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Effect of between-set recovery durations on repeated sprint ability in young soccer players

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ABSTRACT: The purposes of this study were to examine the effect of between-set recovery duration on physiological responses (heart rate and blood lactate), rating of perceived exertion (RPE) and performance indices of repeated sprint sets (RSS) and to investigate their relationship with aerobic power. Twenty-four young male soccer players (age: 17.4 ± 0.32 years) performed three randomized RSS protocols consisting of 2 sets of 5x20 m with 15 s recovery between sprints and 1 min (RSS1), 2 min (RSS2) and 4 min (RSS4) between sets, and a multi-stage aerobic track test to estimate VO_2max. Results showed that in contrast to RSS2 and RSS4, RSS1 leads to a large decline in performance expressed as the sum of sprint times (34.0±1.0 s, 34.0±1.1s and 34.6±1.1s, respectively) and a significant increase of both mean heart rate (124.0±9.7 bpm, 112.5±6.7 bpm and 137.3±12.4, respectively) and RPE (3.2±1.5, 3.4±1.2 and 6.3±1.4, respectively) with no change in blood lactate and peak HR between the three rest conditions. No significant correlations were obtained between estimated VO_2max and any of the indices of the three RSS protocols. In conclusion, 1 min of recovery between sets is sufficient to ensure a significant decrease in performance in the second set, while 2 min and 4 min of recovery were long enough to provide maintenance of high intensity work in the second set. These findings would be useful for coaches and sport scientists when attempting to assess repeated sprint abilities, allowing coaches to accurately define the intended training goals in young soccer players.

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INTRODUCTION

It is widely believed that repeated-sprint ability (RSA) is an important fitness component in intermittent-sport performance. Accordingly, a wide range of RSA tests has been proposed to assess and develop this fitness quality [1,2,3]. Dawson et al. [4] recognized three types of RSA protocols, namely single-set, multiple-set and match simulations/multiple-set tests. Based on the time motion analyses during competitive team sport matches [5-8], it seems that instead of a single-set test to evaluate repeated-sprint ability, repeated sprint sets (RSS), defined as a minimum of three sprints, with recovery of less than 21 seconds in between [8], are more appropriate and mimic the movement pattern of most games to ensure physiological demands of the competition based on intermittent sport activities [9]. In fact, Spencer et al. [10] reported that during an elite field-hockey competition the mean number of sprints within repeated sprint sequences in the game was 4 ± 1 s interspersed with 14.9 ± 5.5 s recovery in-between. They also reported that the defenders performed a maximum of one repeated sprint bout, while the attackers performed 2-4 repeated sprint sequences. Recently, Carling et al. [8] found that most consecutive high-intensity actions in professional soccer matches were performed after recovery durations ≥ 61 s, and players performed 1.1 ± 1.1 repeated high-intensity sets per game with a mean recovery time of 20 s separating sprints. Moreover, Buchheit et al. [7] reported that the occurrence and the nature of repeated sprint interspersed with a maximum of 60 s are affected by age, position and playing time in highly trained young soccer players. As a result, the use of multiple sprint sets allows a more accurate investigation of team-sport performance than the traditional single set one. Nevertheless, the protocols proposed in the literature to assess RSS [9,11,12] are wide-ranging and the authors are not unanimous about the choice of modalities (frequency of sets, distance or time of sprint, type and duration of recovery between both sprints and sets, and total number of sprints to be performed). Among all these RSA protocol parameters, the duration and the nature of recovery have been reported as the most important factors that could affect aerobic and anaerobic energy systems contribution and consequently performance responses to this type of exercise [13-16]. Indeed, it has been previously suggested that during recovery from high intensity intermittent exercise, aerobic metabolism is involved in a major way to restore homeostasis by the resynthesis of phosphocreatine (PCr) and the removal of both accumulated intracellular Pi and lactate [16]. Many authors have highlighted the importance of PCr stores to regenerate ATP during repeated sprint exercise and demonstrated that the maintenance of a high level of performance is mainly associated with the resynthesis of PCr, which is itself strongly dependant on recovery duration [17,18]. Harris et al. [18] reported that in humans the estimated half-time resynthesis of PCr during recovery was about 30-60 s. In addition, Dawson et al. [17] found that after the 1x6 s sprint PCr concentration was respectively 55% (at 10 s), 69% (at 30 s) and 90% (at 180 s) of the pre-exercise value, whereas after the 5x6 s sprints, PCr concentration was respectively 27% (at 10 s), 45% (at 30 s) and 84% (at 180 s) of the pre-exercise value. However, it is clear that the manipulation of the duration of recovery between sprints as well as between the sequences of sprints could produce considerable differences in the profile of metabolic demands during this kind of exercise. Recently a number of studies have been conducted to assess multiple set performance using a variety of recovery durations between sets (from 60-120 to 270 s), and between sprints (20 to 60 s) [9-11,19]. Although these assessments of RSS have provided the best means of directly assessing the physiological responses to this type of work [10], researchers have not standardized the effect of different work-recovery patterns within RSS. Furthermore, the relationship between maximal aerobic power and performance in repeated sprint activities has not always been identified. In fact, although some studies reported significant correlations between VO_2max and RSA performance indices [1,16], others have failed to do so [20]. The difference reported by these studies could be due to the diverse RSA protocols used. Indeed, the recovery durations between both sprints and sets could affect the relationship between aerobic capacity and RSS performance indices. Coaches and fitness trainers need to clearly understand the effects of changes in recovery durations on the physiological and performance responses to RSS exercises in order to choose the most appropriate test based on the objectives of their training programme.

