

Effects of intensity distribution changes on performance and on training loads quantification

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ABSTRACT: The present study analyses the effects of the high-intensity distribution change within sessions on physical performance and on training loads (TL) provided by quantification methods based on heart rate (HR) and on whole body indicators of exercise-induced physiological stress. Fourteen trained physical education students (21.9 ± 1.2 years, 68.3 ± 7.9 kg, 180 ± 7.3 cm) performed two sessions with the same intensities, volumes and pauses but differing in the efforts' intensity distribution: one was composed of exercises dissociating the intensities (12 repetitions of 30 m sprints then 12 min interval runs) and the second mixed the intensities (30 m sprint followed by 60 s rest and 2 runs of 15 s - 15 s at 100% and 50% of maximal aerobic velocity – MAV). Session TL was calculated using methods based on heart rate zones, training impulse, ratings of perceived exertion (session RPE) and endurance limit. Session-induced fatigue was observed using performances in repeated sprints and counter-movement jumps. The heart rate zone method provided higher TL for the mixed session ($p=0.007$), while training impulse described similar TL for the two sessions ($p=0.420$). The endurance limit method showed borderline significantly higher TL in dissociated sessions ($p=0.058$) and session RPE provided similar but the largest differences between sessions' TL ($p=0.001$). The dissociated session induced larger losses in counter-movement jumps ($p=0.010$) but lower speed decreases in sprints ($p=0.007$). Change in intensity distribution within sessions induced contradictory effects on performances and on TL quantification according to the method used. When high intensities are programmed, methods based on heart rate may present limitations for TL quantification, as such methods based on whole body indicators of exercise-induced physiological stress should be preferred.

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INTRODUCTION

According to modern sports history and to the differences observed between the competitive levels, it can be assumed that athletes increase their training loads (TL) to enhance their performance. Therefore, many authors assume that the relationship between training and performance can be reduced to a simple dose-response relationship [1, 2]. Surprisingly, if the methods and tools for the response measurements are largely available (measurements of physiological, physical or sport performances) the measurement of the training dose appears less evident [3, 4]. In the scientific literature, training is described and quantified by training volume (quantities) or by TL [4-6]. When training volume is used, volumes performed at low intensities are likely to be highly elevated, over-expressing low intensity volumes, which leads scientists and coaches to delineate volumes according to specific intensity zones [6, 7]. Conversely, TL has to express in a single value the

exercise-induced physiological stress imposed on athletes by combining the exercise intensity, volume and density (i.e. exercise frequency) [5, 8]. To investigate the relationship between training and performance, this physiological stress is preferably expressed relative to the individual capabilities that can be identified as "internal TL" [8]. In some TL quantification methods, TL is the result of the multiplication of the exercise duration by a parameter describing the exercise intensity, which is, in some cases, the exercise heart rate (HR) [9, 10] or the session rating of perceived exertion (RPE) [11-13]. Other methods are based on the total cumulated work / endurance limit ratio [3] and, more recently, on new technologies such as the Global Positioning System [14, 15]. To date, published data provided by the new technological devices are not expressed relative to individual capabilities. Therefore, some TL quantification methods are based on one specific physiological parameter (HR), while others are based

on the larger assessment of the exercise-induced physiological stress (perceived exertion or level of endurance limit).

The first scientific method of TL quantification was developed for aerobic exercises and was based on HR records [2]. Thereafter, the validity of the RPE-based method has been tested by comparison with HR-based methods, suggesting that the exercises observed were still performed on an aerobic basis [11, 16]. Nevertheless, modern training largely uses high-intensity intervals to promote aerobic power and strength improvements [17]. Furthermore, whilst some training sessions may be composed of a separate distribution of exercise intensities according to the targeted physical capability (i.e., sprint, strength or endurance exercises being dissociated) [18, 19], other sessions may prescribe a mixed distribution of intensities modifying the effort [20, 21]. The mixed distribution of intensities within the exercise appears more and more popular in team, racket and combat sports [21]. The aim of this latter exercise type is to promote similar requirements to those of the competitive event. The effect on intensity distribution within the session has largely been reported for changing the physiological responses to exercise, whereas one study did not observe any effect of the intensity distribution change on sessions' TL calculated by the session-RPE method [19, 22]. It could be hypothesized that the accuracy of the TL quantification methods may depend on their components in regards to the composition of the exercise session.

