and lactate turn point (LTP)[15]. All tests were performed on a motorised treadmill (Pro XL, Woodway GmbH, Germany), with pulmonary gas exchange and HR being recorded throughout.

Part one of the test was a discontinuous step-incremental test with increases in running velocity of 1.0 $km \cdot h^{-1}$ at the start of each stage. Following a 5-min warm-up period of walking and running (up to 8 $km \cdot h^{-1}$) the test began, consisting of five to eight 3-min stages. The initial treadmill velocity was between 11.0 and 13.0 $km \cdot h^{-1}$ for male participants and 11 $km \cdot h^{-1}$ for female participants, prescribed according to their current performance level, with the treadmill gradient fixed at 1.0%. Each stage was separated by a 1-min rest period to allow for assessment of capillary blood lactate. Increments in running velocity were continued until blood lactate had exceeded 4 $mmol \cdot L^{-1}$ and HR was within 5 – 10 $b \cdot min^{-1}$ of HR_{max}. After ~ 10-min of active recovery, part two of the incremental test commenced. This involved running at a fixed velocity (final stage velocity - 2 $km \cdot h^{-1}$) with the treadmill gradient increased by 1.0% each minute until volitional exhaustion.

Two-Week Mesocycle

Following the laboratory visit (5 ± 3 days) participants completed a two-week mesocycle of regular training, as prescribed by their athletics coach. The researchers did not alter the training schedules. Throughout the mesocycle, participants documented their training in a logbook, including session duration (minutes) and the external training load. Participants wore a HR monitor for each exercise session and reported whole-body RPE and dRPE (leg-exertion and breathlessness) at session completion (0 min), 15 min post-session and 30 min post-session.

Experimental Measures

Anthropometry

Body mass was measured to the nearest 0.1 kg using digital scales (Seca 704, Seca GmbH, Germany), and stature was measured to the nearest 0.1 cm using a stadiometer (Seca 217, Seca GmbH, Germany). Using the participant's body mass and stature, (somatic) maturity was calculated as an offset score, in years, from peak height velocity[16].

Heart Rate

During the laboratory visit, HR was recorded every 1 s using a telemetric HR monitor (T31, Polar, Finland). HR_{rest} was accepted as the lowest 10 s average recorded during a 10-min period of rest prior to the incremental test. HR_{max} was accepted as the highest 10 s average observed during the incremental test. Throughout the two-week training mesocycle, HR was recorded every 1 s using an individually coded telemetric HR monitor (Team 2 System, Polar, Finland). HR data were uploaded to a specialist software (ProTrainer 5, Polar, Finland) before being exported to a spreadsheet (Excel, Microsoft, USA) for analysis of ITL. If participants exceeded their laboratory-based HR_{max} during an exercise session then the highest recorded HR value from their training mesocycle was subsequently used for calculating each of the TRIMP methods.

Capillary Blood Lactate

A fingertip capillary blood sample (~100 µL) was collected using a heparinised microvette (CB 300 FH tubes, Sarstedt AG & Co., Germany). These samples were analysed immediately for lactate using a calibrated automatic analyser (YSI 2300, Yellow Springs Instruments, USA) in duplicate and averaged for subsequent analysis. LT and LTP were visually obtained by plotting blood lactate against running velocity and approved by two independent reviewers. LT was accepted as the first sustained increase in blood lactate above baseline levels. LTP was accepted as a distinct and sustained breakpoint in blood lactate following LT[15].

Pulmonary Gas Exchange

Oxygen uptake ($\dot{V}O_2$) was measured using a breath-by-breath automated gas analysis system (Cortex Metalyzer III B, Cortex Biophysik GmbH, Germany). Volume and gas concentrations were calibrated before each test using standard procedures. Maximum oxygen uptake ($\dot{V}O_{2max}$) was accepted as the highest 10 s $\dot{V}O_2$ observed during the incremental test.