The purpose of this study was therefore to examine the effect of recovery durations on cardiovascular response (heart rate), muscle metabolism (blood lactate) and performance indices during three repeated set tests consisting of 2 bouts of 5x20 m with 15 s recovery between sprints and 1-min (RSS1), 2-min (RSS2) and 4-min (RSS4) passive/active recovery breaks between sets. In addition, we examined the relationships between RSS results and endurance performance test scores. We hypothesized that performance decrements and HR would be higher in RSS1 than in RSS2 and RSS4. In addition, based on the fact that no relationship exists between blood lactate concentration and repeated sprint performance indices [14], we expected that no significant differences in blood lactate would be found between the RSS protocols. We also assumed that maximal aerobic power would be more closely associated with RSS1 than RSS4 and RSS2.

MATERIALS AND METHODS

Participants. Twenty-four male youth soccer players (age: 17.4 ± 0.3 years, height: 171.5 ± 8.8 cm, body mass: 67.7 ± 7.2 kg and body fat: 11.1 ± 2.9%) participated in this study. They all belonged to a Tunisian professional team and participated in the national soccer championship “level 1” (under 17). The study was performed in the middle of the soccer season. Training sessions consisted mainly of soccer training and one official competition weekly. At the time of the experiment, the weekly training schedule of the participants included 5 training sessions per week (approximately 120 min per session). Most training sessions at this time of the year are devoted to specific tactic drills and game skills. The participants were free of any known cardiovascular, metabolic, or pulmonary diseases. The study was conducted according to the Declaration of Helsinki 1975 and the protocol was fully approved by the local Ethical Committee before beginning the experiment. Likewise, written approval for testing was given by clubs. The players and their parents were informed about the procedure of the study before giving their consent to participate.

Procedures

Subjects were required to participate in five testing sessions. All tests were completed within a three-week period and each test was separated by at least 48 hours. All tests were performed by players wearing soccer boots outdoors on artificial turf. Before testing sessions, subjects completed a standard 15-minute period of warm-up, including 3-5 minutes of light jogging, lateral displacements, dynamic stretching and jumping. All testing sessions were performed at the same time in the afternoon (18 ± 1 h), and participants were asked to follow their normal diet. During, the first session, anthropometric data (height, body mass, and fat mass) were measured. The percentage of fat mass was assessed using four skin-fold thickness measurements of sub-scapular, biceps, triceps and supra-iliac sites [21]. During the second sessions, subjects performed the multistage aerobic track test [22] as described below.

Design of experiment

After the familiarization session, players performed in a random order (at the three last sessions) 3 RSS protocols consisting of two sets of 5×20 m sprints, with 15 s of active recovery between repetitions and with either 1-min (RSS1), 2-min (RSS2), or 4-min (RSS4) recovery periods between sets.