The present study analyses the effects of the high-intensity distribution change within sessions on physical performance and on TL provided by quantification methods based on HR and on whole body indicators of the exercise-induced physiological stress.

MATERIALS AND METHODS

In the study, the TL of high-intensity interval sessions that were organized in dissociated and mixed manners were compared. With this in mind, models of dissociated and mixed efforts were built where

the same exercise intensities, durations of work and pauses were prescribed. Each subject completed two testing sessions and two exercise sessions performed in a random order in which models of dissociated and mixed efforts were applied (Figure 1). In testing sessions, subjects' maximal physical capacities (maximal aerobic velocity [MAV], and endurance limits) were assessed; these sessions were interspersed by at least 48 h of recovery. This study was performed over a 3-week period.

All the testing and exercise sessions were performed on the same athletics track, in similar weather conditions (10 to 15°C) in the afternoon (starting at 4.00 p.m.), and in each session subjects were verbally encouraged to do their very best. No vigorous exercise was performed 24 h before testing or an exercise session of the study.

Participants

Fourteen physical education students took part in the study (age, 21.9±1.2 years; body mass, 68.3±7.9 kg; height, 180±7.3 cm). Participants physically trained at least 4 times a week and were all engaged in an official competitive sport season. All subjects were medically examined before they read and signed an informed consent form in accordance with the guidelines of the French Sport Sciences ethics committee.

Testing procedures

Each session was preceded by an identical specific warm-up (15 min) composed of low-intensity running, by global and specific muscle movements and by progressive sprints.

In the first testing session, subjects completed a sprint test until exhaustion to determine their endurance limit at maximal speed ($End_{limSprint}$). This test was similar to a Wingate test performed by running including a start performed at an "all out" pace without searching for effort management. Subjects were asked to perform a maximal run of 200 m (on a standard 400 m athletics track), and

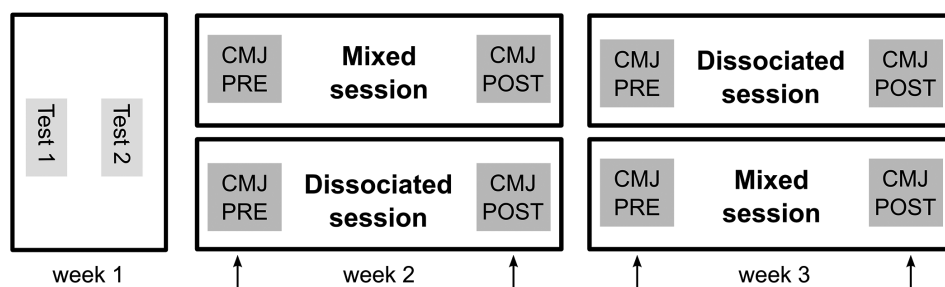


FIG. 1. Study design for weeks 1, 2 and 3. In week 1, testing sessions occurred (test 1 and test 2) and in weeks 2 and 3 dissociated and mixed sessions were performed. Counter-movement jumps (CMJ) were performed at the beginning and the end of the training sessions. Dissociated session: twelve 30 m sprints (pause of 90 s between sprints); 6 min pause; 12 min of interval exercise alternating 15 s at 100% of MAV and 15 s at 50% of MAV. Mixed session consisted in 12 repetitions of a set composed of: 30 m maximal sprint; 60 s pause; 2 runs of 15 s-15 s at 100% and 50% of MAV; 60 s pause.

speeds were assessed each 20 m by a subsequently analysed video recording (LongoMatch software, version 0.18). The individual endurance limit was identified as being the time point where speed loss exceeded 5% of the highest speed observed since the beginning of the test.

After a 20 min rest, subjects performed an incremental exercise test to exhaustion to determine their MAV using the University of Montreal Track Test [23]. The velocity of the first stage was set at $8 \text{ km} \cdot \text{h}^{-1}$ and was increased by $1 \text{ km} \cdot \text{h}^{-1}$ every two minutes. The last full stage completed corresponded to the MAV.

The second testing session took place after three days of recovery. Subjects performed, on a standard athletic track, a test to exhaustion at 100% of their individual MAV to determine their endurance limit at this velocity ($\text{End}_{\text{limMAV}}$). The individual running velocity was indicated to subjects by beeps.

