Abstract

Purpose: To examine the effect of continuous (CON) and intermittent (INT) running training sessions of different durations and intensities on subsequent performance and calculated training load (TL).

Methods: Runners (n=11) performed a 1500m time-trial (1500m TT) as a baseline, and after completing 4 different running training sessions. The training sessions were performed in a randomized order, and were either maximal for 10 minutes (10CON, 10INT) or sub-maximal for 25 minutes (25CON, 25INT). An acute performance decrement (APD) was calculated as the percentage change in 1500m TT speed measured after training compared with baseline. The pattern of APD response was compared to that for several TL metrics (bTRIMP, eTRIMP, iTRIMP, rTSS and sRPE) for the respective training sessions.

Results: Average speed (P<0.001; η_p^2 =0.924) was different for each of the initial training sessions which all resulted in a significant APD. This APD was similar when compared across the sessions, except for a greater APD found after 10INT vs 25CON (P=0.02). In contrast, most TL metrics were different and showed the opposite response to APD, being higher for CON vs. INT, and lower for 10 vs. 25 min sessions (P<0.001; η_p^2 =0.563).

Conclusion: An APD was observed consistently after running training sessions but it was not consistent with most of the calculated TL metrics. The lack of agreement found between APD and TL suggests that current methods for quantifying TL are flawed when used to compare CON and INT running training sessions of different durations and intensities.

Keywords: Exercise, TRIMP, RPE, Heart Rate, Physical Endurance

Introduction

Training is frequently quantified by its load (TL), a metric that is a function of exercise intensity and duration, and assumed to reflect the stress of a given session or sessions.[1] In running[2,3] and team-sports[4–6] research has tended to focus upon the influence of TL on the development of fitness over the longer term involving multiple training sessions. Interest in evaluating TL has grown in recent years, notably driven by interest in injury prevention,[1] and wearable technology development.[7] For example, data from wearables enabled a recent study where the TL for 1.6 million training sessions were quantified in order to gain insight into optimal training strategies.[7] However, some studies have shown that the relationship between TL and performance is not straight forward.[8–10] This may be because relatively little attention has been given to validating how TL is derived from the intensity and duration of individual training sessions,[11] before TL is summed across multiple sessions.

Most TL metrics are based on the concept suggested initially by Banister *et al.*,[12] that training results in short and long term changes in performance that are dictated by the accumulation of both fatigue and fitness. Banister *et al.* derived the training impulse (TRIMP), a function of training intensity and duration, as a means of quantifying training sessions. The TRIMP was used as a TL metric to model how training altered athletes' fatigue and fitness status, and thus changes in their performance. In order to validate the underpinning concepts of TL we measured the acute performance decrement (APD) that results from a single cycling training session.[11] Given how TL is conceptualized, the size of a session's TL should be reflected in a corresponding APD. However, no agreement between the APD and typical TL metrics for that session were found. The largest difference in TL was found when comparing a short intense, maximal 5-min session with a longer 20-min one, yet the APD after both sessions was similar. These findings indicate that the current basis for calculating TL for cycling sessions is flawed and this could explain why the relationship between TL and performance is not straightforward. However, whether an APD occurs and is consistent with changes in TL following other modes of exercise, such as running, remains to be determined.

The prescription of intermittent (INT) training by perceived exertion rather than using relative exercise intensity is becoming increasingly popular due its simplicity, and its potentially greater benefits compared with continuous exercise (CON).[13] The process of INT training prescription varies according to the work interval, its exertion rating, duration, and recovery prescribed.[13] Runners and team sport players in particular, often employ INT methods in their training. The CON and INT sessions can be compared by matching for work,[14] or effort and duration (iso-effort, iso-time).[15,16] When two training sessions (CON vs. INT) were compared after matching for effort and duration, substantial differences in total work, oxygen uptake and blood lactate were reported.[15,16] A greater understanding of the comparative effects of iso-effort, iso-time CON and INT sessions may be provided by evaluating their TL and resulting APD but to our knowledge these have not been assessed together.

