ACCURACY OF THE 20-M SHUTTLE RUN TEST FOR INDIVIDUALIZING EXERCISE INTENSITY OF HIGH-INTENSITY INTERVAL TRAINING

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Abstract:

The aim of the study was to investigate the accuracy of the 20 m shuttle run test (20mSRT) for the prescription of high-intensity interval training (HIIT) and to examine the appropriate intensity, prescribed by the 20mSRT end-test speed, for the execution of HIIT. Twenty physical education students (age: 22.4 ± 0.8 years, body height: 175.7 ± 8.9 cm, body weight: 73.8 ± 13.4 kg) participated in the study. On two separate occasions, the participants were first tested with a maximal incremental exercise test and the 20mSRT. On another two occasions, they were required to perform a 10-minute HIIT session comprised of 15-s runs interspersed with 15-s passive recovery. The intensities of the HIIT sessions were either 100% (T100%) or 110% (T110%) of the end-test speed reached in the 20mSRT. Mean oxygen uptake (VO_2) (84.4 ± 5.5% vs. 77.8 ± 6.9% of VO_{2max}), mean heart rate (HR) (93 ± 2.8% vs. 87.6 ± 4.6% of HR_{max}), blood lactate concentration (12.6 ± 2.1 vs. 5.4 ± 2.6 mmol/l), and ratings of perceived exertion (9.5 ± 0.5 vs. 6.7 ± 1) were all significantly ($p<.01$) higher during T110% vs. T100%. The percentage of the total exercise time spent ≥ 90% VO_{2max} (37.6 ± 25.3 vs. 18.6 ± 18.0%, $p<.05$) and ≥ 90% HR_{max} (73.9 ± 17.7% vs. 37.5 ± 33.3, $p<.001$) were also significantly higher during T110%. The mean VO_2 and HR coefficient of variation during T110% were 6.5 and 3%, respectively. The cardiorespiratory, metabolic, and perceptual responses to T110% were reflective of the responses typical for HIIT, while T100% induced insufficient physiological stress to enable optimal cardiorespiratory adaptation. Therefore, the intensity of 110% 20mSRT is preferable for inducing the appropriate acute physiological responses and the 20mSRT can be used to accurately prescribe HIIT.

Key words: *exercise testing, aerobic endurance, beep test, maximal oxygen uptake, heart rate, acute exercise responses*

Introduction

High-intensity interval training (HIIT) is comprised of short (10-60 seconds) or long (1-5 minutes) work intervals performed at intensities close to velocity associated with attainment of maximal oxygen uptake (vVO_{2max}) interspersed with active or passive recovery periods of similar or shorter duration (Buchheit & Laursen, 2013a). Studies have shown that HIIT is the optimal training programme for enhancing cardiorespiratory and metabolic function as it enables athletes to spend several minutes per session at ≥ 90% of maximal oxygen uptake (VO_{2max}) (Buchheit & Laursen, 2013a, 2013b). Such an acute training stimulus maximally stresses the cardiorespiratory system and therefore may be very effective for improving the VO_{2max} (Dolci, Kilding, Chivers, Piggott, & Hart, 2020; Midgley, McNaughton, & Wilkinson, 2006).

The short interval HIIT is very often utilized in team sports as its intermittent nature closely mimics the activity patterns seen in team sports and its implementation in gym conditions with restricted space available is much easier than the implementation of the long interval HIIT. Studies have shown that the execution of the short interval HIIT, consisting of 15-second work interval at intensities above the vVO_{2max} alternated with 15-second recovery intervals (15 s/15 s), enable athletes to accumulate several minutes in the zone ≥90% VO_{2max} (Buchheit & Laursen, 2013a; Midgley & McNaughton, 2006). The training intensity individualization in these studies was done by using maximal aerobic speed (MAS) or vVO_{2max} attained in maximal incremental exercise tests (IET) performed in the laboratory conditions on the treadmill (de Freitas, et al., 2019; Rozenek, Funato, Kubo, Hoshikawa, & Matsuo, 2007; Twist, Bott, & Highton, 2023) or in the field (Billat, et al., 2001; Collison, et al., 2022; Dupont & Berthoin, 2004; Dupont, Blondel, Lensel & Berthoin, 2002; Julio, et al., 2020), and the training protocols were all conducted in a form of straight-line running. Although a number of objective (Jamnick, Pettitt, Granata, Pyne, & Bishop, 2020) and subjective (Bok, Rakovac, & Foster, 2022) methods can be used for exercise prescription, the translation of exercise test responses to an accurate individualization of training sessions is still an extremely complex task (Bok & Foster, 2021; Foster, et al., 2020). Specifically, physiological responses can be very heterogeneous if training protocols are individualized through MAS or vVO_{2max} assessed with IET and then conducted in-doors in the form of shuttle running (Buchheit, 2008; Sandford, Laursen, & Buchheit, 2021). Therefore, a 30-15 intermittent fitness test (30-15IFT) was developed more than a decade ago in order to provide end-test speed (vIFT) that is more accurate for prescribing such intermittent training protocols (Buchheit, 2010; Buchheit, Dikmen & Vassallo, 2021). Indeed, when the prescription was based on the vIFT, the execution of 15 s/15 s training session showed low level of interindividual variability in cardiorespiratory responses suggesting that this procedure might be the best solution for prescribing the short format HIIT (Buchheit, 2008; Buchheit, et al., 2021). It was subsequently reported that performing 15 s/15 s training sessions prescribed through the vIFT enabled athletes to spend around 45% of an 8-minute total exercise time in the zone ≥90% VO_{2max} (Buchheit, et al., 2009).