Exercise sessions

The sessions organized in dissociated and mixed manner were performed by subjects in a random order. The dissociated session consisted firstly of repeated sprints ($12 \times 30 \text{ m}$ at maximal velocity), interspersed with a 90 s rest pause. After the sprint set, a 6 min recovery pause was prescribed. After this pause, 12 min of interval exercise was performed by alternating 15 s at 100% of MAV and 15 s at 50% of MAV.

The mixed session consisted of 12 repetitions of a set composed of: 30 m maximal sprint followed by 60 s rest pause and 2 runs of 15 s-15 s at 100% and 50% of MAV, terminated by a 60 s rest pause. Consequently, intensities of exercises and pauses, and total durations of efforts and of pauses were similar in the models of dissociated and mixed organizations, but obviously the moments within the session when the exercises and pauses occurred were different.

During the sessions, the time assessment of each sprint was assessed using photocells (Polifemo, Microgate, Bolzano, Italy) and electronic chronometers with 0.001 s accuracy (Racetime 2, Microgate, Bolzano, Italy). To quantify the ability to resist fatigue during the repeated-sprint exercises the speed decrease (S_{dec}) was calculated by using the following equation:

$$S_{\text{dec}}(\%) = \left\{ 1 - \frac{(S_1 + S_2 + S_3 + \dots + S_{\text{final}})}{S_{\text{best}} \times \text{number of sprints}} \right\} \times 100$$

This method is considered as the most valid and reliable method to quantify neuromuscular fatigue in repeated sprints [24].

HR was measured and recorded at rest, as well as every 5 s during each training and testing session, using HR monitors with individually coded HR transmitters to avoid interference (Polar RS400, Kempele, Finland).

Immediately after the warm up and at the end of each session, counter-movement jumps (CMJ) were performed on a Bosco carpet [25]. Subjects performed CMJ four times with twenty seconds of recovery between each jump. Vertical jump standardization was

achieved through a 90-degree knee bend, keeping hands on the waist throughout the jump, avoiding undue lateral and frontal movements, and landing with extended legs. Any jump that did not meet the established criteria was excluded from calculations and was repeated. The average value of the three best jumps was used in the analysis to improve the accuracy of measurements, as recommended by Taylor and Cormack [26, 27]. The jump height was chosen as the dependent variable.

TL quantification

The TL of the dissociated and mixed sessions were calculated using four different methods.

The training impulse (TRIMPS) was determined as described by Banister [28] using the following equation: $\text{TRIMP} = \text{TD} \times \text{HR}_r \times 0.64 \times e^{(1.92 \times \text{HR}_r)}$; in which TD is the training duration of the effective training session expressed in minutes. HR_r is the HR reserve determined from the following equation: $[(\text{HR}_{\text{ts}} - \text{HR}_b) / (\text{HR}_{\text{max}} - \text{HR}_b)]$ where HR_{ts} is the average training session HR; HR_{max} and HR_b are respectively the maximal and basal HR. HR_b was self-measured in the supine position when the subjects awoke and HR_{max} was measured during the MAV test.

TL was also calculated using the summated heart rate (SHR) zone method as proposed by Edwards [10]. The product of the cumulated training duration (duration in minutes) for five HR zones multiplied by a coefficient relative to each zone was calculated (respectively, 50-60% of $\text{HR}_{\text{max}} = 1$; 60-70% $\text{HR}_{\text{max}} = 2$; 70-80% $\text{HR}_{\text{max}} = 3$; 80-90% $\text{HR}_{\text{max}} = 4$; 90-100% $\text{HR}_{\text{max}} = 5$). The results obtained for each zone were summed to provide a single "score" for the exercise session.

RPE was obtained using the category ratio scale (CR-10) modified by Foster et al. [11, 29]. Two weeks before the beginning of the study, subjects were familiarized with the CR-10 scale by using it during their training sessions. Subjects were asked to provide a rating (from rest: 0 to maximal exercise: 10) of the exercise every 6 min while exercising, and approximately 30 min after the cessation of the session to ensure that the perceived effort was referred to the whole session rather than the most recent exercise intensity. The sessions' TL was obtained by multiplying the session RPE by the entire duration (in minutes) of the training session: $\text{TL} = \text{duration} \times \text{CR-10}$.

