European Journal of Sport Science, 2020
Vol. 20, No. 2, 166–173, https://doi.org/10.1080/17461391.2019.1624833

ORIGINAL INVESTIGATION

Use of the anaerobic speed reserve to normalize the prescription of high-intensity interval exercise intensity

URSULA F. JULIO [1], VALÉRIA L. G. PANISSA [1], ANA C. PALUDO[2], ELAINE D. ALVES[1], FÁBIO A. D. CAMPOS[3], & EMERSON FRANCHINI [14]

[1]*School of Physical Education and Sport, University of São Paulo, São Paulo, Brazil;* [2]*Department of Physical Education, Midwest State University of Paraná, Guarapuava, Brazil;* [3]*Air Force Academy, Brazilian Air Force, Pirassununga, São Paulo, Brazil &* [4]*Australian Institute of Sport, Canberra, Australia*

Abstract

The aim of this study was to compare the perceptual and physiological responses and time-to-exhaustion in high intensity interval exercise (HIIE) protocols that are prescribed based on the relative anaerobic speed reserve (ASR) or maximal aerobic speed (MAS) in athletes with different ASR values, as well as the coefficient of variation (CV) of the abovementioned variables. Eleven long-distance runners and ten rugby players were submitted to five experimental sessions on different days; the first and second session were intended for the determination of the anthropometry, MAS and maximal sprint (MSS). In the subsequent sessions, three $HIIE_{15:15s}$ protocols were performed until exhaustion (110% MAS, Δ25%ASR, and Δ50%ASR) in random order. The anthropometric characteristics and variables obtained from the MAS and MSS tests in the different groups were compared by Student's *t*-test. The analysis of mixed models for repeated measures (groups and protocols) was used to compare the speed, delta blood lactate, rating of perceived exertion, and time-to-exhaustion. Rugby players presented higher ASR (13.6 ± 0.9 km h^{-1}) compared to long-distance runners (12.6 ± 0.9 km h^{-1}) ($P = .049$). For the $HIIE_{15:15s}$ protocols, there were no protocol and group interaction effects. However, lower CV values were observed for time-to-exhaustion (a mean reduction of 52%) and delta blood lactate (a mean reduction of 48%) in Δ25%ASR and Δ50%ASR when compared to 110%MAS. Furthermore, the rating of perceived exertion CV was similar in all $HIIE_{15:15s}$ protocols. The prescription of intensity of HIIE based on the ASR was able to reduce the inter-subject variability of lactate and time-to-exhaustion in rugby players and long-distance runners.

Keywords: Fatigue, team sports, performance, aerobic fitness

Highlights

- The prescription of high-intensity interval exercise using the percentage of the anaerobic speed reserve resulted in decreased inter-subject variability of delta blood lactate concentration and time-to-exhaustion when compared to prescription based on the maximal aerobic speed.
- The reduction of delta blood lactate concentration and time-to-exhaustion inter-subject variability occurred equally in athletes with different anaerobic speed reserve values (long-distance runners and rugby players).
- Intervention studies should investigate the influence of an independent variable (e.g. ergogenic aids) on time-to-exhaustion and physiological responses (e.g. delta blood lactate concentration) to high-intensity interval exercise individualizing the exercise intensity based in the percentage of anaerobic speed reserve.

Introduction

High-intensity interval exercise (HIIE) is composed of multiple efforts performed above maximal lactate steady-state and interspersed by recovery periods performed at low-intensity or rest (Buchheit & Laursen, 2013). The intermittent nature of HIIE is similar to the actual demands of competition in a variety of sports, including both team and individual sports, and therefore, this type of training is often incorporated in the preparation of athletes to optimally prepare for the demands of competitions (Bridge, Santos, Chaabène, Pieter, & Franchini, 2014; Chaabène, Hachana, Franchini, Mkaouer, & Chamari, 2012; Franchini, Del Vecchio, Matsushigue, & Artioli, 2011; Stone & Kilding, 2009). The main advantages of HIIE compared to continuous exercise

Correspondence: Ursula Ferreira Julio, School of Physical Education and Sport, University of São Paulo (USP), Av. Prof. Mello Morais, 65, Butantã, São Paulo SP 05508-030, Brazil. E-mail: ursulajulio@usp.br

is the possibility of extending the time until exhaustion at high intensities and to allow higher time spent near or at the maximal oxygen consumption ($\dot{V}O_{2max}$) (Demarie, Koralsztein, & Billat, 2000; Dupont, Blondel, Lensel, & Berthoin, 2002).

Over the last couple of decades, there has been an increase in the number of studies aiming to describe both acute and chronic HIIE physiological and performance responses (Buchheit & Laursen, 2013). The complete understanding of these responses arising from this type of exercise is limited mainly because there are many possible combinations of the variables that can be manipulated for the HIIE prescription (e.g. the duration and intensity of effort and recovery, the number of sets, and the exercise mode) (Buchheit & Laursen, 2013). Moreover, it has been suggested that the responses may be dependent on the athlete's background, which demonstrates the importance of considering the individual characteristics for training prescription (Buchheit & Laursen, 2013; Panissa et al., 2014).