The present study was designed to evaluate the influence of iso-effort, iso-time CON and INT running training sessions of different durations on several TL metrics and subsequent APD. Specifically, we manipulated TL in different CON and INT sessions to evaluate whether the APD reflected these changes. Based on our previous research, we hypothesized that an APD would be observed after running sessions, but that differences in APD between sessions would contradict those for the respective TL metrics.

Methods

Participants

The participants in this study were 10 male and 1 female (mean ± SEM; age: 25 ± 2 years, height: 1.77 ± 0.1 m, weight: 67.3 ± 2.5 kg), well-trained runners. Participants had at least 3 years' experience of competing in events ranging from 800m to half-marathon; they trained >8 hours/ week and had personal best times for 1500m of 266 ± 8 s. All participants gave written informed consent to take part in this study which was approved by the ethics committee of the University of Kent in compliance with the Declaration of Helsinki.

Experimental Overview

Using a randomized, crossover, within-subjects design, over a 4 week period, participants completed 5 test-sessions following preliminary laboratory testing (see Figure 1). All sessions were separated by at least 48 hours. The 5 randomized test-sessions consisted of a baseline 1500m time-trial (1500m TT), and four experimental training sessions followed by a 1500m TT. All training sessions were completed at the same time of the day with participants fully rested and hydrated, having consumed a light meal 3 h before, and having refrained from alcohol and caffeine consumption, and vigorous exercise for 24 hours previously.

Preliminary Laboratory Testing

Participants performed a two-phase incremental test on an indoor treadmill (Woodway ELG, Woodway GmbH, Germany) to determine individual blood lactate concentration (La^-) profiles, and then maximum heart rate (HR_{max}), peak treadmill velocity (PTV), and associated $\dot{V}O_{2max}$.[2] The first phase consisted of 4 min stages, interspersed with 1 min rest, starting at an initial running speed of 10 $km \cdot h^{-1}$ and increasing by 1 $km \cdot h^{-1}$ each stage. The second test phase began when blood lactate concentrations (La^-) reached 4 mmol/l, whereupon running speed was increased continuously by 0.5 $km \cdot h^{-1}$ every 30-seconds until exhaustion. Thumb-prick La^- samples were collected and analyzed (Biosen C-Line analyzer, EKF diagnostics, Wales) during the 1 min rest periods in phase one, and immediately on completing phase two. Expired gases were measured using a breath-by-breath open-circuit indirect calorimetry system (Oxycon Pro, Erich Jaeger, Germany), calibrated according to the manufacturer's instructions prior to each use. The participants' HR_{max} and PTV were recorded as the highest observed values and $\dot{V}O_{2max}$ was calculated as the highest 30-second average.

Experimental Training Sessions

The 5 experimental sessions were conducted on an outdoor synthetic athletics track. The 4 experimental training sessions consisting of CON or INT running for 10 or 25 min (i.e. 10CON, 10INT, 25CON, 25INT) as shown in Figure 1. The CON and INT training sessions were matched for overall effort using the CR-10 scale,[17] and prescribed as maximal (10/10) for both 10 min sessions, and submaximal (6/10) for both 25 min sessions. The two INT training sessions consisted of 150m efforts performed once per minute, with the passive recovery lasting for the remainder of each minute. Participants self-paced their efforts, and no feedback was provided during or between training sessions. On completing the experimental training sessions participants had 5 min of passive recovery, before performing a 1500m TT.

Timing during all training sessions and 1500m TT's time was performed manually with a stopwatch. Speed and heart rate were measured second-by-second using a GPS wristwatch and a Bluetooth connected foot pod, (Polar Oy, Polar Electro, Kempele, Finland). The wind speed was assessed with a digital anemometer (Protmex, MS6252A) for all experimental sessions which were only performed if it was below 2 $m \cdot sec^{-1}$. Prior to all experimental sessions, HR_{rest} was measured for 3 min, seated in a quiet environment before participants undertook a standardized self-paced 3-lap warm-up and dynamic stretching routine.

Measurements

The APD for each experimental training session was calculated as the percentage change in 1500m TT speed, i.e. APD = (P1-P2)/P1•100, where P1 is the baseline 1500m TT speed and P2 is the 1500m TT speed recorded after the training session. Note that the APD is calculated as a positive percentage change to facilitate comparison with the corresponding TL metrics for the session.