TL was also calculated using the work endurance recovery (WER) method [3]. The cumulated work at a given intensity was expressed relative to the endurance limit (End_{lim}) while the exercise frequency was determined using the work-recovery ratio expressed through the duration of the cumulated recovery periods and of the cumulated work [30, 31]. Then, the TL from the WER method was determined using the following equation: $\text{CE} = (\text{CumulatedWork} / \text{End}_{\text{lim}}) + \ln(1 + \text{DurationCumulatedWork} / \text{DurationCumulated Recovery})$ in which the cumulated work was calculated for a given exercise session as the sum of the work that had been completed at the intensity required, and End_{lim} was the individual result recorded for the cor-

responding test session. For each session, the cumulated work and End_{lim} were expressed in the same units (i.e., in minutes or seconds). Duration of cumulated recovery and work were calculated from the sum of the tasks completed in a given exercise session and were expressed in seconds.

Statistical analyses

Results are expressed as means \pm SD values. Using the Shapiro-Wilk test the normality distribution of the data was assessed. Statistical differences for each parameter values between the two sessions were tested with Student's *t* test for paired data. Significant differences are presented in terms of the parameter estimates and corresponding 95% confidence intervals (CI_{95}). The scale proposed by Cohen [32] was used for interpretation; the following criteria were adopted to interpret the magnitude of the difference between test measures: <0.2 trivial, $<0.2-0.5$ small, $<0.5-0.8$ medium and >0.8 large. A two-way repeated-factor analysis of variance (ANOVA) was used to determine the differences in RPE records and sprint performances in the two sessions. The Bonferroni correction post hoc test was used when *F* was significant in the ANOVA according to the Greenhouse–Geisser procedure. Statistical analysis was undertaken using STATISTICA (Version 6.1, StatSoft, France). The level of significance was set at $p < 0.05$.

RESULTS

Subjects' performances recorded during the two test sessions were as follow: $End_{limSprint}$ ($11.9 \pm 0.87s$), MAV ($16.9 \pm 1.02 \text{ km} \cdot \text{h}^{-1}$), End_{limMAV} ($349 \pm 27.78s$). Table 1 reports the results in physical performances recorded over the exercise sessions. The decline in performance in the CMJ was significantly higher for the dissociated session [$t(13)=2.60$, $d=0.69$]. For both sessions a progressive decline in performances appeared throughout the sprints, with a

higher speed loss ($F_{5,22}$, $91.59=2.214$, $p=0.017$) and a greater speed decrease [$t(13)=2.77$, $d=0.74$] observed in the mixed session.

RPE over the dissociated session were higher than in the mixed sessions, showing a combined effect of the type of session and of the repeated RPE values (Figure 2; $F_{9,42}$, $101.29=4.843$, $p=0.016$). RPE 30 min after the end of the session was also higher in the dissociated session compared to the mixed one [$t(13)=4.76$, $p=0.018$, IC (0.55; 1.45), $d=1.27$].

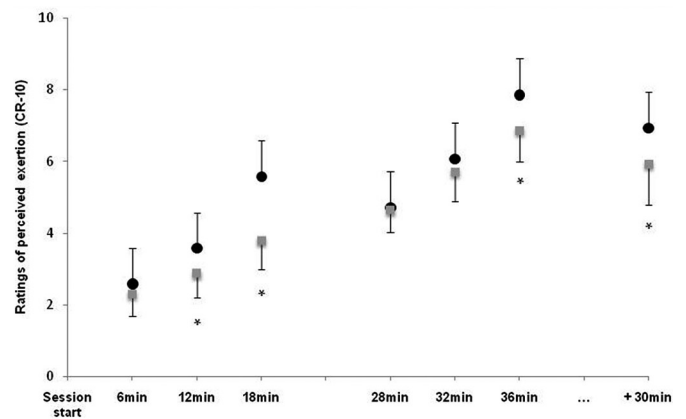


FIG. 2. Ratings of perceived exertion over the dissociated (black dots) and mixed sessions (grey squares), the sessions terminated at 36 min and + 30 min corresponded to the record performed 30 min after the session end. *: Significant differences between the two sessions. At all time points of a given training session a time effect was observed (except from end to +30 min records); for clarity of the figure, this time effect was not graphically presented.

TABLE I. Performances and statistical differences recorded in sprint, counter movement jumps (CMJ) and heart rate in the dissociated and mixed sessions.