Measures of Internal Training Load

For each exercise session, sRPE was calculated by multiplying RPE by session duration (minutes), as reported from the modified CR-10 Borg scale[8]. This category-ratio scale translates perception of effort (from 'rest' to 'maximal') into a numerical score[17], having been previously validated[1]. The sRPE calculation was completed for each RPE measure (whole-body, leg-exertion and breathlessness) at exercise completion ($sRPE_0$, $dRPE\text{-}L_0$, $dRPE\text{-}B_0$), 15 min post-session ($sRPE_{15}$, $dRPE\text{-}L_{15}$, $dRPE\text{-}B_{15}$) and 30 min post-session ($sRPE_{30}$, $dRPE\text{-}L_{30}$, dRPE-B_{30}), expressed in arbitrary units (AU). To improve the accuracy of self-reported RPE scores the incremental treadmill test was used to anchor perception of maximal exertion.

Three individualised HR-based training load methods were used as criterion measures of ITL. Firstly, the individualised training impulse ($TRIMP_I$) was used[18]. This method weights training duration using an individualised weighting factor (Y^i) for each participant, based upon their blood lactate response to incremental exercise, rather than a sex-specific exponential factor[19]; calculated as follows:

$$TD \cdot \Delta HR \cdot Y^i$$

where TD is the session duration (minutes) and ΔHR is the heart rate ratio, determined by the following equation:

$$\Delta HR = [(HR_{TS} - HR_{rest}) / (HR_{max} - HR_{rest})]$$

in which HR_{TS} is the average HR throughout the exercise session.

Y^i is calculated by plotting the participant's blood lactate against their fractional elevation in HR, with the exponential line (best-fit) providing the calculation of the weighting factor.

Secondly, the Edwards[20] summated HR zone score method ($TRIMP_E$) was used. This approach calculates the product of the accumulated session duration (minutes) of five HR zones by a coefficient relative to each zone (1 = 50-60% HR_{max}, 2 = 60-70% HR_{max}, 3 = 70-80% HR_{max}, 4 = 80-90% HR_{max}, 5 = 90-100% HR_{max}), before summating the results.

Thirdly, a modified version of $TRIMP_E$ based on the work of Lucia et al.[21] was used. This method ($TRIMP_L$) was calculated by multiplying the time spent in three different HR zones (zone 1 = below the LT, zone 2 = between the LT and the LTP, zone 3 = above the LTP) by a coefficient (k) relative to each zone (k = 1 for zone 1, k = 2 for zone 2, and k = 3 for zone 3), before summating the results.

Statistical Analyses

Data are presented as mean ± standard deviations. For each participant, we calculated weighted mean session scores for sRPE, dRPE-L and dRPE-B, at time-points 0 min, 15 min and 30 min, to account for the different number of exercise sessions completed per participant. Following this, standardised mean differences (raw and percentage) were calculated between the sRPE, dRPE-L and dRPE-B scores, at time-points 0 min, 15 min and 30 min, with uncertainty of estimates expressed as 90% confidence limits (CL). Standardised mean differences were also calculated to examine the effect of measurement timing on sRPE, dRPE-L and dRPE-B scores, at time-points 0 min, 15 min and 30 min, with 90% CL. Paired samples t-tests were used to calculate the necessary *P* values, before reporting the differences in relation to the chance of the true effect being substantial or trivial. Results were reported using magnitude-based inferences (mechanistic), informed by the following probabilistic terms: 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely. A smallest worthwhile change of 10% was used, in relation to percentage differences between the mean RPE scores, based on the work of Weston et al.[22].

Within-participant correlations (*r*) were calculated[23] to examine the relationships between each of the sRPE, dRPE-L, dRPE-B and HR-based ITL methods (pooled data), at time-points 0 min, 15 min and 30 min. The magnitude of the correlations was interpreted using the following scale[24]: <0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large; >0.9, nearly perfect. Magnitude-based inferences (mechanistic) were employed[25] based on the smallest worthwhile effect size of 0.1[26] and 90% CL. The chance of the true effect being substantial or trivial was calculated as previously described. The statistical package SPSS (version 24.0) was used for all analyses, alongside a spreadsheet (Excel, Microsoft, USA) published by Hopkins[24].