The participants' RPE (scale 6-20) was recorded at 300m, 700m, 1100m, and 1500m during each 1500m TT and every 2 minutes throughout the experimental training sessions.[14] The National Aeronautics and Space Administration Task Load Index (NASA-TLX) rating scale[18] was used to assess TL immediately on completion of the experimental training sessions by summating the scores from its 6 sub-categories.[19] Motivation was assessed prior to experimental training sessions and 1500m TT's.[20] Participants were familiarized with all scales during their laboratory visit.

The TL metrics were calculated using 3 different TRIMP formulae (bTRIMP, iTRIMP and eTRIMP), session RPE[21] (sRPE) and a running training stress score (rTSS). The bTRIMP[22] was calculated from HR using a weighting factor according to the formula: bTRIMP = duration training (minutes) · ΔHR · y, where $\Delta HR = (HR_{ex} - HR_{rest}) / (HR_{max} - HR_{rest})$, where *y* represents a classic increase in blood lactate of $0.64e^{1.92x}$ for males and $0.84e^{1.67x}$ for females. The iTRIMP[2] was calculated using individualized weighting factors (y_i) for each participant using their phase 1 laboratory test data.[2] The eTRIMP[23] was calculated from the time spent in five pre-defined HR zones[22] multiplied by arbitrary zone-based weighting factors. The sRPE was collected immediately after the training session using the CR-10 scale[17] and multiplied by training duration ($sRPE_r$)[21] and excluding recovery ($sRPE_{wr}$).[24] The running training stress score (rTSS) was calculated as previously described[25,26] with functional threshold pace being assumed to be 88% of 10CON.[27] The TL metrics were also normalized by dividing them by the training session duration in order to remove the influence of duration and evaluate intensity separately.

Statistical Analysis

Statistical analysis was conducted using IBM SPSS Statistics 25 (SPSS Inc., Chicago, IL, ISA). Following a Kolmogorov-Smirnov test to check data for normality, where appropriate a one-way repeated measures ANOVA with Bonferroni post-hoc test was performed to compare mean values for the experimental training sessions, including the TL metrics, and the APD. Some TL metrics were not normally distributed (sRPE, eTRIMP, iTRIMP) and these were evaluated with the non-parametric Friedman and Bonferroni post-hoc test instead. Two-way repeated measures ANOVA (session x time) was used to compare the responses of variables (speed, HR, and RPE) during both the experimental training sessions and the 1500m TT's. Where the sphericity assumption was violated, the Greenhouse-Geisser correction was used. Effect sizes were calculated as partial eta squared (η_p^2) and small, medium, and large effects were taken as $\eta_p 2 \geq 0.01$, $\eta_p^2 \geq 0.059$, and $\eta_p 2 \geq 0.138$ respectively.[27] Statistical significance was accepted where $P < 0.05$ was found. All results are presented as mean ± SEM.

Results

Incremental Test

$\dot{V}O_{2peak}$ and PTV from the incremental test were 4.63 ± 0.22 L min^{-1} (68.8 ± 2.7 ml kg^{-1} min^{-1}) and 19.7 ± 0.5 km·h^{-1}, whilst HR_{max} and La^- were 188 ± 3 bpm and 12.6 ± 1.3 mmol/L respectively.

Experimental Training Sessions

Total distance covered in each session was 2914 ± 77, 1500, 6316 ± 193 and 3750 m for 10CON, 10INT, 25CON and 25INT, respectively. Technical problems meant HR analysis not performed for 1 participant. When comparing 10CON and 10INT a main effect of time was found for HR and RPE (P<0.001; η_p^2 >0.898) but not speed (P=0.306; η_p^2 =0.107). A main effect for session was found for speed and HR (P<0.001; η_p^2 >0.898) but not RPE (P=0.499; η_p^2 =0.047). A significant interaction was found only for HR (P<0.001; η_p^2 =0.463). When comparing 25CON and 25INT, a main effect of time was observed for all variables (P<0.001; η_p^2 >0.829), and a main effect of session was found for speed (P<0.001; η_p^2 =0.87), but not HR or RPE. A significant interaction was found for speed and HR (P<0.042; η_p^2 >0.248), but not for RPE (see Figure 2A).