Variables	Dissociated session	Mixed session	<i>t</i>	<i>P</i>	<i>CI</i>
Mean sprint times (s)	4.33 \pm 0.12	4.38 \pm 0.08	2.28	0.019	- 0.08 – 0.002
Sprint speed decreases (%)	0.05 \pm 0.13	0.06 \pm 0.15	2.77	0.007	- 0.01 – 0.001
CMJ decline (cm)	5.14 \pm 1.86	3.69 \pm 1.29	2.60	0.01	0.24 2.65
HR mean (bpm)	135.79 \pm 5.73	136.07 \pm 5.49	0.29	0.38	- 2.39 1.82
HR max (bpm)	192.71 \pm 6.57	189.50 \pm 5.82	5.16	< 0.001	1.87 4.55
Duration Hr zone 100-90% (s)	236.14 \pm 37.53	103.21 \pm 40.69	12.04	< 0.001	109.09 156.76
Duration Hr zone 90-80% (s)	541.21 \pm 100.22	649.43 \pm 74.81	4.99	< 0.001	49.52 166.90
Duration Hr zone 80-70% (s)	628.14 \pm 209.55	1015.50 \pm 129.77	4.99	< 0.001	219.83 554.88
Duration Hr zone 70-60% (s)	804.93 \pm 238.72	676.36 \pm 208.51	1.20	< 0.001	-102.12 359.26
Duration Hr zone 60-50% (s)	779.21 \pm 103.38	573 \pm 117.22	5.48	< 0.001	124.94 287.48