As exercise intensity is one of the most important variables driving the HIIE prescription, acute and chronic studies aiming to describe the performance and physiological responses and the effect of the training protocols should have a precise characterization of exercise intensity because a generalized prescription may result in bias (Lansley, Dimenna, Bailey, & Jones, 2011). Typically, high-intensity exercise prescription may be conducted in percentages of maximal sprint speed (MSS) or maximal aerobic speed (MAS), and Buchheit and Laursen (2013) indicated that the anaerobic speed reserve (ASR – the difference between MSS and MAS) is an important variable to consider in the individualized prescription of HIIE intensity. Considering that athletes may have different ASR ranges, which may result in distinct physiological solicitation involved in the provision of energy, and consequently, a tolerance to exhaustion, the individualization of intensity based on a percentage of ASR (percentages of ASR plus MAS) should be investigated.

It seems reasonable to assume that perceptive, physiological and performance responses may be similar when the intensity of the HIIE prescription is based on a percentage of the ASR, and a higher variation would be observed when HIIE is prescribed based only on the MAS. However, this assertion has not been directly investigated and has been contested by lack of scientific evidence (Boullosa, 2014; Boullosa & Abreu, 2014). Thus, it is clear that there is need to compare the acute physiological responses in intensities relative to the ASR, especially in athletes with different values of this variable. By investigating constant load exercise, Lansley et al. (2011) compared the inter-subject variability of physiological and performance responses in three exercise intensity domains (moderate, heavy and severe) expressed relative to the MAS or the deltas (the difference between the respiratory compensation point and the MAS plus the respiratory compensation point) and observed an inter-subject variability reduction when the delta prescription was used. Specifically, the coefficient of variation of the time-to-exhaustion during exercise at the severe domain was lower when the intensity was prescribed by deltas compared to the intensity prescribed by the percentage of the MAS (21% and 43%, respectively).

Thus, the aim of the present study was to compare the physiological, perceptual and performance responses to HIIE protocols prescribed using intensities relative to the ASR and MAS in athletes with different ASRs. We hypothesized that exercise prescription using the ASR to individualize intensity would result in lower physiological and performance response variation for these athletes, even when athletes differed in the ASR values, compared to the traditional prescription based on the MAS.

Materials and methods

Subjects

Eleven male recreational long-distance runners (recreationally trained with their best performances in 10 km competitions with times below 40 min) and ten male rugby players (eight aviation cadets from the Air Force Academy, one college athlete, and one athlete from a national team) voluntarily participated in the present study after reading and signing an informed consent form explaining all of the procedures, risks and benefits of the present investigation. All of the procedures were approved by the local ethics committee. The groups were chosen to characterize sports with different physical demands, i.e. a predominantly aerobic sport and an intermittent sport. The inclusion criteria for participation in the study were: to be regularly involved in a systematized training programme (more than 4 times/week) for at least 3 years, to be participating in official competition in their sport, and to be not currently using any drugs or medicines known to improve performance.

Design

The participants completed five sessions; each session was conducted on separate days and at least 48 h apart (Panel A, Figure 1). In the first two sessions, anthropometric measurements were taken, and the athletes performed two tests on a track to

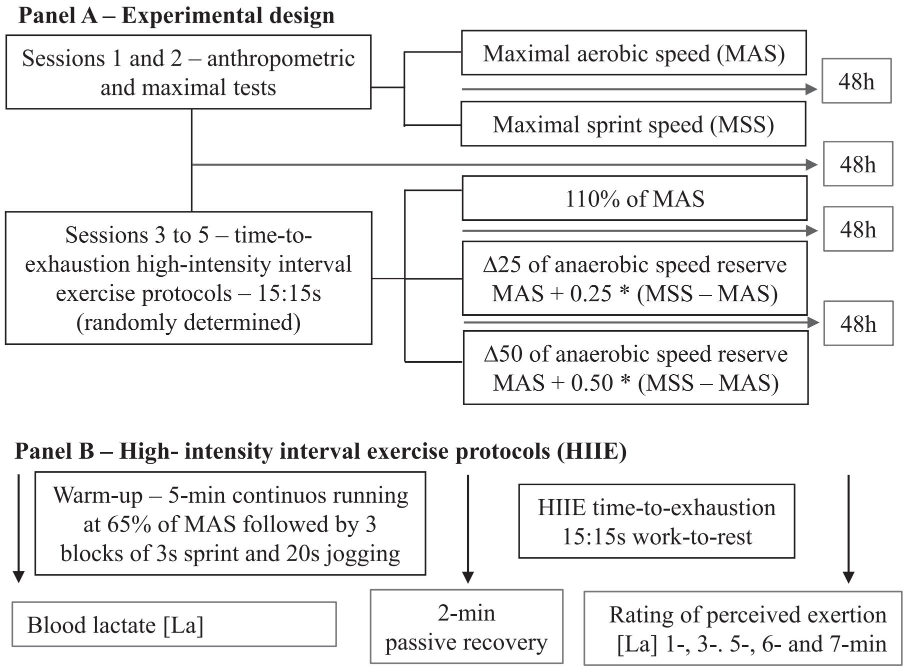

Figure 1. Experimental design of the study (Panel A) and high-intensity interval exercise protocols (Panel B).

determine the MAS and MSS. During the 3rd, 4th and 5th sessions, participants were submitted to HIIE protocols with 15:15s effort-pause ratio ($HIIE_{15:15s}$) until exhaustion at 25% and 50% of the ASR and 110% of the MAS. After each experimental session, the rating of perceived exertion (RPE) was requested and registered. Before and after each exercise session, blood samples were taken from the earlobe to determine blood lactate concentration ([La]) (Panel B, Figure 1). All of the experimental sessions were conducted at the same track and at the same period of the day and in similar climatic conditions to eliminate the possible effects on the variation in performance.