Table 1 shows average speed was different between all the 4 training sessions (P<0.001; η_p^2 =0.924), %PTV (P<0.001; η_p^2 =0.92), as was HR_{mean} (P<0.001; η_p^2 =0.657), and RPE_{end} (P<0.001; η_p^2 =0.917), but motivation was similar (P=0.585; η_p^2 =0.062). A difference between sessions was found for all TL metrics, $sRPE_r$ (P<0.001), $sRPE_{wr}$ (P<0.001), rTSS (P<0.001; η_p^2 =0.882), bTRIMP (P<0.001; η_p^2 =0.781), eTRIMP (P<0.001), iTRIMP (P=0.001), and NASA-TLX (P<0.001; η_p^2 =0.74) and are shown in Figure 3. Bonferroni post-hoc testing revealed between-session differences for TL metrics as shown in Figures 3 and 4. Differences in the opposite direction were found when the TL metrics were normalized, sRPE (P<0.001), bTRIMP (P<0.001; η_p^2 =0.662), eTRIMP (P<0.001), iTRIMP (P<0.001) and rTSS (P<0.001; η_p^2 =0.799) and are shown in Figure 4). Figure 5 presents speed and HR for the 4 training sessions (A and C), and example minute periods (B and D).

1500m TT's

An APD was observed after all experimental training sessions ($P<0.001$; η_p^2 =0.454; β = 0.984). Bonferroni post-hoc testing found no differences in the size of APD except for 10INT vs. 25CON (P = 0.02; see Figure 3). Table 2 presents the measurements during the 1500m TT's. A main effect of time was observed for all variables measured during the 1500m TT's; speed (P=0.01, η_p^2 =0.429), HR ($P<0.001$, η_p^2 =0.956), and RPE (P=0.001, η_p^2 =0.869). A main effect of session was found for speed ($P<0.001$, η_p^2 =0.662), and RPE (P=0.05, η_p^2 =0.227) but not for HR (P=0.2, η_p^2 =0.148). A significant interaction was observed for speed (P=0.03, η_p^2 =0.229), but not for HR (P=0.16) or RPE (P=0.601), see Figure 2B. No difference was observed in motivation before the 1500m TT's, except for baseline vs. 10CON (P=0.01) and 25CON (P=0.02).

Discussion

This study examined the APD that results from running training sessions, and the effects of iso-effort CON and INT sessions. The main finding of the study was that an APD measured as a change in 1500m TT speed, was found after all training sessions regardless of their duration or intensity. The magnitude of this APD, was similar for all sessions, except when comparing 10INT with 25CON, where the shorter session resulted in a larger APD. Contradicting the APD response, the session TL metrics were significantly smaller for the shorter sessions when compared with the longer ones (Figure 3). Furthermore, whilst APD was not different when comparing CON and INT trials of the same duration, most of the TL metrics were significantly lower for the INT sessions. As can be seen in Figure 3, the APD showed the opposite pattern of response to its corresponding TL metrics, with the exception of the NASA-TLX responses, which broadly followed the same pattern as the APD. When TL metrics were normalized for session duration however, their pattern of response reversed and was seen to be much more consistent with that of APD.

The disagreement observed between APD and TL metrics questions the usefulness of TL metrics for comparing dissimilar training sessions. These findings are consistent with our previous study of continuous cycling bouts,[11] and extends these observations to situations involving running and CON vs. INT exercise. Previously, we observed a higher APD and lower TL metrics following 5 min maximal cycling compared with 20 and 40 min submaximal bouts. In the present study we found that comparing iso-effort CON and INT exercise highlighted further discrepancies between APD and TL. Typically, TL was lower for INT than CON whilst APD was not different. Previous studies[16,28,29] have shown that differently structured iso-time and iso-effort bouts require similar levels of effort. These findings are consistent with the APD response observed in the present study, and further support the use of the iso-effort method for prescribing exercise (Figure 2:E). The findings from the present study reinforce our previously expressed concerns on the shortcomings of using TL to compare training sessions of different intensity and duration and highlight further problems with using TL for INT activities.