However, aerobic fitness in team sports players is often assessed by different aerobic field tests such are the 20-metre shuttle run test (20mSRT) (Léger & Lambert, 1982; Mayorga-Vega, Aguilar-Soto, & Viciana, 2015) and the YoYo intermittent recovery test (YoYoIRT) (Bangsbo, Iaia, & Krustrup, 2008) mostly due to the claims that these tests possess high ecological validity for team sports (Bok & Foster, 2021; Castagna, Manzi, Impellizzeri, Weston, & Alvarez, 2010). Unfortunately, the end-test speeds between all these aerobic field tests are markedly different due to the disparate nature of the test protocols and, therefore, can hardly be used interchangeably for exercise prescription (Bok & Foster, 2021; Buchheit, 2008; Dupont, et al., 2010). It is currently unknown whether the v20mSRT can be used to accurately prescribe the short interval HIIT and what is the appropriate intensity for yielding the greatest accumulation of time spent ≥90% VO_{2max}. Namely, when 10 minutes of 15 s/15 s HIIT session at the intensity of 140% v20mSRT was performed, young team sports athletes exercised at 89.5% of their maximal heart rate reserve (HR_{res}), with a coefficient of variation (CV) of 10.6% (Buchheit, 2008). This rather high CV indicated poor practical validity of the test for the accurate individualization of HIIT sessions (Buchheit, 2008, Buchheit, et al., 2021). However, time spent in the zone ≥90% VO_{2max} was not reported in the study and the fact that the training session was performed on the 40 m court, which was double the distance used in the 20mSRT, can provide a partial explanation for the rather high CV of the heart rate response. Executing HIIT session through 20 m shuttle running, which makes the training session more similar to the testing protocol, could provide a more stable physiological response.

Therefore, the aims of the present study were: 1) to investigate whether the 20mSRT can be used for HIIT prescription if performed using 20-m shuttle runs by assessing the time spent ≥90% of maximal heart rate (HR_{max}) and VO_{2max}, and 2) to compare the cardiorespiratory, metabolic and perceptual responses to 15 s/15 s HIIT sessions performed at 100% and 110% of v20mSRT with the purpose to determine the appropriate intensity for the execution of the short format HIIT session.

Methods

Participants

Twenty physical education students (seven females and 13 males; age: 22.4 ± 0.8 years, height: 175.7 ± 8.9 cm, weight: 73.8 ± 13.4 kg, % body fat: 17.4 ± 4.9 %) volunteered to participate in the study. All participants were physically active individuals with training background from different individual and team sports. Five participants were still active national level competitors in their respective sports, whereas the rest of the participants practiced their sport and other physical activities several times a week for the purpose of physical recreation while pursuing a healthy lifestyle. The participants were aware that they could withdraw from the study at any point without any consequences. The study protocol was approved by the Ethics Committee of the Faculty of Kinesiology University of Zagreb (protocol # 2/2021, approved on 28th January 2021) and conformed to the recommendations of the Declaration of Helsinki.

Experimental design

The participants were required to undertake two testing and two training sessions over a two-week period. All testing and training sessions were performed at the approximately same time of the day to avoid circadian rhythm influence on performance. Participants were familiarized with both tests and the training sessions before the study commencement, and they all had recent experience in the execution of testing and training as this was part of their practical academic requirements. First, the participants performed the 20mSRT and maximal IET on two different occasions separated by at least 48 hours. The 20mSRT was performed for the purpose of determining the end-test speed (v20mSRT), while the maximal IET was performed in order to assess the VO_{2max} and HR_{max} of the participants. Subsequently, on another two occasions, separated by at least 72 hours, the participants performed a 10-minute HIIT session comprised of 15-second shuttle running at either 100% or 110% of the v20mSRT interspersed with 15-second passive recovery. To ensure running at the appropriate intensity, the total distance for 15 s run was calculated based on each participant's v20mSRT. Both training sessions were performed indoors, and the participants were required to run back and forth between two lines set 20 metres apart. Heart rate and respiratory gas exchange were continuously monitored and recorded during the training sessions. Ratings of perceived exertion (RPE) were collected immediately after, whereas blood lactate concentration (La) was determined three minutes after the end of each training session. The participants refrained from any strenuous exercise for 24 hours preceding the test and had consumed their last meal at least 2.5 hours before each testing or training session to avoid any undue fatigue or possible gastrointestinal discomfort. They were also required to maintain their regular diet and habitual lifestyle during experimental procedure to reduce the influence of the uncontrolled variables.