Anthropometric measures. The body mass was measured to the nearest 0.01 kg using a digital calibrated scale, and the height was measured to the nearest 0.1 cm with a wall stadiometer while the participants stood barefoot with their heels touching the wall. Body density was estimated from 7 skinfold measures (triceps, subscapular, chest, abdominal, suprailiac, thigh and calf) using the Jackson and Pollock (1978) equation, and the body fat percentage was calculated using the Siri equation (1961).

Maximal aerobic speed. An incremental track test was performed to determine the MAS (km h^{-1}). Cones were placed around the track 20 m apart. The incremental test started at 8.0 km h^{-1} for rugby players and at 10 km h^{-1} for long-distance runners with an increase of 1.0 km h^{-1} every minute (Panissa et al., 2014). The intensity of running was determined by a beep, whereupon the participants should reach the cone within the time of the beep and a double sound marked a change of the stage. The subjects were encouraged to exert their maximum effort, and the test was finished when the participants did not reach the cone within the beep time twice, consecutively. The maximal speed reached during the test was established as the MAS, and if the participant did not finish the last stage, the speed was relativized by the permanence time in this stage: MAS (km h^{-1}) = speed of penultimate stage + (1.0 km h^{-1} *time in the last stage/time of stage (s)) (Panissa et al., 2014). From the MAS values, the speed was calculated on $HIIE_{15:15}$ at 110% MAS: speed on time-to-exhaustion (km h^{-1}) = MAS (km h^{-1}) * 110%.

The $\dot{V}O_2$ was measured during the whole test using a portable breath-by-breath system (MetaLyzer 3B, Cortex, Leipzing, Germany), and the heart rate (HR) (Polar *Electro Oy*) was recorded using telemetric systems via electronic integration with the spirometer software and well-adjusted with an electrode transmitter belt firmly held around the thorax. The $\dot{V}O_{2peak}$ was established as the highest 15 s value in the test, and the HR_{max} was determined by the highest value during the test. Moreover, the RPE was collected at the end of the test (Borg, 1982), and blood samples (25 μL) were collected from the earlobe at 1, 3, 5, 6, and 7 min post-exercise. The peak of lactate was the highest value among the measurements.

Maximal sprint speed. Two 40 m sprints with 5 min of passive recovery between them were performed to establish the MSS (km h^{-1}). Before starting the test, the participants carried out a 5 min running warm-up at 65% of the MAS, followed by three blocks of 3 s sprints and 20 s of jogging with a 2-min recovery. Sprint times were recorded by five electronic time sensors (Hidrofit, Brazil) positioned at 0, 10, 20, 30 and 40 m. It was recommended that the participants should be positioned 0.5 m before the initial point to run as fast as possible and only decelerate after crossing the last sensor. The subjects were able to choose their own start time. The times of each 10 m interval of each sprint were recorded, and the shortest 10 m time was considered to determine the MSS (km h^{-1}).

Anaerobic speed reserve. The ASR was calculated by the difference between the MSS and MAS. From the ASR values, it was possible to calculate the speed on $HIIE_{15:15}$ at 25% ($V_{\Delta 25\%ASR}$) and 50% ($V_{\Delta 50\%ASR}$) speed using the following equation: $HIIE_{15:15s}$ (km h^{-1}) = MAS (km h^{-1}) + Δ (0.25 or 0.50) * ASR (km h^{-1}).

High-intensity interval exercise. The $HIIE_{15:15s}$ protocols were performed on the same track, on three different days at least 48 h apart in random order. Before starting the test, the participants carried out the same warm-up protocol utilized during the MSS test. These protocols consisted of 15 s of sprints (Δ25% ASR or Δ50% ASR or 110% MAS) and 15 s of passive recovery between the sprints. The sprints were performed only in the straight part of the track and a sound was utilized to count down 3 s and was then followed by a long beep to start the sprint. During the sprint, a beep rang out every 3 s to help the subjects to properly maintain an established speed. This sound remained available throughout the exercise session. Six cones were utilized to mark the distance that should be covered into the 3, 6, 9, 12 and 15 s. After 15 s of passive recovery, the athletes started a new sprint in the opposite direction for 15 s. The test was finished when the participants could not follow the established speed. The number of sprints completed was registered to calculate the time-to-exhaustion.