For the 5 sprints performed in each set, best sprint time (BST), total sprint time (TST: sum of the 5 sprints), and fatigue index (FI) were determined. HR was continuously recorded during the three sessions of RSS using a heart rate monitor (Polar Accurex Plus, Kempele, Finland), and both mean HR and peak HR reached during the test were used in the statistical analyses. Finger-tip capillary lactate concentrations ([Lac]) were measured before and three minutes after each test using a hand-held Lactate Pro device (Arkray, KDK, Japan). Δ [Lac] was calculated as the difference between [Lac] at rest and the value recorded after the protocols. Only for RSS4 was Δ [Lac] calculated for each set. After each test, the rating of perceived exertion (0-10 scale) was registered [23].

Repeated-sprint sets (RSS)

Participants performed RSS according to the protocol described above. At the completion of each sprint, players performed a 10 m deceleration and a 10 m active jog recovery (Figure 1). The test was performed on artificial turf to replicate typical team-sport conditions. A 20 m sprint distance was chosen as it approximates the mean sprint distance in common field-based team sports [10]. The number of repetitions in each set was based on the works of Gabett [24] and King and Duffield. [25]. Participants were given standard strong verbal encouragement throughout all trials to ensure maximal effort for each sprint. Sprint times were recorded using electronic timing gates (Brower timing system, Salt Lake City, UT, USA; accuracy of 0.01 s) placed approximately 0.75 m above the artificial turf and were positioned 3 m apart facing each other on either side of the starting line located at the start and finish lines. Performance measures recorded included TST, sum of sprint times performed during the two sets (SST) and BST for each set. The fatigue index was also calculated for each set (FI) and for the entire two sets (TAF: total accumulated fatigue) using the equation proposed by Fitszimons et al. [26]. The interclass correlation coefficient and the coefficient of variance for one set of 5x20 m were 0.91, 2.0%; 0.91, 1.9% and 0.45, 55.1% for TST, BST and FI, respectively.

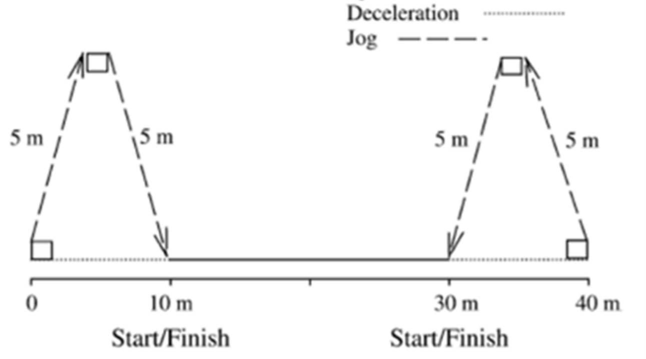

FIG. 1. Schematic diagram of the repeated sprint sets test with active recovery.

Multistage aerobic track test

A multistage aerobic track test of the University de Montréal [27] was used to measure maximal aerobic velocity (vVO_2max) of the players. This test consisted of a running trial around a 200 m track calibrated by reference marks placed every 50 m. The initial speed was set at 6 km.h−1 and was increased by 1 km.h−1 every two minutes. Cones were set at 50 m intervals along the 200 m track (inside the first line). The running pace was dictated by audio signals and the participants had to be within 2 m of the cones at each beep signal. When a subject was behind a cone for three consecutive times, the test was stopped for him. The last stage reached and completed by the subject corresponds to his maximal aerobic velocity (vVO_2max), which is considered as an indicator of maximal aerobic power. The reliability and validity of this test to estimate the VO_2max of trained and untrained young and middle-age females and males have been previously reported [27]. Maximal heart rate reached at the end of the test was 200 ± 5 bpm and was significantly higher than the predicted maximal heart rate (196 ± 0.2 bpm) calculated using the Tanaka et al. [28] equation (208 - 0.7 x age).

Statistical analyses

All analyses were carried out using SPSS 18 for Windows (SPSS, version 18 for Windows. Inc., Chicago, IL, USA). Values were expressed as mean and SD. Normality of all dependent variables was assessed using the Kolmogorov-Smirnov test. The effects of recovery duration on measures of RSS performance indices (TST, BST, SST and FI), Δ [Lac], peak HR, mean HR, and RPE were analyzed using repeated measure ANOVA. Bonferroni post-hoc analyses were performed where appropriate. The paired t-test was used to determine any differences between set 1 vs. set 2 measures of RSS performance indices for each protocol. Effect sizes (ES) for statistical differences were determined. Effect size was assessed using the following criteria: ≤0.2, trivial; >0.2–0.6, small; >0.6–1.2, moderate; >1.2–2.0, large; and >2.0, very large [29]. Pearson's product–moment correlations were employed to examine relationships between RSS performance indices and estimated VO_2max. The correlation coefficients (r) were interpreted in accordance with the following scale of magnitude [29]: ≤ 0.1, trivial; >0.1–0.3, small; >0.3–0.5, moderate; >0.5–0.7, large; >0.7–0.9, very large; and >0.9–1.0, almost perfect. Statistical significance was set at $p \leq 0.05$.