RESULTS

Descriptive Characteristics

Participant descriptive characteristics are shown in Table 1. A total of 76 exercise sessions were completed by the participants. Due to data loss from the telemetric HR monitors, a total of 69 exercise sessions were used for subsequent analysis. The average number of exercise sessions completed per participant was 5 ± 3 (range 3 to 11), with the average duration of these sessions being 50.7 ± 23.5 min. Out of the 69 exercise sessions, 42 were interval sessions, 20 were continuous (steady-state) runs and 7 were competitive races (i.e. 800 m). In total, 59 of the exercise sessions included a cool-down. The pooled average $TRIMP_I$; $TRIMP_E$, $TRIMP_L$, sRPE, dRPE-L and dRPE-B scores (AU) during the two-week mesocycle are shown in Table 2.

Latency Effect

The effect of time on sRPE, dRPE-L and dRPE-B scores is shown in Table 3. Differences between sRPE, dRPE-L and dRPE-B scores, across each time-point (0 min, 15 min and 30 min), are shown in Table 4.

Correlations Between Measures of ITL

Within-participant correlations between sRPE, dRPE-L, dRPE-B and each of the HR-based ITL measures ($TRIMP_I$, $TRIMP_E$ and $TRIMP_L$), at each time-point (0 min, 15 min and 30 min), are presented in Table 5. Correlations ranged from r = 0.61 to 0.89, across all HR-based criterion measures.

DISCUSSION

To our knowledge, this is the first study to have investigated both the latency effect and concurrent validity of sRPE, dRPE-L and dRPE-B, as measures of ITL, in adolescent distance runners. The main findings were that: (1) sRPE, dRPE-L and dRPE-B scores were all *most* *likely lower* when reported 30 min post-session, compared to scores reported at session completion (0 min), and (2) sRPE, dRPE-L and dRPE-B all maintained their largest correlations (r = 0.74 to 0.89) when reported at session completion (0 min), in comparison to each of the HR-based criteria measures.

Latency Effect

Traditionally, sRPE, dRPE-L and dRPE-B have been reported 30 min following session completion, in order to reduce the effect of the final section of an exercise session on an athlete's self-reported scores[8]. However, while this approach has been utilised across multiple studies[12], there remains a dearth of scientific literature in relation to the effect of measurement timing on sRPE, dRPE-L and dRPE-B. This is surprising, given that reporting scores at session completion (0 min) would be both practical and time-efficient.

Our data evidence a latency effect, whereby sRPE, dRPE-L and dRPE-B scores were all *most likely lower* when reported 30 min post-session. This finding is in contrast to the laboratory-based work of Christen et al.[9], conducted in well-trained youth athletes (n = 15; 18.9 ± 0.7 y), where it was found that measurement timing did not influence sRPE scores during a 24 hour follow-up period, in relation to steady-state and interval cycling exercise. However, these contrasting findings are likely an outcome of differences in exercise mode, as evidenced between cycling and distance running[27]. This argument is supported by McLaren et al.[11], who demonstrated more substantial latency effects on sRPE, dRPE-L and dRPE-B scores for treadmill running, when compared to ergometer cycling, between session completion (0 min) and 30 min post-session. However, this study was conducted with older participants (n = 22; 23 ± 3 y), consisting of male university soccer players. Therefore, although direct comparison with our results is difficult, the direction of the reported latency effect (i.e. decreasing over time) supports our findings. Nonetheless, both of the discussed studies were conducted in a laboratory setting, allowing the ecological validity of these studies to be questioned.