In all $HIIE_{15:15s}$, the blood samples (25 μL) were collected from the earlobe at rest, 1, 3, 5, 6, and 7 min post-exercise. The blood samples were collected in a sterile 1.5 mL plastic tube with 50 μL of sodium fluoride and stored until ready for the assay. After thawing, the blood lactate analysis was conducted using a YSI 1500 Sport (Yellow Spring, United States). The delta of blood lactate (Δ [La]) was calculated using the peak lactate concentration minus the lactate concentration at rest. After $HIIE_{15:15s}$, the participants were asked to rate their perceived exertion using the 6–20 Borg scale (1982) with scores ranging from "very, very light" to "very, very hard". These data were verbally collected by the lead investigator.

Statistical analysis

Data are presented as the mean and standard deviation. The coefficient of variation (CV) was calculated for the RPE, Δ [La] and time-to-exhaustion obtained in all $HIIE_{15:15s}$. A Student's unpaired *t*-test was conducted to compare the anthropometric, MAS, MSS and ASR values between the long-distance runner and rugby player groups. Comparison of the dependent variables on $HIIE_{15:15s}$ protocols (speed, Δ [La], RPE and time-to-exhaustion) were performed with an analysis of mixed models (2-way) for repeated measures (groups × protocols) followed by a Bonferroni post hoc test whenever a significant F value was obtained (Statistical Analysis System 9.2, SAS Institute Inc, Cary, NC, USA). The significance level was determined a priori at $P < .05$. Due to the large amount of data from the interaction effect in the two-way analysis, statistical details were only presented for the same group and different protocols and for the same protocol and different groups. The effect sizes for significant pairwise comparisons were calculated using Cohen d (1969) and classified according to Hopkins (2002).

Results

For athletes characteristics, rugby players were 11% heavier (77.9 ± 6.5 kg) ($t_{19} = 2.88$; $P = .010$; $d = 1.26$, large), had 31% higher body fat (15.11% ± 3.92%) ($t_{19} = 2.73$; $P = .014$; $d = 1.23$, large) and reported 8% higher RPE during the incremental test (18 ± 1) ($t_{19} = 2.26$; $P = .036$; $d = 0.99$, moderate) compared to long-distance runners (69.5 ± 6.8 kg; 10.42% ± 3.74%; 16 ± 2; respectively); whereas long-distance runners had 21% higher $\dot{V}O_{2peak}$ (65.19 ± 5.16 ml kg^{-1} min^{-1}) ($t_{19} = 6.34$; $P < .001$; $d = 2.89$, very large) and achieved 17% higher [La] peak in the incremental test (11.99 ± 1.61 mmol L^{-1}) ($t_{19} = 2.18$; $P = .042$; $d = 0.94$, moderate) compared to rugby players (51.75 ± 4.10 ml kg min^{-1}; 9.96 ± 2.58 mmol L^{-1}; respectively). There were no differences for age ($t_{19} = 1.03$; $P = .314$), height ($t_{19} = 1.19$; $P = .250$) and HR_{max} ($t_{19} = 1.80$; $P = .089$) between rugby players (22 ± 3 years old; 173.9 ± 4.1 cm; 194 ± 11 bpm respectively) and

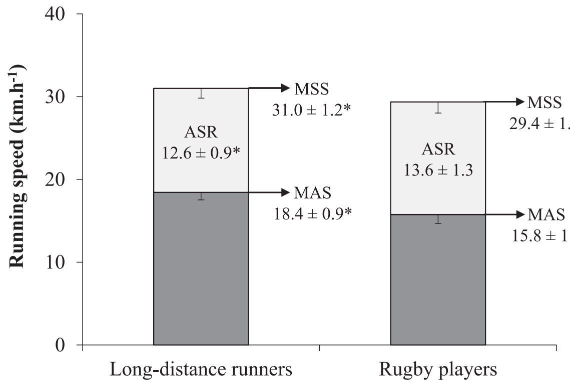

Figure 2. The maximal aerobic speed (MAS), maximal sprinting speed (MSS) and anaerobic speed reserve (ASR) in long-distance runners ($n = 11$) and rugby players ($n = 10$) (values are mean and standard deviation). * = different from rugby players ($P < .05$).

long-distance runners (25 ± 8 years old; 176.9 ± 6.8 cm; 185 ± 12 bpm, respectively).

For performance variables obtained in the maximal tests (Figure 2) long-distance runners presented higher values in MAS (15%) ($t_{19} = 6.15$; $P < .001$; $d = 2.67$, very large) and MSS (5%) ($t_{19} = 2.99$; $P = .008$; $d = 1.30$, large), and lower ASR (8%) ($t_{19} = 2.10$; $P = .049$; $d = 0.91$, moderate) when compared to rugby players.