RESULTS

RSS performance indices. The TST, BST and FI values are presented in table 1. Within RSS protocols, TST and BST increased significantly in set 2 compared to set 1 for the RSS1 ($p<0.0001$, ES=1.15 and $p=0.002$, ES=0.55, respectively) and RSS2 ($p=0.001$, ES=0.41 and $p=0.001$, ES=0.49, respectively). No significant differences in TST and BST were observed between set 1 and set 2 for RSS4. FI was significantly higher ($p=0.001$, ES=0.94) in set 2 compared to set 1 only for RSS1. No significant changes in

TABLE 1. Repeated sprint set performance indices during protocols with different recovery periods.

		RSS1	RSS2	RSS4
TST (s)				
	Set 1	16.97 ± 0.69	16.90 ± 0.57	16.97 ± 0.64
	Set 2	17.69 ± 0.58*†	17.11 ± 0.47*	17.06 ± 0.55
SST (s)		34.62 ± 1.10†	34.02 ± 1.02	34.03 ± 1.14
BST (s)				
	Set 1	3.31 ± 0.14	3.28 ± 0.10	3.31 ± 0.11
	Set 2	3.38 ± 0.12*	3.33 ± 0.11*	3.31 ± 0.11
FI (%)				
	Set 1	2.91 ± 1.65	3.19 ± 1.56	2.69 ± 1.28
	Set 2	5.06 ± 2.85*†	2.79 ± 1.61	3.12 ± 1.40
TAF (%)		5.44 ± 1.69†	4.07 ± 1.45	3.66 ± 1.19

Note: RSS: recovery between sprints - 1 min (RSS1), 2 min (RSS2) and 4 min (RSS4), TST = total sprint time for the five sprints; SST: sum of sprint times performed during the two sets; BST = best 20 m sprint time; FI = fatigue index; TAF: total accumulated fatigue during RSS.
*Significantly different from set 1.
† Significantly different from RSS2 and RSS4

FI were found between the two sets for RSS2 and RSS4. Between RSS protocols, no significant differences were observed between the first sets for TST, BST and FI. In addition, the BST recorded at the second set were not significantly different in the three protocols. However, decreasing the recovery period from 4 and 2 min to 1 min resulted in a significant increase of the TST ($p<0.0001$, ES=1.12 for RSS1 vs. RSS2; $p<0.0001$, ES=1.14 for RSS1 vs. RSS4) and FI ($p=0.007$, ES=1.00 for RSS1 vs. RSS2; $p=0.021$, ES=0.88 for RSS1 vs. RSS4). No significant changes were observed in TST and FI between the second sets for RSS2 and RSS4. The same results were observed for the SST ($p=0.030$, ES=0.58 for RSS1 vs. RSS2; $p=0.009$, ES=0.54 for RSS1 vs. RSS4) and TAF ($p=0.025$, ES=0.89 for RSS1 vs. RSS2; $p=0.001$, ES=1.24 for RSS1 vs. RSS4).

Blood lactate

Blood lactate at rest, at the end of the test and Δ [Lac] of the three test protocols are illustrated in table 2. No significant differences in mean blood lactate concentrations at rest were observed between the three RSS protocols (1.84 ± 0.57 mmol·L^{-1}, 1.47 ± 0.23 mmol·L^{-1} and 1.58 ± 0.26 mmol·L^{-1} for RSS1, RSS2 and RSS4, respectively $p>0.05$). Similarly, no significant differences were found between blood lactate concentrations at the end of the test for the three RSS protocols (8.12 ± 2.16 mmol·L^{-1}, 8.17 ± 1.05 mmol·L^{-1} and 8.55 ± 1.78 mmol·L^{-1} for RSS1, RSS2 and RSS4, respectively $p>0.05$). Variation of recovery durations between sets did not significantly affect Δ [Lac] during the test protocols. However, with respect to RSS4, Δ [Lac] in set 1 was significantly greater than that recorded at the second set (4.90 ± 1.37 vs. 2.05 ± 1.15 mmol·L^{-1}, $p<0.0001$, ES=2.30) (Figure 2).