Previous literature has shown that the intensity towards the end of an exercise session and the inclusion (or exclusion) of a cool-down can influence the self-reported sRPE, dRPE-L and dRPE-B scores[9, 11]. Throughout this study, 59 exercise sessions included a cool-down, even though participants were not obliged to do so. Notably, the 10 exercise sessions that excluded a cool-down were all continuous (steady-state) runs. Therefore, it is unlikely that the sRPE, dRPE-L and dRPE-B scores would have been influenced by the given intensity towards the end of these exercise sessions. As a result, in contrast to how sRPE was initially implemented by Foster et al.[8] (i.e. reported 30 min post-session), our findings show that sRPE, dRPE-L and dRPE-B scores can be reported at session completion (0 min), when used with adolescent distance runners. However, in situations where an intense exercise session excludes a cool-down, sRPE, dRPE-L and dRPE-B may be biased towards higher scores.

Concurrent Validity

The pooled data demonstrate that sRPE, dRPE-L and dRPE-B all maintained their largest correlations (r = 0.74 to 0.89) when reported at session completion (0 min), in comparison to each of the HR-based criteria measures (Table 5). Also, when compared to previous literature[12], these correlations remained consistent (large to very large) across all time-points (0 min, 15 min, 30 min). This finding is similar to that reported by Lupo et al.[28], whereby the magnitude of correlation between sRPE and $TRIMP_E$ only marginally increased when reported 30 min post-session (r = 0.57), compared to reporting 1 min post-session (r = 0.55), in young taekwondo athletes (n = 9; 12.0 ± 0.7 y). Our data show that correlations between sRPE, dRPE-L, dRPE-B, and each of the HR-based criteria measures were similar when reported 0 min, 15 min and 30 min post-session. Therefore, these findings allow sRPE, dRPE-L and dRPE-B scores to be reported at session completion (0 min), in addition to 15 min and 30 min post-session.

Previous studies have typically only investigated the validity of $sRPE_{30}$[12], making direct comparison with our findings limited. Nevertheless, in youth martial arts[28, 29], individual correlations range from $r = 0.57$ to 0.97 ($TRIMP_E$), across all exercise intensities. However, when solely analysing the aerobic exercise sessions (n = 107), completed by male taekwondo athletes (n = 10; 13.1 ± 2.4 y), analogous to the external training loads applied in distance running, Haddad et al.[29] reported a correlation of $r = 0.57$. This correlation is lower than that found in our data ($r = 0.74$), at $sRPE_{30}$. In youth team sports, Impellizzeri et al.[30] found correlations ranging from $r = 0.54$ to 0.78 ($TRIMP_E$) and $r = 0.61$ to 0.85 ($TRIMP_L$), in male footballers (n = 19; 17.6 ± 0.7 y), while Lupo et al.[31] reported a correlation of $r = 0.88$ ($TRIMP_E$), in male water polo athletes (n = 13; 12.6 ± 0.5 y). These correlations are similar to our data ($sRPE_{30}$), whereby $r = 0.74$ ($TRIMP_E$), $r = 0.84$ ($TRIMP_L$) and $r = 0.78$ ($TRIMP_I$), respectively. However, throughout our study, reporting sRPE, dRPE-L and dRPE-B scores at session completion (0 min) always maintained the largest correlations.

PRACTICAL APPLICATIONS

Our results indicate that sRPE provides a valid measure of ITL when reported at session completion (0 min), 15 min and 30 min post-session, in adolescent distance runners. This finding is useful for coaches and practitioners, as $sRPE_0$ can be used as a practical and time-efficient approach for monitoring ITL, without having to delay the data collection process. Furthermore, considering that dRPE-L and dRPE-B maintain similar correlations to sRPE, across each of the HR-based criteria measures, it can be argued that these differential measures should also be used, due to their high degree of shared variance. For example, the sRPE and dRPE-L measures were very similar in terms of RPE scores (see Table 2), deterioration over time (see Table 3) and validity with the HR-based measures of ITL (see Table 5), at all time-points (0 min, 15 min and 30 min). Furthermore, the *very likely higher* (15 min post-session) and *most likely higher* (30 min post-session) differences between dRPE-L and dRPE-B scores (see Table 4) indicate that these measures reflect different components of exertion. Therefore, using dRPE-L and dRPE-B alongside sRPE, at all time-points (0 min, 15 min and 30 min), may be beneficial during particularly intense periods of training and/or competition, in order to discriminate between central and peripheral exertion.