The perceptual, physiological and performance responses obtained in $HIIE_{15:15s}$ are presented in Figure 3. For running speed in the $HIIE_{15:15s}$ there was a main effect of group ($F_{1,11.6} = 44.06$; $P < .001$) and protocol ($F_{2,8.32} = 1025.00$; $P < .001$), with higher values in long-distance runners compared to rugby players ($P < .001$; $d = 1.04$, moderate), lower values in 110% MAS compared to Δ25 ASR ($P < .001$; $d = 1.07$, moderate) and Δ50 ASR ($P < .001$; $d = 2.99$, very large), and lower values in Δ25 ASR compared to Δ50 ASR ($P < .001$; $d =$ 2.19, very large). For time-to-exhaustion there was a main effect of protocol ($F_{2,9.98} = 67.00$; $P < .001$), with higher values in 110% MAS compared to Δ 25ASR ($P = .003$; $d = 1.57$, large) and Δ 50ASR ($P < .001$; $d = 2.59$, very large), and higher values in Δ 25ASR compared to Δ 50ASR ($P < .001$; $d =$ 3.95, very large). For Δ [La] there was a main effect of protocol ($F_{2,45} = 8.53$; $P < .001$) with lower values in 110% MAS compared to Δ 25ASR ($P = .011$; $d = 0.82$, moderate) and Δ50ASR ($P < .001$; $d = 0.99$, moderate). For RPE there was a main effect of group ($F_{1,43} = 9.98$; $P = .003$) with lower values in long-distance runners compared to rugby players ($P = .003$; $d = 0.80$, moderate).

Table I presents the CV of the perceptual, physiological and performance responses obtained in $HIIE_{15:15s}$. Lower CV values were observed for the percentage of the ASR compared to the percentage of the MAS for time-to-exhaustion with a mean

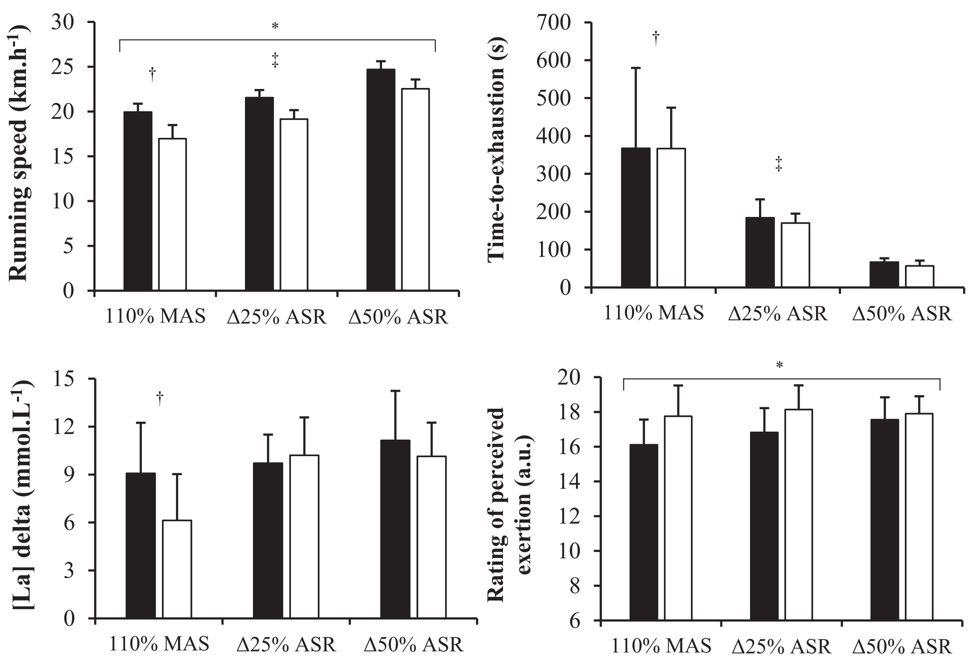

Figure 3. The performance, perceptual and physiological responses to time-to-exhaustion high-intensity intermittent exercise protocols with 15:15s effort-pause ratio at 25% and 50% of anaerobic speed reserve (Δ25%ASR and Δ50% ASR), and 110% of maximal aerobic speed (110% MAS) in long-distance runners (black bars; $n = 11$) and rugby players (white bars; $n = 10$) (values are mean and standard deviation). *group main effect = different from rugby players ($P < .05$); † protocol main effect = different from Δ25%ASR ($P < .05$) and Δ50%ASR ($P < .05$); ‡ = different from Δ50% ASR ($P < .05$).

Table I. Coefficient of variation of rating perceived exertion, delta of blood lactate and time-limit responses in high-intensity interval exercise protocols prescribed using % of maximal aerobic speed (MAS) and delta (Δ) of anaerobic speed reserve (ASR) in long-distance runners ($n = 11$) and rugby players ($n = 10$).

	Long-distance runners	Rugby players	All athletes
Rating of perceived exertion (%)			
110% MAS	9	7	9
Δ25% ASR	8	7	8
Δ50% ASR	7	6	7
Delta of blood lactate (%)			
110% MAS	31	47	44
Δ25% ASR	18	23	20
Δ50% ASR	28	21	26
Time-limit (%)			
110% MAS	58	29	45
Δ25% ASR	26	15	22
Δ50% ASR	15	24	21

reduction of 52% and for delta blood lactate with a mean reduction of 48%, whereas the RPE CV was similar in all $HIIE_{15:15s}$ protocols.