The HR-based TL metrics (bTRIMP, eTRIMP, iTRIMP) had lower values for 10INT compared to 10CON training sessions (Figure 3). This is probably attributable to the delay in HR response that is most noticeable at the onset and offset of exercise (Figure 5). This effect is well-documented for INT activities in football[28] and cycling[29,30] and here we repeat those findings for INT running sessions. Table 1 summarizes the training session data which indicates that the APD's were not proportional to running speed, total distance, session duration or HR but were associated with differences in prescribed exercise intensity. Similar to the findings of our previous study, iso-effort sessions, although different in nature, resulted in similar APD's.

It seems unlikely that issues with the measurement of APD are responsible for its divergence from TL metrics, although the effect of pacing on performance is well known.[31] Previous studies have used maximum effort TT's effectively to evaluate changes in performance[32,33] and over similar distances.[3] Nonetheless, given the field nature of this study, we carefully monitored factors such as pacing and motivation. All participants were experienced middle-distance runners used to running this distance, and they were instructed to follow strictly the same pacing strategy for all their 1500m TT's. Figure 2B suggests that this approach was successful, as similar shaped pacing profiles can be seen for all 1500m TT's. Motivation was similar for most 1500m TT's after the training sessions, except when the baseline was compared with 10CON (*P*=0.012) and 25CON (*P*=0.016). Moreover, similar values were observed during all 1500m TT's for RPE_{mean}, RPE_{end} and HR_{mean}, which suggests that differences in motivation did not prevent participants from reproducing their maximum effort in all trials. Additionally, the similar time-course for changes in HR, and RPE shown in Figure 2:B, also suggest that the 1500 TT's were performed to a high level of consistency and therefore changes in APD reflect the impact of the prior training session rather than poor 1500m TT execution.

The reason for the contradiction between APD and TL may be related to the way in which exercise duration is incorporated into the TL metrics as a multiplier. Given that the present study used an RPE based prescription that appears to have been applied effectively, it may appear surprising that the sRPE was not consistent with the resulting APD. Most TL metrics, including sRPE, quantify TL based on the model proposed initially by Bannister *et al*,[12] multiplying the exercise intensity component (e.g. HR, speed or RPE) by its duration. But it is notable that the APD's observed in the current study were independent of changes in exercise duration. As a RPE scale was used both for prescription[17] and to calculate the sRPE,[21] it seems more likely that it is the use of duration as a multiplier that leads to discrepancies between the resulting APD and TL. This suggestion is reinforced when the TL metrics are evaluated after normalizing them for the training session duration to remove its influence (Figure 4). Once normalized the TL metrics show the opposite response and are much more consistent with the changes in APD, especially sRPE. This finding is consistent with that of Weaving and colleagues,[34] who concluded that duration was the main contributor to the TL variance observed for rugby players over an extended period of time. Notably, in the present study the NASA-TLX was the only metric that tracked APD reasonably, reinforcing the findings of our previous study.[11] The NASA-TLX does not use exercise duration as a multiplier, instead aggregating scores across six different subscales (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, Frustration). Thus, we suggest that the stress imposed by a training session may be better represented by weighting the importance of its duration and intensity separately.

Study Limitations

The field-based nature of this study poses some specific limitations. Due to the nature of the study it is not possible to comment on the potential mechanisms underpinning the APD. Bannister *et al.*,[12] when first introducing the TRIMP noted training sessions create a fatigue effect, quantified in the present study as an APD. As the etiology of the decrement in 1500m TT performance trials is unknown, we have avoided use of the term fatigue and referred to an APD instead. Indeed, we speculate that the etiology of the APD will likely vary according to the characteristics of the training session. Consequently, the APD measured directly after the session may not be proportional to the recovery time course, nor the overall stimulus for adaptation. Further studies are required to determine how the magnitude of APD varies in response to different sessions, and whether it corresponds to the recovery duration and resulting longer-term adaptations. A further limitation was that because most data collection occurred on an outdoor athletics track, differences in the weather could have influenced the training sessions and subsequent 1500m TT performances.