TABLE 2. Blood lactate at rest and Δ [Lac] during the RSS protocols using different recovery durations between sets.

	RSS1	RSS2	RSS4
Lactate (mmol·L^{-1})			
Rest	1.84 ± 0.57	1.47 ± 0.23	1.58 ± 0.26
After exercise	8.12 ± 2.16	8.17 ± 1.05	8.55 ± 1.78
Δ [Lac]	6.45 ±1.97	6.71 ± 1.04	6.97 ± 1.86

Note: RSS: recovery between sprints - 1 min (RSS1), 2 min (RSS2) and 4 min (RSS4), Δ [Lac] difference between blood lactate concentrations at rest and those recorded after exercises.

Heart rate

The effect of recovery duration on mean HR is presented in figure 3. The mean HR increased significantly with the decrease of recovery durations between sets ($p=0.016$, ES=1.19 for RSS1 vs. RSS2; $p<0.0001$, ES=2.48 for RSS1 vs. RSS4 and $p<0.0001$, ES=1.38 for RSS2 vs. RSS4). Peak HR values were 186 ± 14 bpm, 182 ± 9 bpm and 180 ± 10 bpm for RSS1, RSS2 and RSS4, respectively. There were no significant differences in peak HR recorded between the three RSS protocols.

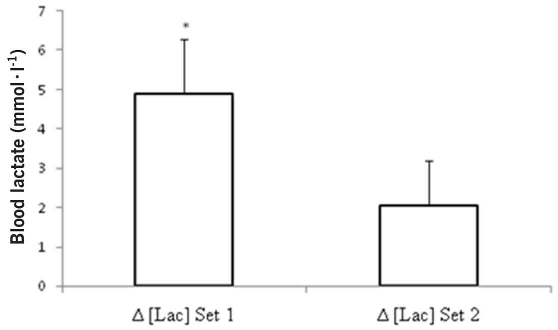

FIG. 2. Δ [Lac] of set 1 and set 2 during RSS4. * Significantly different from set 2 ($p<0.001$). Δ [Lac] set 1: difference between blood lactate concentrations at 3 after set 1 and those recorded at rest. Δ [Lac] set 2: difference between blood lactate concentrations at 3 after set 2 and those recorded at 3 after set 1.

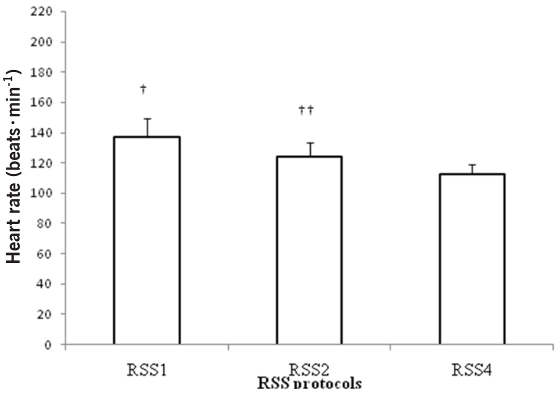

FIG. 3. Mean heart rate recorded during the three RSS protocols with different recovery periods. † MeanHR is significantly different from RSS2 and RSS4; †† MeanHR is significantly different from RSS4.

Ratings of perceived exertion

Figure 4 illustrates the RPE values obtained at the end of the three RSS protocols. Although there was no significant difference between RPE recorded at RSS2 and RSS4, significant differences were observed between RSS1 and both RSS2 and RSS4 ($p<0.0001$, ES=2.17 and $p<0.0001$, ES=2.29, respectively).

Relationships between RSS indices and estimated VO_2max

Maximal aerobic velocity and estimated VO_2max were 14.8 ± 1.6 $km \cdot h^{-1}$ and 51.8 ± 5.7 $ml \cdot min^{-1} \cdot kg^{-1}$, respectively. The Pearson product moment correlation between RSS performance indices and estimated VO_2max is provided in table 3. No significant correlations were found between all RSS performance indices of the three protocols and maximal aerobic power.