Discussion

The main findings of the present study partially confirmed our hypotheses and indicated a decrease in inter-subject variability (CV) of Δ [La] and time-to-exhaustion responses to $HIIE_{15:15s}$ prescribed using intensities relative to ASR when compared to the prescription using the MAS in athletes with different ASRs. For perceptual responses, the CV was similar for the two intensity prescription methods. Furthermore, the running speed in different $HIIE_{15:15s}$ protocols was different – 110% MAS (18.5 ± 1.9 km h^{-1}) < Δ25 ASR (20.4 ± 1.5 km h^{-1}) < at Δ50 ASR (23.7 ± 1.5 km h^{-1}) – and was accompanied by different time-to-exhaustion and Δ [La] values but similar RPE values. Finally, long-distance runners presented a higher running speed and lower RPE values than rugby players.

To the best of our knowledge, this is the first study to compare physiological, perceptual and performance responses to the prescribed $HIIE_{15:15s}$ protocols using intensities relative to the ASR and MAS. In the present study, the three protocols were performed at intensities above the MAS, and considering all athletes, the use of ASR delta (Δ25% and 50%) reduced the CV to time-to-exhaustion (a mean reduction of 52%) and Δ [La] (a mean reduction of 48%) compared to 110% MAS. These results corroborate the proposition of Buchheit and Laursen (2013), suggesting the ASR as an important variable for consideration in the individualized prescription of HIIE intensity. The decrease in the CV in the time-to-exhaustion represents a more matched physiological cost for individuals and allows them to more sensitively compare the influence of an independent variable on a determined response to exercise (Barnett, Jenkins, MacKinnon, & Green, 1996; Lansley et al., 2011) and also design effective training programmes (Lansley et al., 2011).

Specifically, for HIIE, there are no studies comparing different methods to normalize exercise intensity, but the utilization of two mechanical variables (e.g. MAS and maximal lactate steady-state) compared to only one mechanical variable (e.g. MAS) is commonly used to prescribe continuous exercise (Carter, Pringle, Jones, & Doust, 2002; Lansley et al., 2011; Özyener, Rossiter, Ward, & Whipp, 2001). Lansley et al. (2011) compared the degree of inter-subject variability in performance and physiological responses to six cycle ergometer prescribed protocols of continuous exercises using different percentages of $\dot{V}O_{2max}$ (50%, 70% and 90%) and a 60% gas exchange threshold (GET), as well as Δ 40% and Δ 80% – power at GET plus 40% or 80% of the difference between the power at the GET and power at $\dot{V}O_{2max}$. When the outcomes from the severe domain (90% of $\dot{V}O_{2max}$ vs. Δ80%) were considered, these authors reported a CV of 28% vs. 12% for [La], 6% vs. 3% for RPE, and 43% vs. 21% for time-to-exhaustion for the exercise prescribed using $v\dot{V}O_{2max}$ or the delta-based parameters, respectively. The delta-based intensities reduced the CV for all variables when compared with exercise intensities prescribed based on GET and $v\dot{V}O_{2max}$. The CV found in Lansley et al. (2011) in the delta-based intensities was similar to the CV found in the present study (~21%). Although the CV was lower when the HIIE was prescribed by deltas, it remained quite high, which was probably because the other variables continue influencing the time-to-exhaustion, such as aerobic (critical velocity and endurance index of Péronnet and Thibault) and anaerobic fitness (anaerobic running distance) (Blondel, Berthoin, Billat, & Lensel, 2001; Buchheit, Laursen, Millet, Pactat, & Ahmaidi, 2008).

Blondel et al. (2001) observed that the high inter-subject variability in running time-to-exhaustion of four exercise protocols prescribed in intensities related to $v\dot{V}O_{2max}$ (90%, 100%, 120% and 140%) was a consequence of the protocols only prescribed by intensities related to $v\dot{V}O_{2max}$, since this marker represents a selected aspect of the metabolic profile. The authors observed negative correlations between the time-to-exhaustion at the four intensities and the running speeds expressed relative to the maximal speed reserve (MSS minus critical speed) and between time-to-exhaustion at 120% and 140% of $v\dot{V}O_{2max}$ and the running speeds expressed with respect to ASR. Bundle, Hoyt, and Weyand (2003) proposed that the ASR can estimate the portion of the power output provided by the anaerobic metabolism and the performance decrement during all-out efforts, which contribute to a more individualized intensity prescription.

The RPE reported by athletes in the present study in $HIIE_{15:15s}$ was 17, which represents "*very hard*" (Borg, 1982). The coefficient of variation in the RPE was small (~8%) and was similar for $HIIE_{15:15s}$ prescribed using the ASR delta and the percent of MAS. The effort characteristics of the present study (running to volitional exhaustion) may explain the low inter-subject variability and similar response between these methods (ASR delta and percent of MAS). However, the rugby players reported higher RPE values compared to long-distance runners in $HIIE_{15:15s}$ (18 vs. 17) and in the incremental track test (18 vs. 16). It is important to state that these values are close to "very hard", and this difference may represent the characteristics of athletes (typical modes of training) from different modalities. It is possible that, because long-distance runners are accustomed to running close to $v\dot{V}O_{2max}$, they had a lower RPE. Other studies also showed this response (Garcin et al., 2003), and their explanation is related to past experiences at the same task and considering that runners are more accustomed to performing the HIIE protocols used in the present study. Another mechanism is related to the level of aerobic fitness (Manzi et al., 2010; Milanez et al., 2011). When athletes of the same modality were evaluated, a negative relationship ($r = -0.75$) was observed between the aerobic fitness indexes and the values reported for the internal load, which was obtained through the session-RPE (Milanez et al., 2011). Because the long-distance runners had better aerobic power indexes (MAS and $\dot{V}O_{2peak}$), this observation suggests that this higher aerobic power should result in a reduced RPE even when these athletes were submitted to the same stimulus (an incremental test or HIIE protocols).