In relation to study limitations, the collection of sRPE, dRPE-L and dRPE-B scores were not counterbalanced, possibly resulting in an order effect. Additionally, the number of exercise sessions completed per participant ranged from three to eleven, with data loss from the HR monitors compounding this issue. As a result, future research should extend the monitoring period, in order to capture a more substantial number of exercise sessions.

CONCLUSION

Our results indicate that regardless of whether sRPE is reported at session completion (0 min), 15 min or 30 min post-session, it provides a valid measure of ITL in adolescent distance runners. Our results also highlight that both dRPE-L and dRPE-B can be used in conjunction with sRPE, across all time-points (0 min, 15 min and 30 min), in order to discriminate between central and peripheral exertion.

Acknowledgements

The authors acknowledge the athletes and coaches involved in this research. Ricardo S. Olivera is acknowledged for supporting with data analysis. Robert H. Mann is supported by an Economic and Social Research Council PhD studentship, as part of the South West Doctoral Training Partnership. This PhD research is in collaboration with England Athletics.

References

1. Borresen J, Lambert MI. The quantification of training load, the training response and the effect on performance. *Sports Med*, 2009; 39:779-795.

2. Windt J, Gabbett TJ. How do training and competition workloads relate to injury? The workload—injury aetiology model. *BJSM*, 2017; 51:428-435.

3. Murray A. Managing the training load in adolescent athletes. *Int J Sports Physiol Perform* 2017; 12:S2,42-49.

4. Brenner JS. Sports specialization and intensive training in young athletes. *Pediatrics*, 2016; 138.

5. Astrand P-O, Rodahl K. Textbook of work physiology *New York: McGraw-Hill Book Company*, 1986.

6. Buchheit M. Monitoring training status with hr measures: Do all roads lead to rome? *Front Physiol*, 2014; 5:19.

7. Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med*, 2014; 44:139-147.

8. Foster C, Hector LL, Welsh R, Schrager M, Green MA, Snyder AC. Effects of specific versus cross-training on running performance. *Eur J Appl Physiol Occup Physiol* 1995; 70:367-372.

9. Christen J, Foster C, Porcari JP, Mikat RP. Temporal robustness of the session rating of perceived exertion. *Int J Sports Physiol Perform* 2016; 11:1088-1093.

10. Hutchinson JC, Tenenbaum G. Perceived effort — can it be considered gestalt? *Psychol Sport Exerc*, 2006; 7:463-476.

11. McLaren SJ, Graham M, Spears IR, Weston M. The sensitivity of differential ratings of perceived exertion as measures of internal load. *Int J Sports Physiol Perform* 2016; 11:404-406.

12. Haddad M, Stylianides G, Djaoui L, Dellal A, Chamari K. Session-rpe method for training load monitoring: Validity, ecological usefulness, and influencing factors. *Frontiers in Neuroscience*, 2017; 11:612.

13. Groslambert A, Mahon AD. Perceived exertion : Influence of age and cognitive development. *Sports Med*, 2006; 36:911-928.

14. Mujika I. Quantification of training and competition loads in endurance sports: Methods and applications. *Int J Sports Physiol Perform* 2017; 12:S2-9-17.

15. Jones A. Middle- and long-distance running *Sport and exercise physiology testing.*, 2007:147-154.

16. Moore SA, McKay HA, Macdonald H, Nettlefold L, Baxter-Jones AD, Cameron N, Brasher PM. Enhancing a somatic maturity prediction model. *Med Sci Sports Exerc*, 2015; 47:1755-1764.