Procedures

Maximal incremental exercise test. For the assessment of VO_{2max}, a maximal IET was performed on a motor-driven treadmill (h/p Cosmos, Nussdorf-Traunstein, Germany) in laboratory conditions. At the beginning of the test, the participants walked for two minutes at 3 km/h. The treadmill speed was thereafter increased by 0.5 km/h every 30 seconds until volitional exhaustion. The grade of the treadmill was set to 1%. Respiratory gas exchange and heart rate were continuously recorded with an automated breath-by-breath portable metabolic system (Metamax 3b, Cortex Biophysik, Leipzig, Germany). The metabolic system was calibrated according to the manufacturer guidelines. The collected raw data were manually filtered and averaged on a 5-second interval basis, while VO_2 data were additionally averaged across 30-second time epochs for the purpose of VO_{2max} determination. The highest VO_2 response recorded during a 30-second time epoch was defined as VO_{2max}. A plateau in VO_2 and HR response despite an increase in running speed and/or RPE ≥8 on the Borg's category ratio scale (Borg, 1982) were used as criteria for attainment of the VO_{2max} (Mezzani, et al., 2012). A verification exercise bout was not performed.

20-m shuttle run test. For the assessment of the end-test velocity, the 20mSRT was performed indoors on a handball court (Léger, Mercier, Gadoury, & Lambert, 1988). The initial speed was set at 8.5 km/h for the first minute and increased by 0.5 km/h for each subsequent minute thereafter. The participants were required to run back and forth between two lines set 20 m apart at a pace dictated by the pre-recorded audio track. This pacing strategy assisted participants in adjusting their running speed so that they entered the 3-m zone demarcating the end-court lines at each beep. The participants were instructed to complete as many stages as possible. The test stopped when the participant was no longer able to maintain pace or was unable to reach the 3-m zone at each end of the court for three consecutive times. The HR was recorded during the test (Polar Team App, Polar Electro, Kempele, Finland) and the velocity of the last stage successfully completed was recorded as the v20mSRT. The test-retest reliability (r=0.975) for v20mSRT in adults has been reported to be excellent (Léger & Lambert, 1982).

HIIT sessions. To investigate whether the v20mSRT can be used for HIIT training prescription, the participants performed two 10-minute 15 s/15 s HIIT sessions comprised of shuttle running over a 20-metre distance at 100% (T100%) and 110% (T110%) of the v20mSRT interspersed with passive recovery. Both training sessions were performed indoors and were scheduled so as to allow at least 72 hours recovery for each participant. A 20-m distance was used for the execution of both training sessions to replicate the locomotor activity of the testing protocol and to induce physiological responses with minimal between-subject variability. The targeted distance of the 15-second run for each participant was calculated based on the v20mSRT and was demarcated with cones on the 20-m course. A short warm-up consisting of 5-minute low-intensity continuous running and 3-minute lower-body dynamic stretching was performed before the commencement of the HIIT sessions. The participants were required to adjust their running speed in accordance with the 15-second beeps which demarcated running and recovery intervals. The two intensities chosen for the execution of the training sessions were selected based on the fact that the 20mSRT was a continuous incremental aerobic field test and therefore intensities of at least 100% of the end-test speed and higher have to be used for the prescription of short format HIITs (Buchheit & Laursen, 2013a). Pilot tests conducted before the commencement of the study with just one participant confirmed the correctness of such decisions. Heart rate was recorded throughout the training sessions for all the participants (Polar Team App, Polar Electro, Kempele, Finland), while respiratory gas exchange values were collected only for eleven participants due to the time and equipment constraints (only one portable gas analyser Metamax 3b, Cortex Biophysik, Leipzig, Germany was available for the study). Collected data were analysed as for the maximal IET. The time spent in the zone ≥90% of VO_{2max} (t@90% VO_{2max}) and HR_{max} (t@90% HR_{max}) was calculated using the 5-second averaged data. Three minutes after the end of each training session, fingertip blood samples were collected for the La assessment (Lactate Scout+, EKF Diagnostics, Cardiff, UK). Immediately upon finishing the training session the participants also reported their RPE using a modified Category Ratio 0-10 Borg's scale (Borg, 1982; Foster, et al., 2001).