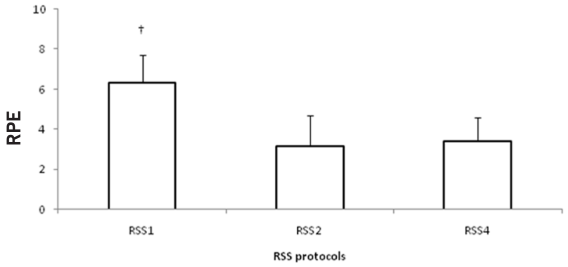

FIG. 4. Rating of perceived exertion data (RPE) at the end of the three RSS protocols with different recovery periods. † Significantly different from RSS2 and RSS4.

TABLE 3. Relationships between estimated VO2max and both SST and TAF achieved during RSS protocols.

		Estimated VO2max
SST (s)	RSS4	-0.331 (p=0.114)
	RSS2	-0.262 (p=0.216)
	RSS1	-0.133 (p=0535)
TAF (%)	RSS4	-0.198 (p=0.354)
	RSS2	0.255 (p=0.230)
	RSS1	-0.226 (p=0.289)

Note: RSS: recovery between sprints - 1 min (RSS1), 2 min (RSS2) and 4 min (RSS4), SST: sum of sprint times performed during the two sets; TAF: total accumulated fatigue during RSS.

DISCUSSION

The aim of the present study was to examine the effect of recovery durations between sets on different physical and physiological measures of repeated sprint set exercise. We found that 1 min of recovery between sets led to a large decrease in performance and a significant increase of both mean HR and RPE at the end of the second set with no change in Δ [Lac] and peak HR between the three rest conditions compared to 2-min and 4-min recovery.

Although previous research had demonstrated the effect of recovery durations on performance and the profile of metabolic demands during a single repeated sprint test [13,14, 16], it seems to the best of our knowledge that our work is the first study to assess the effect of different recovery durations on physical performance indices and physiological responses during RSS exercises.