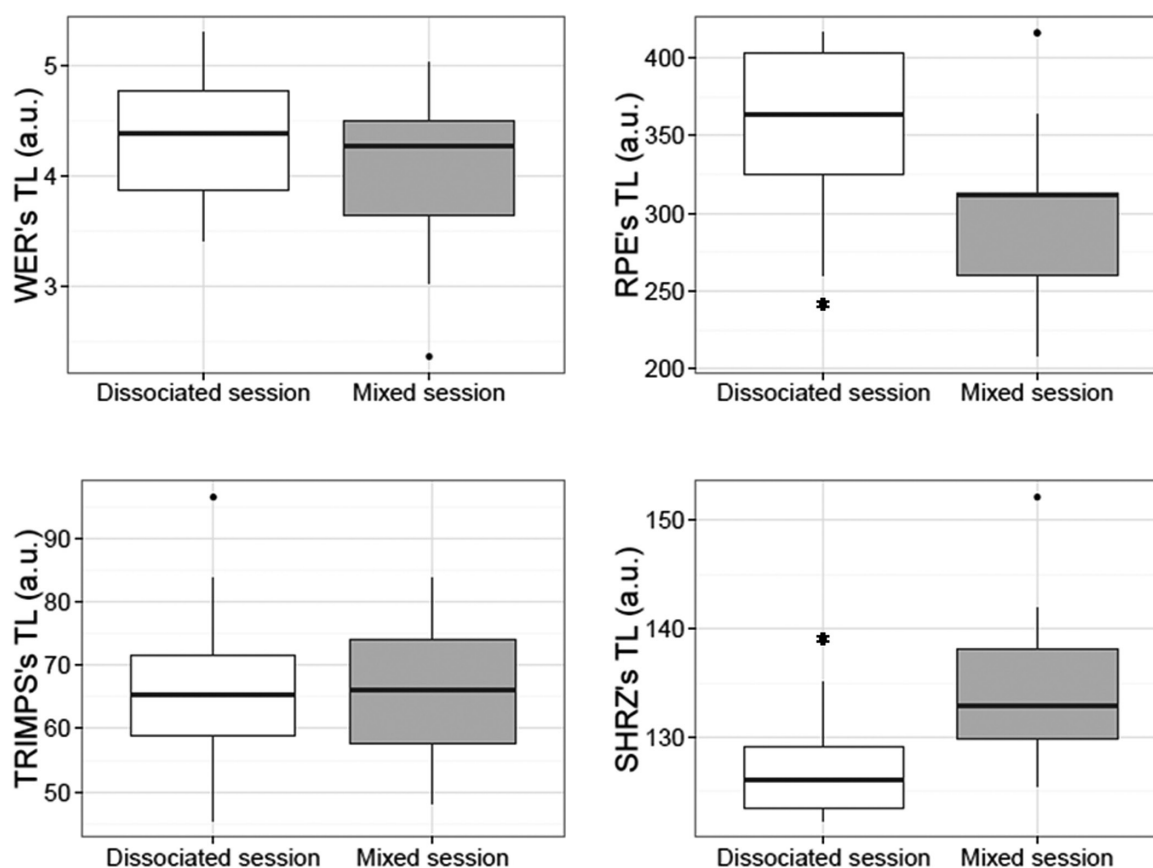


FIG. 3. Box plots for training loads in dissociated and mixed sessions using endurance limit based method (WER, up-left), training impulse method (TRIMP, down left), session ratings of perceived exertion method (RPE, up-right) and summated heart rate zone method (SHRZ, down right). *: Significant differences between the two sessions; TL differences for the WER method were on the verge of statistical significance ($p=0.058$). Continuous and horizontal black lines for medians, and black dots for outliers.

The two sessions did not exhibit significant differences in the mean HR recorded [$t(13)=0.29$, $d=0.007$], while HR_{max} was higher in the dissociated session [$t(13)=5.16$, $d=1.38$]. Longer times spent in the 100-90, 70-60 and 60-50% zones of HR_{max} were observed for the dissociated than for the mixed session [respectively, $t(13)=12.04$, $d=3.21$; $t(13)=1.20$, $d=0.32$; $t(13)=5.48$, $d=1.46$]. Times spent in 90-80 and 80-70% of HR_{max} were higher in the mixed session [respectively, $t(13)=3.98$, $d=1.60$ and $t(13)=4.99$, $d=1.33$].

TL calculated from the RPE-based method was higher in the dissociated session than in the mixed one [$t(13)=4.76$, $p=0.001$, IC (28.45; 75.55), $d=1.27$; Figure 3], while TL from the SHR-zone method was higher in the mixed session [$t(13)=3.99$, $p=0.007$, IC (3.57; 11.99), $d=1.06$]. When using the WER method, borderline significantly higher TL in the dissociated than in the mixed session was observed [$t(13)=1.68$, $p=0.058$, IC (-0.07; 0.61), $d=0.44$]. TL calculated from the TRIMPS method showed no significant difference between the sessions [$t(13)=0.19$, $p=0.420$, IC (-4.08; 3.39), $d=0.05$].

DISCUSSION

The aim of the study was to analyse the effects of the dissociated and mixed high-intensity distributions on physical performances and on TL quantifications. Although prescribing the same total work and pauses, the dissociated and mixed intensity distributions have contrasting effects: *i*) similar sessions' mean HR but different times spent in HR zones; and *ii*) a smaller speed decrease in sprints but higher loss in CMJ performances in the dissociated distribution. In addition, for the same sessions, this study revealed marked differences in the TL provided by the four quantification methods.

Methods' components and calculated TL depend on distribution of intensities

The present study is the first to show, for the same sessions, that the TL provided by different quantification methods may greatly differ; the RPE-based and WER methods suggest that the dissociated session results in higher TL, the TRIMP method assumes similar TL for the two sessions, and the SHR-zone method results in lower TL for the dissociated than for the mixed session.

Among the TL quantification methods, those based on HR records have been the first used in the scientific literature and were used to validate new methods proposed thereafter [9-11]. Surprisingly, the TRIMP and SHR-zone methods do not assess the sessions similarly; the first method provides similar TL for the two sessions, whereas the second assumes that the mixed distribution of intensities results in higher TL. According to the fact that these methods are composed of the same component of exercise duration, TL differences result from the intensity component of the methods [2, 4, 11]. The TRIMP method is based on the session's mean HR, while the SHR-zone method is based on an HR-zone coefficient applied to the time spent in each zone [4]. The sessions resulted in similar mean HR resulting in the same TL quantification for the mixed and dissociated sessions when using the TRIMP method. Nevertheless, the time spent in the five HR zones differed between the sessions. The dissociated session presents a longer time spent in the 90-100% zone, suggesting that repeated runs of 15 s with 15 s of active recovery involved a higher level of maximal oxygen consumption [33]. However, time spent in zones 70-80 and 80-90% of HR_{max} are higher in the mixed session, resulting in the fact that the SHR-zone method provides higher TL for the mixed session than for the dissociated session.