Statistical analysis

All the data are presented as mean ± standard deviation. Normality assumptions were verified using the Kolmogorov-Smirnov test. Differences between T100% and T110% in peak and mean values for VO_2, HR, and La were evaluated by one-way analysis of variance (ANOVA) for repeated measures. Wilcoxon matched pairs test was used for assessing differences in RPE between the HIIT sessions as the variables were not normally distributed. Statistical significance was accepted at $p<.05$. Statistical analyses were performed with Statistica (v 13.2; Dell Inc, Tulsa, OK).

Results

The results obtained at the maximal IET and 20mSRT are presented in Table 1. The v20mSRT corresponded to 81.1% of vIET.

Peak VO_2 during T110% and T100% corresponded to 100.5 ± 4.8% and 94.6 ± 7.4% of VO_{2max}, while mean VO_2 corresponded to 84.4 ± 5.5% and 77.8 ± 6.9% of VO_{2max}, respectively. The CV of the mean VO_2 was 6.5% and 8.9% for T110% and T100%, respectively. The participants spent 18.6 ± 18% and 37.6 ± 25.3% of total exercise time in the zone ≥90% VO_{2max} during T100% and T110%,

Table 1. Anthropometric and physiological characteristics of the subjects

Characteristics	Value (mean ± SD)
Age (years)	22.4 ± 0.8
Height (cm)	175.7 ± 8.9
Weight (kg)	73.8 ± 13.4
% body fat (%)	17.4 ± 4.9
VO_{2max} (l/min)	4.0 ± 1.0
VO_{2max} (ml/kg/min)	53.3 ± 6.4
HR_{max} (IET) (bpm)	195.2 ± 8.8
vIET (km/h)	15.9 ± 1.4
HR_{max} (20mSRT) (bpm)	197.9 ±8.7
v20mSRT (km/h)	12.9 ± 1
20mSRT (distance) (m)	1730 ± 428.3

Note. VO_{2max} – maximal oxygen uptake; HR_{max} – maximal heart rate; IET – maximal incremental exercise test; vIET – final velocity achieved in IET; 20mSRT – 20-metre shuttle run test; v20mSRT – final velocity achieved in 20mSRT.

respectively. Peak HR corresponded to 98.5 ± 2.3% and 93.6 ± 3.9% of HR_{max}, while mean HR corresponded to 93 ± 2.8% and 87.6 ± 4.6% of HR_{max} during T110% and T100%, respectively. The mean HR response had CV of 3.0% and 5.3% for T110% and T100%, respectively. The participants spent 37.5 ± 33.3% and 73.9 ± 17.7% of total exercise time in the zone ≥90% VO_{2max} during T100% and T110%, respectively. All the participants completed the T100%, whereas three subjects were unable to finish the T110% session and terminated their running after having completed 9, 16 and 18 intervals. An individual example of oxygen uptake (VO_2) and heart rate (HR) responses to T110% and T100%, expressed as percentage of VO_{2max} and HR_{max}, are presented in Figure 1.

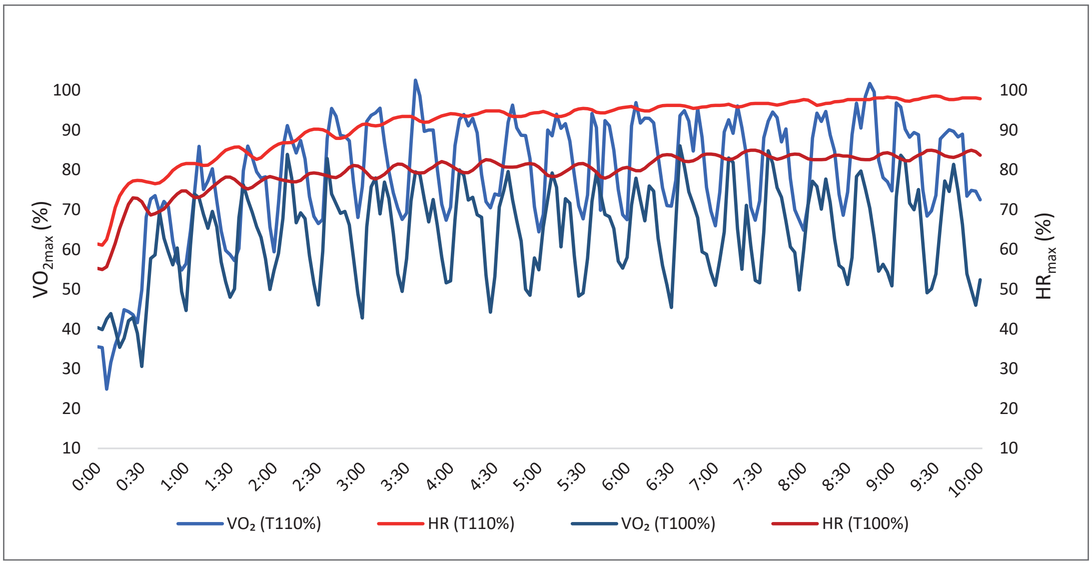

Figure 1. An individual example of oxygen uptake (VO_2) and heart rate (HR) responses to T110% and T100% expressed as the percentage of VO_{2max} and HR_{max} obtained in the maximal incremental exercise test.