Additionally, a comparison of the variables on different $HIIE_{15:15s}$ demonstrated differences in running speed (110% MAS < Δ25 ASR < Δ50 ASR) and was accompanied by a reduction in the time-to-exhaustion (110% MAS > Δ25 ASR > Δ50 ASR) and increases in the Δ [La] (110% MAS < Δ25 ASR and Δ50 ASR). In fact, Dupont et al. (2002) submitted nine male physical education students to four HIIE conditions (110%, 120%, 130% and 140% of MAS) and observed similar CV values in all protocols (51% for 110%, 67% for 120%, 42% for 130% and 50% for 140%). Therefore, the reduction in the CV in time-to-exhaustion and Δ [La] for $HIIE_{15:15s}$ observed in the present study is associated with the utilization of the percentage of the ASR that represents the difference between the MSS and MAS to normalize the intensity of HIIE compared to the percentage of MAS as a single parameter.

The prescription of HIIE based on a percentage of the ASR compared to the percentage of the MAS resulted in a reduction in the inter-subject variability of 48% for time-to-exhaustion (from 45% to 22%) and of 52% for Δ [La] (from 44% to 23%). Therefore, coaches and sport scientists can use the percentage of the ASR to prescribe more individualized HIIE sessions. In doing so, an increase in the outcome similarity for the same external load can likely be achieved, i.e. more equalized tolerance and training stimulus can be presented to individuals with variance in their MSS and MAS. These aspects are especially relevant for training monitoring and prescription, since exercise intensity is a key variable to organize the HIIE sessions and may directly affect exercise tolerance. The HIIE individualized prescription still needs to be investigated to understand the long-term effects. Additionally, studies that aim to more sensitively compare the influence of an independent variable (e.g. ergogenic aids) on time-to-exhaustion and physiological responses (for example, Δ [La] and $\dot{V}O_2$) to HIIE could consider individualizing the exercise intensity based in the percentage of ASR.

The main limitation of the present study is the absence of the $\dot{V}O_2$ data during the HIIE to estimate the time above 90% of the $\dot{V}O_{2max}$, which is an important variable to improve the athletes' aerobic power. Consequently, it was impossible to know if decreasing the CV could result in a similar time above 90% of the $\dot{V}O_{2max}$ between subjects. Moreover, the lack of the assessment of $\dot{V}O_2$ measurements limits the understanding concerning the quantification of the energy system contributions during HIIE. Finally, it is necessary to conduct other studies that aim to validate the ASR percentages method to individualize the intensity of the HIIE and to explain the inter-subject variability in time-to-exhaustion when analyzing aerobic and anaerobic parameters.

In conclusion, the prescription of HIIE using the delta ASR resulted in decreased inter-subject variability regarding performance and physiological response when compared to prescription based only on the MAS.

Acknowledgments

We would like to thank all the athletes for their participation. Ursula Ferreira Julio was supported by CNPQ under Grant 150549/2016-4. Emerson Franchini was supported by CNPq under the 302242/2014-7 grant. Valéria Leme Gonçalves Panissa was supported by FAPESP under Grant 2015/11302-3 and 2017/07304-6.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico [grant number 487302/2013-3].

ORCID

URSULA F. JULIO http://orcid.org/0000-0002-0274-851X
VALÉRIA L. G. PANISSA http://orcid.org/0000-0001-7102-7452
EMERSON FRANCHINI http://orcid.org/0000-0002-0769-8398

References

Barnett, C., Jenkins, D., MacKinnon, L., & Green, S. (1996). A new method for the calculation of constant supra-VO_{2peak} power outputs. *Medicine & Science in Sports & Exercise*, *28* (12), 1505–1509. doi:10.1097/00005768-199612000-00010

Blondel, N., Berthoin, S., Billat, V., & Lensel, G. (2001). Relationship between run times to exhaustion at 90, 100, 120, and 140% of vVO_{2max} and velocity expressed relatively to critical velocity and maximal velocity. *International Journal of Sports Medicine*, *22*, 27–33. doi:10.1055/s-2001-11357

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise*, *14*(5), 377–381. doi:10.1249/00005768-198205000-00012

Boullosa, D. A. (2014). The forgotten pieces of the high-intensity interval training puzzle. *Sports Medicine*, *44*(8), 1169–1170. doi:10.1007/s40279-014-0188-4

Boullosa, D. A., & Abreu, L. (2014). Boullosa's forgotten pieces don't fit the puzzle: A response to Dr. Buchheit and Dr. Laursen. *Sports Medicine*, *44*(11), 1625–1628. doi:10.1007/s40279-014-0271-x