One might assume that the use of exercise's mean HR presents limits for the assessment of the physiological demand of sessions with intervals performed at high intensities [34]. Conversely, TL provided by the SHR-zone method takes into account the marked differences appearing in the time spent in the five HR zones. However, it is noticeable that the coefficients of HR zones evolve linearly whereas the capacity to maintain intensities according to duration evolves in a logarithmic or exponential manner [35]. Consequently, the weight of the exercise's parts performed in higher HR zones may be underestimated compared to the lower ones. TL quantified using methods based on heart rate when sessions prescribe varied and high exercise intensities should be accepted cautiously [7]. The inability of HR to assess the intensities of sprint exercises is self-evident.

Conversely, the RPE-based and WER methods result in higher TL for the dissociated session, underlining the fact that changes in intensity distribution may have an effect on TL quantification. Our results differ from those of a recent study analysing mixed sessions which did not report alterations of session RPE [22]. Differences in sessions' TL appear significant with the RPE-based method and weaker with the WER method, which provides a small effect. These two quantification methods are based on whole assessments of the exercise-induced physiological stress by using RPE and the cumulated work according to the endurance limit. As no universal parameter can be used to assess a wide range of exercise intensity, exercise-induced physiological stress in sessions with varied high intensities may not be easy to assess [4].

Distribution of intensities influences the level of physical performances

Session-induced decreases in CMJ performance indicate that the two sessions induced neuromuscular fatigue with a higher decrease in the dissociated distribution, probably due to the occurrence of interval runs at MAV at the end of this latter exercise organization. Additionally, the speeds recorded over the repetition of sprints in the dissociated session decreased in a lower manner than in the mixed session, allowing cumulation of slightly more runs at V_{max} .

Nevertheless, RPE-based and WER methods provide a similar trend for higher TL in the dissociated session. Although these two methods are constituted by different parameters (objective or subjective), they may correspond to a similar assessment of exertion. TL provided by the WER method is a ratio of the cumulated work relative to the endurance limit, and many studies have shown that the RPE increases relatively to the percentage of distance completed or yet to be completed [36, 37]. The higher RPE values observed in the dissociated session could be linked to a longer relative distance covered in this session compared to the mixed one. Similarly, the WER method was based on the accumulation of efforts relative to individuals' capability. Subjects' capability to cumulate runs at 100% of MAV should differ in dissociated and mixed organizations; interval sessions with 15 s effort alternating with 15 s of active pauses were reported to allow a maximal effort of about 15 min, whereas runs should be maintained in a longer duration in the mixed distribution of intensities [38]. Conversely, the differences in the accumulation of sprints in the two sessions appear weak. Using different methods, RPE and WER assess the level of exhaustion the subjects have achieved and provide a similar appreciation of sessions' TL. However, the endurance limit used for the WER method was assessed using a continuous exercise test; an assessment in mixed conditions might be better.

The rate of RPE increase is linked to subjects' capacity to cumulate runs. This result underlines the fact that RPE describes not only the exercise intensity, as considered by the RPE-based method, but a combination of exercise duration, intensity and rest. Consequently, as suggested previously, it could be assumed that RPE alone may reflect the physiological stress induced by exercise without requiring to be multiplied by duration to obtain the exercise TL [39].

It could be assumed that methodological improvements are still required for training load quantification. Heart rate based methods should be limited to exercises performed at sub-maximal intensities. The TRIMP method may be exclusively used in continuous exercises, whereas a modification of the coefficients of heart rate zones should benefit the SHR-zone method. RPE and WER methods without having such limitations of components should require some modifications for better use in mixed exercises quantification. RPE by itself may be assumed as insufficient to quantify TL, rather requiring to be multiplied by exercise duration. The WER method should assess endurance limit in the given exercise conditions (i.e., in a mixed way when used by coaches) that could require several testing sessions.

CONCLUSIONS

The intensity distribution and therefore the exercise's organization may result in marked differences in TL quantification according to the method used. When high intensities characterize the training programme, the use of heart rate to quantify TL appears invalid. Conversely, methods based on whole body indicators (RPE and endurance limit) of the exercise-induced physiological stress should be preferred to quantify such sessions. Some improvement in these latter methods, such as testing the endurance limit according to the

intensity distribution frequently used in a continuous way and assuming RPE itself as a TL measure, should improve their accuracy.

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