However, environmental conditions and wind speed in particular were monitored for every session which was postponed if wind speed was above 2 $m \cdot sec^{-1}$.

In the present study we adopted the conservative Bonferroni test for post-hoc analysis to find differences in TL metrics whilst APD was similar. Had we adopted a less conservative post-hoc test, the APD's for both 10-min sessions are found to be greater than those for both the 25-min sessions which reinforces our observation as APD and TL metrics change in opposite directions. However, given the limited sample size of the present study we preferred to adopt the more conservative perspective. Further research may be needed to examine a more diverse range of training sessions reflecting those typically adopted by athletes and coaches.[13,16]

Practical applications

Our findings have important implications for comparing training sessions and quantifying INT-based sessions using HR-based TL metrics in particular. Collectively, current TL metrics overestimate the stress imposed by longer running training sessions, independently of whether they are prescribed as CON or INT. Despite different methods implemented for computing TL, such as non-linear (bTRIMP, rTSS), zone-based (eTRIMP) or individualized (iTRIMP), the TL metrics changed in a contradictory manner to APD. In contrast, TL metrics normalized for session duration were reversed in response and much more consistent with APD. When coaches and athletes use TL metrics to evaluate training sessions of varying exercise duration they should be aware of the potential bias caused by using session duration as a multiplier and consider the influence of duration and intensity separately.

The use of effort-based methods was effective for the purposes of training session prescription for well-trained middle-distance runners as it resulted in an APD following every session. Importantly, APD is not suggested as a replacement for current methods of TL quantification, rather as an objective and theoretical contribution towards the development of new approaches. In this regard, future research could explore the use of NASA-TLX as the APD's found in the present study showed good agreement with these ratings. This finding is consistent with the conclusions of a systematic review on self-report measures,[35] but the use of NASA-TLX has not been examined thoroughly in a sporting context specifically.

Conclusion

A significant APD was observed as a decrease in 1500m TT performance following training sessions of 10, and 25 min duration comprised of CON and INT running. The changes in APD contradicted the TL metrics for the training sessions both for changes in exercise duration and when performed as CON or INT running. These results suggest that current methods for quantifying TL may be flawed and new methods need to be developed. Lastly, the present study found NASA-TLX was associated with APD and suggests its potential for evaluating training sessions may be worth exploring further.

References

1. Bourdon PC, Cardinale M, Murray A, et al. Monitoring athlete training loads: Consensus

statement. *Int J Sports Physiol Perform*. 2017;12:161-170. doi:10.1123/IJSPP.2017-0208

2. 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(11):2090-2096. doi:10.1249/MSS.0b013e3181a6a959

3. Wallace LK, Slattery KM, Coutts AJ. A comparison of methods for quantifying training load: Relationships between modelled and actual training responses. *Eur J Appl Physiol*. 2014;114(1):11-20. doi:10.1007/s00421-013-2745-1

4. Manzi V, Bovenzi A, Impellizzeri MF, Carminati I, Castagna C. Individual training-load and aerobic-fitness variables in premiership soccer players during the precompetitive season. *J Strength Cond Res*. 2013;27(3):631-636. doi:10.1519/JSC.0b013e31825dbd81

5. Akubat I, Patel E, Barrett S, Abt G. Methods of monitoring the training and match load and their relationship to changes in fitness in professional youth soccer players. *J Sports Sci*. 2012;30(14):1473-1480. doi:10.1080/02640414.2012.712711

6. Impellizzeri FM, Rampinini E, Coutts AJ, Sassi A, Marcora SM. Use of RPE-based training load in soccer. *Med Sci Sports Exerc*. 2004;36(6):1042-1047. doi:10.1249/01.MSS.0000128199.23901.2F

7. Emig T, Peltonen J. Human running performance from real-world big data. *Nat Commun*. 2020;11(1):1-9. doi:10.1038/s41467-020-18737-6