17. Borg G. Borg's percieved exertion and pain scales *United States: Human Kinetics*, 1998.

18. Manzi V, Iellamo F, Impellizzeri F, D'Ottavio S, Castagna C. Relation between individualized training impulses and performance in distance runners. *Med Sci Sports Exerc*, 2009; 41:2090-2096.

19. Morton R, Fitz-Clarke J, Banister E. Modeling human performance in running. *J Appl Physiol*, 1990; 69:1171-1177.

20. Edwards S. High performance training and racing. *The Heart Rate Monitor Book: Sacramento, CA: Feet Fleet Press*, 1993:113-123.

21. Lucia A, Hoyos J, Santalla A, Earnest C, Chicharro JL. Tour de france versus vuelta a espana: Which is harder? *Med Sci Sports Exerc*, 2003; 35:872-878.

22. Weston M, Siegler J, Bahnert A, McBrien J, Lovell R. The application of differential ratings of perceived exertion to australian football league matches. *J Sci Med Sport*, 2015; 18:704-708.

23. Bland JM, Altman DG. Statistics notes: Calculating correlation coefficients with repeated observations: Part 1—correlation within subjects. *Bmj*, 1995; 310:446.

24. Hopkins WG. A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a p value. *Sportscience*, 2007; 11:16-20.

25. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*, 2009; 41:3-13.

26. Cohen J. A power primer. *Psychological bulletin*, 1992; 112:155.

27. Millet GP, Vleck VE, Bentley DJ. Physiological differences between cycling and running. *Sports Medicine*, 2009; 39:179-206.

28. Lupo C, Capranica L, Cortis C, Guidotti F, Bianco A, Tessitore A. Session-rpe for quantifying load of different youth taekwondo training sessions. *J Sports Med Phys Fitness*, 2017; 57:189-194.

29. Haddad M, Chaouachi A, Castagna C, Wong DP, Behm DG, Chamari K. The construct validity of session rpe during an intensive camp in young male taekwondo athletes. *International Journal of Sports Physiology and Performance*, 2011; 6:252-263.

30. Impellizzeri FM, Rampinini E, Coutts AJ, Sassi A, Marcora SM. Use of rpe-based training load in soccer. *Med Sci Sports Exerc*, 2004; 36:1042-1047.

31. Lupo C, Capranica L, Tessitore A. The validity of the session-rpe method for quantifying training load in water polo. *Int J Sports Physiol Perform*, 2014; 9:656-660.

Table 1. Descriptive characteristics of the participants (Mean ± SD).

Characteristic	**Overall (n=15)**	**Boys (n=12)**	**Girls (n=3)**
Age (y)	15.2 ± 1.6	15.0 ± 1.8	15.4 ± 0.8
Stature (cm)	167.2 ± 9.9	168.2 ±10.6	160.7 ± 3.3
Body Mass (kg)	54.3 ± 9.8	55.5 ± 10.2	46.3 ± 2.3
Maturity Offset (y)	1.5 ± 1.5	1.2 ± 1.5	2.7 ± 0.6
VO_{2max} ($mL\cdot kg^{-1}\cdot min^{-1}$)	62.1 ± 5.7	63.7 ± 4.6	55.7 ± 5.5
V_{max} ($km\cdot h^{-1}$)	17.3 ± 2.6	17.7 ± 2.2	15.7 ± 4.1
HR_{max} ($b\cdot min^{-1}$)	201 ± 9	202 ± 9	196 ±10
HR_{rest} ($b\cdot min^{-1}$)	58 ± 10	58 ± 8	55 ± 13
% VO_{2max} at the LT	75.3 ± 5.8	75.4 ± 5.6	74.7 ± 7.7
% HR_{max} at the LT	86.0 ± 10.3	85.1 ± 11.4	89.4 ± 2.6
% VO_{2max} at the LTP	85.9 ± 3.3	86.9 ± 2.8	82.0 ± 2.7
% HR_{max} at the LTP	94.1 ± 3.9	93.8 ± 4.2	95.2 ± 2.7

Abbreviations: VO_{2max}, maximal oxygen uptake; V_{max}, maximal aerobic velocity; HR_{max}, maximal heart rate; HR_{rest}, resting heart rate; LT, lactate threshold; LTP, lactate turn point.