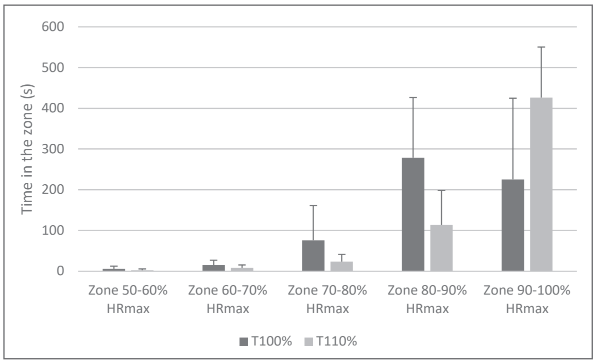

Figure 2. Time spent (mean ± standard deviation) in the particular heart rate intensity zones during the training sessions.

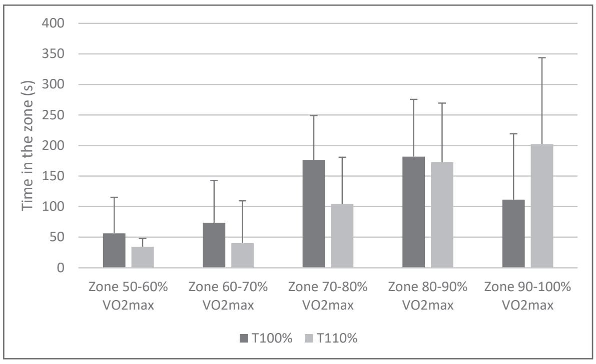

Figure 3. Time spent (mean ± standard deviation) in the particular oxygen uptake intensity zones during the training sessions.

Peak VO_2 ($p=.03$), mean VO_2 ($p<.01$), peak HR ($p<.001$) and mean HR ($p<.001$) during T110% were all significantly higher than during T100%. Time spent in the zone ≥90% HR_{max} was significantly greater during T110% ($p<.001$) (Figure 2), but time spent in the zone ≥90% VO_{2max} was not significantly ($p=.07$) different between the sessions (Figure 3). On the other hand, the percentage of total exercise time spent in the zone ≥90% VO_{2max} ($p=0.02$) and HR_{max} ($p<.001$) were both significantly different between the sessions. For the subjects that did not complete the full training session the percentage of time spent ≥90% of VO_{2max} and HR_{max} was calculated using their respective total exercise time. Significant differences between the sessions were also found in La ($p<.001$) and RPE ($p<.001$) (Table 2).

Table 2. Participants' cardiorespiratory, metabolic and perceptual responses recorded during the training sessions

	T100%	T110%
VO_{2peak} (ml/kg/min)	50.5 ± 6.4	53.8 ± 6.8*
VO_{2mean} (ml/kg/min)	41.6 ± 5.2	45.2 ± 5.9**
HR_{peak} (bpm)	182.8 ± 10.4	192.4 ± 9.5***
HR_{mean} (bpm)	171.1 ± 11.4	181.5 ± 9.4***
La (mmol/l)	5.4 ± 2.6	12.4 ± 2.1***
RPE (a.u.)	6.7 ± 1.0	9.5 ± 0.5***
t@90% VO_{2max} (s)	111.4 ± 107.8	202.3 ± 141.4
t@90% HR_{max} (s)	225.2 ± 199.5	426.1 ± 124.3***
%t@90% VO_{2max} (%)	18.6 ± 18.0	37.6 ± 25.3*
%t@90% HR_{max} (%)	37.5 ± 33.3	73.9 ± 17.7***

Note. T100% – training session performed at 100% v20mSRT; T110% – training session performed at 110% v20mSRT; VO_{2peak} – peak oxygen consumption; VO_{2mean} – mean oxygen consumption; HR_{peak} – peak heart rate; HR_{mean} – mean heart rate; La – blood lactate concentration; RPE – rating of perceived exertion; t@90%VO_{2max} – time spent in the zone ≥90% of VO_{2max}; t@90%HR_{max} – time spent in the zone ≥90% of HR_{max}; %t@90%VO_{2max} – percentage of total exercise time spent in the zone ≥90% of VO_{2max}; %t@90%HR_{max} – percentage of total exercise time spent in the zone ≥90% of HR_{max}. * Significant difference between the sessions ($p<.05$); ** Significant difference between the sessions ($p<.01$); *** Significant difference between the sessions ($p<.001$).