8. Vermeire KM, Vandewiele G, Caen K, Lievens M, Bourgois JG, Boone J. Training Progression in Recreational Cyclists. *J Strength Cond Res*. 2019:1. doi:10.1519/jsc.0000000000003340

9. Taylor AR, Sanders D, Myers T, Abt G, Taylor C, Akubat I. The dose-response

relationship between training load and aerobic fitness in academy rugby union players. *Int J Sports Physiol Perform*. 2017;13:163-169. doi:10.1073/pnas.0703993104

10. Van Erp T, Hoozemans M, Foster C, De Koning JJ. Case Report: Load, Intensity, and Performance Characteristics in Multiple Grand Tours. *Med Sci Sports Exerc*. 2020;52(4):868-875. doi:10.1249/MSS.0000000000002210

11. Kesisoglou A, Nicolò A, Passfield L. Cycling Performance and Training Load : Effects of Intensity and Duration. *Int J Sports Physiol Perform*. 2020:1-9. doi:doi.org/10.1123/ijspp.2020-0072

12. Banister, E. W., Calvert, T, W., Savage, M. V., Bach A. A systems model of training for athletic performance. *Aust J Sport Med*. 1975;7:57-61.

13. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle: Part II: Anaerobic energy, neuromuscular load and practical applications. *Sport Med*. 2013;43(10):927-954. doi:10.1007/s40279-013-0066-5

14. Gibala MJ, Little JP, Macdonald MJ, Hawley JA. Physiological adaptations to low-volume, high-intensity interval training in health and disease. *J Physiol*. 2012;590(5):1077-1084. doi:10.1113/jphysiol.2011.224725

15. Seiler S, Jøranson K, Olesen B V., Hetlelid KJ. Adaptations to aerobic interval training: Interactive effects of exercise intensity and total work duration. *Scand J Med Sci Sport*. 2013;23(1):74-83. doi:10.1111/j.1600-0838.2011.01351.x

16. Nicoló A, Bazzucchi I, Haxhi J, Felici F, Sacchetti M. Comparing continuous and intermittent exercise: An “isoeffort” and “isotime” approach. *PLoS One*. 2014;9(4). doi:10.1371/journal.pone.0094990

17. Borg GA V. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377-381.

18. Hart SG, Staveland LE. Development of NASA-TLX (Task Load Index). *Adv Psychol*. 1988;52:139-183. doi:10.1016/S0166-4115(08)62386-9

19. Hart SG. Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proc Hum Factors Ergon Soc Annu Meet*. 2012;50(9):904-908. doi:10.1177/154193120605000909

20. Lurquin JH, Michaelson LE, Barker JE, et al. No evidence of the ego-depletion effect across task characteristics and individual differences: A pre-registered study. *PLoS One*. 2016;11(2):1-20. doi:10.1371/journal.pone.0147770

21. Foster C, Florhaug J, Franklin J, Gottschall L. A New Approach to Monitoring Exercise Training. *J strength Cond Res*. 2001;15(1):109-115.

22. Bannister EW. Physiological testing of elite athletes. In: Macdouggal, J. D. Wenger, H. A. Green HJ, ed. *Physiological Testing of Elite Athletes.* Champaign,IL: Human Kinetics; 1991:403-424.

23. Edwards S. *The Heart Rate Monitor Book.* Sacramaneto: Fleet Feet Press; 1993.

24. Wallace LK, Slattery KM, Impellizzeri FM, Coutts AJ. Establishing the criterion validity and reliability of common methods for quantifying training load. *J Strength Cond Res*. 2014;28(8):2330-2337. doi:10.1519/JSC.0000000000000416

25. McGregor S, Weese R, Ratz I. Performance modeling in an olympic 1500-m finalist: A practical approach. *J Strength Cond Res*. 2009;23(9):2515-2523.

26. Skiba P. Calculation of Power Output and Quantification of Training Stress in Distance

Runners: The Development of the GOVSS Algorithm. 2006.

27. van Djik H, van Megen R. *Secret of Running: Maximum Performance Gains Through Effective Power Metering and Training*. Meyer & Meyer Sport; 2017.