Table 2. Internal training load during the two-week training mesocycle using the heart rate and rating of perceived exertion methods (Mean ± SD).

	Overall (69 sessions)	**Boys (62 sessions)**	**Girls (7 sessions)**
$TRIMP_I$ (AU)	24.6 ± 12.2	24.6 ± 12.3	23.9 ± 11.2
$TRIMP_E$ (AU)	137.1 ± 66.9	131.7 ± 63.6	184.7 ± 81.3
$TRIMP_L$ (AU)	67.2 ± 37.9	66.4 ± 38.5	73.9 ± 34.2
$sRPE_0$ (AU)	6.2 ± 2.0	6.0 ± 2.0	7.4 ± 1.9
$sRPE_{15}$ (AU)	5.2 ± 2.1	5.0 ± 2.1	6.6 ± 2.6
$sRPE_{30}$ (AU)	4.5 ± 2.3	4.4 ± 2.1	5.9 ± 3.7
dRPE-L_0 (AU)	6.0 ± 2.0	6.0 ± 2.0	6.6 ± 2.8
dRPE-L_{15} (AU)	5.2 ± 2.1	5.2 ± 2.0	5.7 ± 3.3
dRPE-L_{30} (AU)	4.8 ± 2.3	4.7 ± 2.1	5.3 ± 3.7
dRPE-B_0 (AU)	5.9 ± 2.0	5.8 ± 2.0	6.7 ± 2.4
dRPE-B_{15} (AU)	4.2 ± 2.5	4.0 ± 2.4	5.4 ± 3.5
dRPE-B_{30} (AU)	3.6 ± 2.8	3.4 ± 2.7	5.1 ± 3.8

Abbreviations: AU, arbitrary unit; $TRIMP_I$, individualised training impulse; $TRIMP_E$, Edwards' summated heart rate zone method; $TRIMP_L$, Lucia's training impulse; sRPE, session rating of perceived exertion; dRPE-L, differential rating of perceived exertion for leg exertion; dRPE-B, differential rating of perceived exertion for breathlessness; $_0$, time-point 0 min; $_{15}$, time-point 15 min; $_{30}$, time-point 30 min.

Table 3. Effect of time when collecting sRPE, dRPE-L and dRPE-B scores after exercise session completion (0 to 15 min, 15 to 30 min, and 0 to 30 min).

	Raw Change (AU; ±90% CL)	**% Change (±90% CL)**	**Qualitative Inference**
sRPE			
0 to 15 min	-1.0; ±0.2	-16.2; ±3.1	Most likely lower
15 to 30 min	-0.6; ±0.2	-12.3; ±2.9	Likely lower
0 to 30 min	-1.6; ±0.3	-26.5; ±5.0	Most likely lower
dRPE-L			
0 to 15 min	-0.8; ±0.2	-13.0; ±3.4	Likely lower
15 to 30 min	-0.4; ±0.1	-8.6; ±2.1	Likely trivial
0 to 30 min	-1.2; ±0.3	-20.5; ±4.9	Most likely lower
dRPE-B			
0 to 15 min	-1.7; ±0.4	-29.3; ±5.3	Most likely lower
15 to 30 min	-0.6; ±0.2	-13.6; ±3.5	Likely lower
0 to 30 min	-2.3; ±0.5	-38.8; ±6.8	Most likely lower

Abbreviations: AU, arbitrary unit; CL, confidence limits; sRPE, session rating of perceived exertion; dRPE-L, differential rating of perceived exertion for leg exertion; dRPE-B, differential rating of perceived exertion for breathlessness.