Discussion and conclusions

This study is the first to report the cardiorespiratory, metabolic, and perceptual responses to the short interval HIIT prescribed based on the v20mSRT. The main findings of the study were the following: 1) 20mSRT can be used effectively for the prescription of HIIT; 2) the intensity of 110% v20mSRT is more appropriate for creating the optimal acute training stimulus required for the enhancement of VO_{2max}; and 3) not all athletes were able to complete the intended duration at 110% v20mSRT.

Peak VO_2 and peak HR were both above 90% of their respective maximal values during both training sessions suggesting the potential of each session intensity to elicit a high enough acute cardiovascular stress necessary for VO_{2max} enhancement. However, even though the percentages of peak VO_2 and peak HR values reached during both sessions were very similar to each other, the mean VO_2 and HR values were rather different. Namely, the mean HR values were above the 90% of HR_{max} during both training sessions, whereas the mean VO_2 values were only 84.4% and 77.8% of VO_{2max} during T110% and T100%, respectively. This indicates lower association between HR and VO_2 dynamics during a short format HIITs and suggests that during this type of training sessions HR cannot be used to accurately estimate VO_2 responses. The dissociation is due to the fact that VO_2 kinetics is much faster than HR in response to the changes in exercise intensity (Midgley, McNaughton, & Carroll, 2007) and this is especially evident in training sessions comprised of very short intervals incorporating large amplitudes between work and recovery intensities (Billat, et al., 2001; Borel, et al., 2010) (Figure 1). This discrepancy between mean VO_2 and mean HR is also reflected in the time spent ≥90% of VO_{2max} and HR_{max} during the training sessions (Figures 2 and 3). Therefore, the mean intensity of the training session as well as the time spent in the zone ≥90% of VO_{2max} could easily be overestimated if only HR is monitored and used for the interpretation.

Time spent ≥90% of VO_{2max} was 202.3 seconds or 37.6% of total exercise time for T110%, which was significantly greater than 111.4 seconds or 18.6% of total exercise time obtained for T100%. This, along with the higher mean VO_2 and mean HR registered during T110%, indicates that intensity of 110% v20mSRT should be used for the prescription of 15 s/15 s HIIT. This is congruent with the general recommendation that intensities between 100% and 120% of vVO_{2max} obtained through continuous IET are used for the execution of the short format HIIT (Buchheit & Laursen, 2013a). More specifically, when acute responses to different intensities applied to 15 s/15 s HIIT were investigated, it was shown that the intensity of 110% MAS in particular enabled the longest time to exhaustion and the greatest time spent ≥90% VO_{2max} (Dupont, et al., 2002). So, even though only two intensities were investigated in this study, it appears that, similar to when continuous straight-line IET is used for training prescription, the percentage of 110% of v20mSRT is optimal for the execution of 15 s/15 s HIIT.

It was previously reported that, when total exercise time was predetermined to eight minutes, the 15 s/15 s training session performed at intensity of 95% vIFT resulted in 216.1 seconds or 45% of total exercise time spent ≥90% of VO_{2max} (Buchheit, et al., 2009). When three sets of 6-minute 15 s/15 s bouts, performed at the intensity of 120% vVO_{2max}, were executed on the treadmill, the total exercise time spent ≥90% of VO_{2max} was 288 s or 26.7% of the total working exercise time (Twist, et al., 2023). On the other hand, when exercise was performed until exhaustion, participants managed to spend 383 seconds or 54.9% (Dupont, et al., 2002), 335.5 seconds or 25% (de Freitas, et al., 2019), and 317 seconds or 43.2% of total exercise time (Dupont & Berthoin, 2004) ≥90% of VO_{2max} during sessions performed on an indoor track or on the treadmill. As optimal time spent ≥90% VO_{2max} for team sport athletes is estimated to be around five minutes (Buchheit & Laursen, 2013a), the T110% fell just a bit short to reach that goal. Therefore, the total session time needs to be prolonged in order to accumulate five or more minutes in the zone. However, as exhaustion during HIIT sessions, when performed as on-ground straight-line running, was reached after 745 (Dupont & Berthoin, 2004) and 698 seconds (Dupont, et al., 2002), it is obvious that such a prolonged training session would need to be broken into sets if exhaustion is likely to be avoided. This is further supported by the fact that even the 10-minute training session in this study was not completed by all the participants since three subjects quit running after having executed 9, 16 and 18 intervals. Therefore, prescribing the 10-minute short interval HIIT based on the 20mSRT appears less effective in terms of the cardiorespiratory response when compared to a shorter 8-minute session prescribed through vIFT (Buchheit, et al., 2009).