28. Nicolò A, Montini M, Girardi M, Felici F, Bazzucchi I, Sacchetti M. Respiratory Frequency as a Marker of Physical Effort During High-Intensity Interval Training in Soccer Players. *Int J Sports Physiol Perform*. 2019;15(1):73-80.

29. Nicolò A, Marcora SM, Bazzucchi I, Sacchetti M. Differential control of respiratory frequency and tidal volume during high-intensity interval training. *Exp Physiol*. 2017;102(8):934-949. doi:10.1113/EP086352

30. Nicolò A, Bazzucchi I, Lenti M, Haxhi J, Di Palumbo AS, Sacchetti M. Neuromuscular and metabolic responses to high-intensity intermittent cycling protocols with different work-to-rest ratios. *Int J Sports Physiol Perform*. 2014;9(1):151-160. doi:10.1123/IJSPP.2012-0289

31. Jones A, Whipp B. Bioenergetic constraints on tactical decision making in middle distance running. *Br J Sports Med*. 2002:102-104.

32. Currell K, Jeukendrup A. Validity, Reliability and Sensitivity of Measures of Sporting Performance. *Sport Med*. 2013;43(2):297-316. doi:10.2165/00007256-200838040-00003

33. Passfield L, Doust JH. Changes in cycling efficiency and performance after endurance exercise. *Med Sci Sports Exerc*. 2000;32(11):1935-1941. doi:10.1097/00005768-200011000-00018

34. Weaving D, Dalton-Barron N, McLaren S, et al. The relative contribution of training intensity and duration to daily measures of training load in professional rugby league and

union. *J Sports Sci.* 2020;38(14):1674-1681. doi:10.1080/02640414.2020.1754725

35. Saw A, Main L, Gastin P. Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. *Br J Sports Med.* 2015;50:281-291.

Figure captions

Figure 1. Diagram of the experimental design. Visit 1 is for preliminary testing. The baseline, 10CON, 10INT, 25CON and 25INT visits are the experimental training sessions (open boxes) performed in randomized order* and the 1500 TT's (filled boxes) evaluate APD.

Figure 2. The left panels show responses to the experimental training sessions and the right hand panels show responses to the subsequent 1500 TT's. Individual plots are for Speed (A and B), HR (C and D), RPE (E and F). See text for abbreviations. baseline (filled squares), 10CON (filled circles), 10INT (open circles), 25CON (filled triangles), 25INT (open triangles). Values are mean ± SEM. Statistical significance is indicated as follows; (‡) interaction of condition by time ($P < 0.05$), (*) main effect of condition ($P < 0.05$), (†) main effect of time ($P < 0.05$).

Figure 3. Training load metrics for the training sessions: APD - Panel A, NASA-TLX - Panel B, $sRPE_r$ - Panel C, $sRPE_{wr}$ - Panel D, bTRIMP - Panel E, eTRIMP – Panel F,

iTRIMP - Panel G, and rTSS^{TM} – Figure H. See text for abbreviations. Values are mean ± SEM. Significant pairwise comparisons are shown as follows; $^{*}P < 0.05$ from 25CON and 25INT, $^{\dagger}P < 0.05$ from 10INT, $^{\#}P < 0.05$ from 25CON.

Figure 4. Normalized training load metrics for the training sessions: sRPEr- Panel A, bTRIMP - Panel B, eTRIMP - Panel C, iTRIMP - Panel D, rTSS - Panel F. See text for abbreviations. Values are mean ± SEM. Significant pairwise comparisons are shown as follows; $^{*}P < 0.05$ from 25CON and 25INT, $^{\dagger}P < 0.05$ from 10INT, $^{\#}P < 0.05$ from 25CON.

Figure 5: The left panels show the group mean time course for Speed (A) and HR (C) from the experimental training sessions. The right panels show the group time course within the work-recovery cycle for Speed (B) and HR (D). Values are mean ± SEM. Statistical significance is indicated as follows; $^{(\ddagger)}$ interaction of condition by time ($P < 0.05$), $^{(*)}$ main effect of condition ($P < 0.05$), $^{(\dagger)}$ main effect of time ($P < 0.05$).