Bridge, C. A., Santos, J. F. S., Chaabène, H., Pieter, W., & Franchini, E. (2014). Physical and physiological profiles of taekwondo athletes. *Sports Medicine*, *44*(6), 713–733. doi:10.1007/s40279-014-0159-9

Buchheit, M., & Laursen, P. B. (2013). High-intensity interval training, solutions to the programming puzzle: Part I: Cardiopulmonary emphasis. *Sports Medicine*, *43*, 313–338. doi:10.1007/s40279-013-0029-x

Buchheit, M., Laursen, P. B., Millet, G. P., Pactat, F., & Ahmaidi, S. (2008). Predicting intermittent running performance: Critical velocity versus endurance index. *International Journal of Sports Medicine*, *29*(4), 307–315. doi:10.1055/s-2007-965357

Bundle, M. W., Hoyt, R. W., & Weyand, P. G. (2003). High-speed running performance: A new approach to assessment and prediction. *Journal of Applied Physiology*, *95*, 1955–1962. doi:10.1152/japplphysiol.00921.2002

Carter, H., Pringle, J. S., Jones, A. M., & Doust, J. H. (2002). Oxygen uptake kinetics during treadmill running across exercise intensity domains. *European Journal of Applied Physiology*, *86*(4), 347–354. doi:10.1007/s00421-001-0556-2

Chaabène, H., Hachana, Y., Franchini, E., Mkaouer, B., & Chamari, K. (2012). Physical and physiological profile of elite karate athletes. *Sports Medicine*, *42*, 829–843. doi:10.2165/11633050-000000000-00000

Cohen, J. (1969). *Statistical power analysis for the behavioural sciences*. New York: Academic Press.

Demarie, S., Koralsztein, S. D., & Billat, V. (2000). Time limit and time at VO_{2MAX}' during a continuous and intermittent run. *Journal of Sports Medicine and Physical Fitness*, *40*(2), 96.

Dupont, G., Blondel, N., Lensel, G., & Berthoin, S. (2002). Critical velocity and time spent at a high level of for short intermittent runs at supramaximal velocities. *Canadian Journal of Applied Physiology*, *27*(2), 103–115. doi:10.1139/h02-008

Franchini, E., Del Vecchio, F. B., Matsushigue, K. A., & Artioli, G. G. (2011). Physiological profiles of elite judo athletes. *Sports Medicine*, *41*, 147–166. doi:10.2165/11538580-000000000-00000

Garcin, M., Mille-Hamard, L., Devillers, S., Delattre, E., Dufour, S., & Billat, V. (2003). Influence of the type of training sport practised on psychological and physiological parameters during exhausting endurance exercises. *Perceptual and Motor Skills*, *97*(3_suppl), 1150–1162.

Hopkins, W. G. (2002). *A scale of magnitudes for effect statistics. A new view of statistics*. Retrieved from www.sportsci.org/resource/stats/index.html

Jackson, A. S., & Pollock, M. L. (1978). Generalized equations for predicting body density of men. *British Journal of Nutrition*, *40* (3), 497–504. doi:10.1079/BJN19780152

Lansley, K. E., Dimenna, F. J., Bailey, S. J., & Jones, A. M. (2011). A 'new' method to normalise exercise intensity. *International Journal of Sports Medicine*, *32*(7), 535–541. doi:10.1055/s-0031-1273754

Manzi, V., D'Ottavio, S., Impellizzeri, F. M., Chaouachi, A., Chamari, K., & Castagna, C. (2010). Profile of weekly training load in elite male professional basketball players. *Journal of Strength and Conditioning Research*, *24*(5), 1399–1406.

Milanez, V. F., Pedro, R. E., Moreira, A., Boullosa, D. A., Salle-Neto, F., & Nakamura, F. Y. (2011). The role of aerobic fitness on session rating of perceived exertion in futsal players. *International Journal of Sports Physiology and Performance*, *6*(3), 358–366.

Özyener, F., Rossiter, H. B., Ward, S. A., & Whipp, B. J. (2001). Influence of exercise intensity on the on-and off-transient kinetics of pulmonary oxygen uptake in humans. *The Journal of Physiology*, *533*(3), 891–902. doi:10.1111/j.1469-7793.2001.t01-1-00891.x

Panissa, V. L. G., Julio, U. F., Pinto-E-Silva, C. M., Andreato, L. V., Schwartz, J., & Franchini, E. (2014). Influence of the aerobic fitness on time spent at high percentage of maximal oxygen uptake during a high-intensity intermittent running. *Journal of Sports Medicine and Physical Fitness*, *54*, 708–714.

Siri, W. (1961). Body composition from fluid spaces and density: Analysis of methods. In J. Brozek & A. Hanschel (Eds.), *Techniques for measuring body composition* (pp. 223–244). Washington, DC: National Academy of Sciences.

Stone, N. M., & Kilding, A. E. (2009). Aerobic conditioning for team sport athletes. *Sports Medicine*, *39*(8), 615–642. doi:10.2165/00007256-200939080-00002