Practical validity and accuracy of the fitness test for individualizing HIIT can be evaluated by assessing interindividual variation in acute cardiorespiratory responses (Buchheit, 2008, 2010). Previous study reported a rather high CV (10.6%) for mean $\%HR_{res}$ when 10-minute 15 s/15 s HIIT session was performed based on the 20mSRT, while much lower CV (2.9%) was found when identical training session was performed based on the 30-15IFT (Buchheit, 2008). Conversely, lower CVs of 3% and 6.5% for mean %HR and mean $\%VO_2$, respectively, were obtained in our study. So, even though different variables were analysed, it does appear that interindividual variation in cardiorespiratory responses was lower in this study, which indicates better precision for training prescription. These lower CVs found in this study could be due to the fact that training sessions were performed on a 20 m distance course as opposed to the 40 m running course and at training intensity of 140% v20mSRT that were used in the other study (Buchheit, 2008). Making the locomotor activity of the training session more similar to the testing procedure obviously enables more homogenous cardiorespiratory responses during the session. Namely, when the session was executed on a longer running course, the smaller number of changes of direction (COD) and the higher running speed selected for each work interval during the session probably caused greater deviation from the physiological responses captured during the testing procedure, creating more heterogeneous responses between participants (Buchheit, 2008). On the other hand, when the training session is organized as to be more similar to the testing procedure, the physiological responses and energy cost of running can be more closely matched (Buchheit, et al., 2021). In this latter case other physiological capacities, such as the COD ability, anaerobic capacity, and power, which also contribute to the performance of the 20mSRT aside from the VO_{2max}, had been utilized in similar extension during the session as they were during the final stage of the test. So, using the 20 m running course and exercise intensities relatively close to the v20mSRT (i.e., 110% v20mSRT) enabled higher practical validity and greater accuracy of the test for individualizing the short format HIIT.

However, it must be acknowledged that three subjects were not able to finish the entire 10-minute session. One of the limitations of the study was the fact that participants were physical education students with different sports background making the 20mSRT more or less specific for each person. Therefore, the contribution of anaerobic capacity, as well as neuromuscular and COD abilities to the performance of the test probably differentiated more among the participants in such a heterogenous group of people than it would have had if the group was comprised of players from a single sport. In this case similar or even identical v20mSRT could have been reached by subjects presenting with greatly different physiological profiles (Buchheit, et al., 2021). In addition, in terms of their practical validity, continuous maximal aerobic tests are inferior to the intermittent ones (e.g., 30-15IFT) as their end-test speeds do not incorporate the ability of inter-effort recovery which is extremely important for performing intermittent exercise (Haydar, Al Haddad, Ahmaidi, & Buchheit, 2011). All this may enable participants with very high aerobic capacity and the ability to tolerate acidosis, but with lower leg power and COD abilities, to reach high v20mSRT; however, they may exhibit poor performance during intermittent shuttle exercise. Indeed, the participant that ceased exercising after having completed only nine intervals was a top-level rower who reached top scores in both maximal IET and 20mSRT. Probably, his pronounced aerobic profile and the ability to tolerate high levels of acidosis enabled him to reach high v20mSRT, but his poorer COD abilities and lower running economy, associated with the execution of the unfamiliar and prolonged shuttle running, prevented him from maintaining exercise at this intensity for longer. Namely, frequent decelerations and accelerations at such high speed taxed his aerobic capacity very heavily early into the exercise, mostly due to the impaired running economy during shuttle running, and consequently increased the contribution from the anaerobic capacity leading to the early exhaustion. This was probably even further emphasized by the participant's high body mass and height as it was previously shown that subjects of high stature might present with greater running economy deterioration during COD running (Buchheit, Haydar, Hader, Ufland, & Ahmaidi, 2011). Lower training and competition volumes were also associated with greater deterioration of running economy during shuttle running (Buchheit, et al., 2011) and this, along with their high stature, may explain premature exhaustion of the other two participants who recently stopped competing in basketball and soccer and became recreational players. Finally, the requirement to carry the portable metabolic analyser during the training sessions, while this was not the case during testing, may have further amplified the energy cost of shuttle running.