Table 4. Differences between sRPE, dRPE-L and dRPE-B scores at time-points 0 min, 15 min and 30 min.

	Raw Difference (AU; ±90% CL)	% Difference (±90% CL)	Qualitative Inference
0 min			
sRPE vs. dRPE-L	0.1; ±0.1	2.4; ±2.2	Most likely trivial
sRPE vs. dRPE-B	0.3; ±0.1	4.5; ±1.9	Most likely trivial
dRPE-L vs. dRPE-B	0.1; ±0.1	2.1; ±2.2	Most likely trivial
15 min			
sRPE vs. dRPE-L	-0.1; ±0.3	-1.2; ±3.1	Most likely trivial
sRPE vs. dRPE-B	1.0; ±0.3	19.5; ±4.7	Most likely higher
dRPE-L vs. dRPE-B	1.1; ±0.3	20.4; ±4.3	Most likely higher
30 min			
sRPE vs. dRPE-L	-0.2; ±0.1	-5.3; ±3.5	Very likely trivial
sRPE vs. dRPE-B	1.0; ±0.3	22.2; ±5.3	Most likely higher
dRPE-L vs. dRPE-B	1.2; ±0.3	28.7; ±7.1	Most likely higher

Abbreviations: AU, arbitrary unit; CL, confidence limits; sRPE, session rating of perceived exertion; dRPE-L, differential rating of perceived exertion for leg exertion; dRPE-B, differential rating of perceived exertion for breathlessness.

Table 5. Correlations between sRPE, dRPE-L, dRPE-B and each of the individualised heart rate-based methods of quantifying internal training load

	$TRIMP_I$			**$TRIMP_E$**			**$TRIMP_L$**		
	r	**±90% CL**	**Qualitative Inference**	***r***	**±90% CL**	**Qualitative Inference**	***r***	**±90% CL**	**Qualitative Inference**
$sRPE_0$	0.88	0.12	Most likely positive	0.78	0.20	Most likely positive	0.89	0.11	Most likely positive
$sRPE_{15}$	0.83	0.16	Most likely positive	0.78	0.20	Most likely positive	0.87	0.13	Most likely positive
$sRPE_{30}$	0.78	0.20	Most likely positive	0.74	0.22	Most likely positive	0.84	0.15	Most likely positive
$dRPE\text{-}L_0$	0.84	0.15	Most likely positive	0.74	0.22	Most likely positive	0.84	0.15	Most likely positive
$dRPE\text{-}L_{15}$	0.78	0.20	Most likely positive	0.72	0.24	Most likely positive	0.82	0.17	Most likely positive
$dRPE\text{-}L_{30}$	0.77	0.20	Most likely positive	0.72	0.24	Most likely positive	0.83	0.16	Most likely positive
$dRPE\text{-}B_0$	0.84	0.15	Most likely positive	0.75	0.22	Most likely positive	0.83	0.16	Most likely positive
$dRPE\text{-}B_{15}$	0.71	0.24	Most likely positive	0.67	0.27	Very likely positive	0.77	0.20	Most likely positive
$dRPE\text{-}B_{30}$	0.66	0.27	Very likely positive	0.61	0.30	Very likely positive	0.72	0.24	Most likely positive

Abbreviations: $TRIMP_I$, individualised training impulse; $TRIMP_E$, Edwards’ summated heart rate zone method; $TRIMP_L$, Lucia’s training impulse; CL, confidence limits; sRPE, session rating of perceived exertion; dRPE-L, differential rating of perceived exertion for leg exertion; dRPE-B, differential rating of perceived exertion for breathlessness; $_0$, time-point 0 min; $_{15}$, time-point 15 min; $_{30}$, time-point 30 min