Blood lactate concentration and RPE were also significantly different between the T110% and T100% sessions. Namely, when 15 s/15 s HIIT session was performed for eight minutes, it elicited blood lactate concentration of 11.6 mmol/l and RPE of 6.6 (Buchheit, et al., 2009), while a bit shorter predetermined session lasting ≈445 seconds resulted in blood lactate concentration of 9.2 ± 1.4 mmol/l (Dupont, Blondel, & Berthoin, 2003). In addition, the same HIIT exercise performed in the format of four 4-minute bouts separated with 3-minute passive recovery elicited blood lactate concentration of 4.7 ± 0.6 mmol/l and RPE of 7.1 ± 1 (Selmi, et al., 2017), while three sets of 6-minute running separated with 5-minute passive recovery elicited blood lactate concentration of 5.9 ± 2.5 mmol/l (Twist, et al., 2023). On the other hand, performances to exhaustion elicited blood lactate concentration of 11.7 ± 2.1 mmol/l after 745 ± 171 seconds (Dupont & Berthoin, 2004), 11.1 ± 2.5 mmol/l after 698 ± 355 seconds (Dupont, et al., 2002), 9.5 ± 2.6 mmol/l after 495 ± 124 seconds (Buchheit, Laursen, Millet, Pactat, & Ahmaidi, 2008) and 5.5 ± 2.6 mmol/l with RPE of 18 ± 1 after 1342 ± 446 seconds of exercise (de Freitas, et al., 2019). Also, delta of blood lactate concentration was around 9 and 6 mmol/l with RPEs around 16 and 18 for long-distance runners and rugby players, respectively, after performing exercise to exhaustion that lasted approximately six minutes on average for both groups (Julio, et al., 2020). It does seem that performing this type of HIIT session through 20-m shuttle running elicits higher perceptual responses for the corresponding blood lactate concentration than when it is performed over a 40-m course (Buchheit, et al., 2009) or in the form of the straight-line running (Dupont, et al., 2003). Even the sessions performed until volitional exhaustion that lasted for longer caused lower blood lactate concentrations than the T110%. More frequent decelerations and accelerations obviously outweigh lower running speeds utilized in sessions based on the 20mSRT. So, the accumulation of 37.6% or 202.3 seconds of total exercise time in the zone ≥90% VO_{2max} comes with rather high metabolic and perceptual stress making this particular format of 15 s/15 s training session less efficient in comparison to the ones prescribed on 30-15IFT or maximal IET. However, as studies in which HIIT exercise was performed in multiple 4- to 6-minute sets generally report lower metabolic and perceptual stress (Selmi, et al., 2017; Twist, et al., 2023) in comparison to longer duration bouts (Buchheit, et al., 2009) and especially exercise to exhaustion (Dupont & Berthoin, 2004; Julio, et al., 2020), it is prudent to assume that optimal acute physiological and perceptual responses could be obtained by performing the HIIT session within a few shorter bouts.

Generally, the results of this study suggest that 20mSRT can be used effectively for the prescription of short format HIIT and that the intensity of 110% v20mSRT seems to be appropriate for creating the optimal acute training stimulus required for the enhancement of VO_{2max}. Performing HIIT on a 20-m running course and executing locomotor activity of the training session most similar to the testing procedure leads to less interindividual variation in cardiorespiratory responses and more accuracy in individualization. It does, however, seem that performing the session on such a short distance course elicits higher metabolic and perceptual responses in comparison to the sessions performed over longer distances and based on maximal IET or 30-15IFT. This should be kept in mind when this type of HIIT session is integrated into a periodized weekly training regime. Additionally, future research should aim to determine the exact magnitude of the neuromuscular stress imposed by performing frequent COD during these sessions in order to enable better training periodization. Finally, athletes who are not accustomed to shuttle running and who possess rather high levels of VO_{2max} might be susceptible to early exhaustion during HIIT, probably due to the deterioration of running economy and an increase in energy cost of running associated with COD. Therefore, caution should be exercised when 20mSRT is used to prescribe HIIT for a very heterogeneous group of people.

The main limitation of the study was the fact that the VO_2 was not collected for all participants during the sessions. However, comparing the HR responses of the participants for whom VO_2 was measured with HR responses of the participants for whom VO_2 was not measured revealed that no significant differences existed between them. Therefore, it is prudent to assume that VO_2 responses collected on a subsample can be considered as representative for the entire sample.

The study results show that 20mSRT can effectively be used to prescribe a short format HIIT when the session is performed over a 20-m running distance. To elicit the appropriate cardiorespiratory response, the intensity of 110% v20mSRT should preferably be used. However, very high peak VO_2 and HR responses during the 10-minute session, along with the early exhaustion of three subjects, point out that shortening of the exercise time could be beneficial. Namely, performing the training session in two to three shorter, e.g., 6- to 8-minute bouts, could possibly reduce the metabolic and perceptual responses, while also mitigate the risk of reaching exhaustion in athletes with poor shuttle running economy. However, the exact optimal duration of the set/bout should be experimentally determined through future studies. Additionally, performing the session in the form of several shorter bouts could provide for greater accumulation of time in the zone ≥90% VO_{2max}.

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