Our results showed that shortening the recovery durations between sets had a significant impact on TST as well as accumulated fatigue (FI) during the second set of RSS protocols. In fact, 1 min of recovery between sets produces the highest TST and FI in comparison with longer recovery intervals (2 min and 4 min), which means that young soccer players were able to reproduce the same TST with no significant change in the FI in the second set of RSS4. This result agrees with previous research [9,11,12] that reported no differences between set 1 and set 2 using RSS protocols involving three sets of repeated sprints interspersed with ~240 s recovery in between. In addition, we found that 120 s of recovery between sets has little effect on RSS performance indices as no significant differences in SST and TAF were obtained between RSS2 and RSS4. It seems that when using long recovery durations between sets (≥120 s), at least three sets should be performed in order to ensure a drop in performance at the end of the test. In this context, it has been reported that 3 repeated sets of sprints interspersed by 270 s of recovery in between lead to high lactate concentrations (12.3 ± 2.8 $mmol \cdot L^{-1}$) at the end of the test [9]. Such blood lactate concentrations values were considerably higher than those obtained during team sport competition [30]. Indeed, Krustrup et al. [31] reported that blood lactate was 6.0 ± 0.4 and 5.0 ± 0.4 $mmol \cdot L^{-1}$ during the first and second halves, respectively, in Danish soccer players. Likewise, Aslan et al. [5] reported that mean blood lactate concentrations during the first half of the matches were significantly higher than in the second half (4.52 ± 1.88 vs. 3.38 ± 1.15 $mmol \cdot L^{-1}$) in young soccer players (age: 17.6 ± 0.6 years). Our results showed that Δ [Lac] in the first set of RSS4 was 4.94 ± 1.38 $mmol \cdot L^{-1}$, suggesting the intervention of anaerobic glycolysis. This increase in lactate could be due to the fact that the recovery period is very short for a complete resynthesis of PCr. In fact, it has been reported that short intervals of recovery between sprints (≤ 30 s) would result in a progressive decrease of the muscle PCr stores, making therefore a higher demand on anaerobic glycolysis for the regeneration of ATP during following sprints of exercise [17,32]. However, Δ [Lac] decreased significantly in the second set compared to the first set from 4.94 ± 1.38 to 2.04 ± 1.18 $mmol \cdot L^{-1}$. This result was in agreement with Gaitanos et al. [33], who reported a significant decrease in the contribution of glycolysis to the total anaerobic ATP provision from 44% during the first sprint of a 10×6s protocol to 16% in the final sprint. Generally, during intermittent high intensity exercise, progressive changes in the metabolic environment lead to gradual inhibition of glycolysis with repeated sprints. Furthermore, it has been suggested that the degree of glycolytic inhibition might be influenced by the recovery periods between sprints, since small increases in recovery duration have been shown to allow individuals to maintain a high level of performance during a single repeated sprint set [14,16]. Unfortunately, this was not the case in the current study as no significant differences were found between Δ [Lac] in the three rest conditions despite the high performance decline in RSS1 compared to both RSS2 and RSS4. This result suggests that the decline in RSS performance with reduced recovery periods was not attributable to blood lactate concentrations. In this context, many investigators considered that blood lactate is a poor indicator of fatigue in repeated sprint tests, and other metabolic factors such as Pi, pH and PCr have been suggested to play an important role in fatigue during this type of exercise [14,34,35]. Given that full regeneration of PCr stores to resting value took more than 3 minutes to achieve during repeated high-intensity exercise [17], it seems that the recovery duration between sets considerably affects RSS performance especially at the second set when the rest duration is less than 120 s. Nevertheless, the PCr alone cannot explain differences between protocols in SST and TAF, because it has been recently suggested that Pi with its inhibitory effect on release of calcium ions from sarcoplasmic reticulum could also be considered as a major factor of fatigue during repeated sprint exercises [36]. In addition, 2 min of rest is necessary to re establish low intracellular concentrations of this ion [37]. From all considerations cited above, we expected that 1 min of recovery between sets is insufficient not only for resynthesis of PCr, but also to get rid of accumulated Pi, which causes an early decline in performance in the second set. The significant contribution of the aerobic system in the present study may be confirmed by the significantly greater mean HR recorded during the RSS protocols with shorter rest intervals. In fact, mean HR increased significantly as the rest period between sets was reduced (113 ± 7 bpm, 124 ± 10 bpm and 137 ± 12 bpm in RSS4, RSS2 and RSS1, respectively). In contrast, peak HR did not differ between the three RSS protocols. In addition, mean HR values recorded during the RSS1 are closest to those reported by Aslan et al. [5] during the competition in young soccer players (167 ± 9 bpm and 162 ± 8 bpm in the first and second half, respectively). In summary, our data showed that 1 min of recovery between sets leads to progressive inhibition of glycolysis which could be compensated by a gradual increase in aerobic ATP provision in the second set of the test. In the present study, no relationship was found between RSS performance indices and estimated VO_2max. This was in agreement with the result reported by Serpiello et al. [9], who did not find any relationship between repeated sprint set performance indices and VO_2max. The lack of correlation could be due to the fact that maximal aerobic power is thought to be determined essentially by central factors [38] while RSA performance is more associated with peripheral factors [39]. In addition, the VO_2max is not the only indicator of aerobic fitness. Indeed, aerobic capacity, as represented by anaerobic threshold or the velocity at the onset of blood lactate accumulation, could have a greater association with RSA than VO_2max [39,40], since the aerobic capacity is strongly associated with peripheral factors. Furthermore, Dupont et al. [41] reported that a shorter time constant for the fast component of VO_2 kinetics was a better indicator of RSA than maximal aerobic power itself.

Numerous studies have reported the interest in the use of RPE as a simple, reliable and valid method to quantify and monitor soccer exercise intensities [22,25,42]. In the present study, while no significant difference was observed between RPE values recorded at the end of both RSS2 and RSS4 (3.17 ± 1.54 and 3.38 ± 1.20 or "moderate", respectively), 1 min of recovery between sets produces the highest RPE (6.33 ± 1.37 or "hard"). Shortening the between-set rest periods from 4 min and 2 min to 1 min led to an increase of 3 Borg scale units in the second set of RSS1. These results confirmed the differences in the overall accumulated fatigue reflected by the highest TAF and mean HR recorded during RSS1 in comparison with RSS2 and RSS4. Aslan et al. [5] reported RPE scores of about 14-15 or "hard" during the last 15 min of the match in young soccer players. Although in the current study we used a different Borg scale (0 to 10) from that used by Aslan et al. [5], RSS1 seems to lead to a similar subjective appreciation of fatigue (6.33 or "hard") recorded at the end of young soccer competitions, whereas RSS2 and RSS4 were comparable to those recorded during the first half of the matches. Furthermore, these results were in line with those of Little et al. [22], who reported RPE scores of 15-16 or "hard" during different soccer training drills. In fact, RPE in RSS1 was similar to the values reported during 2v2, 3v3 and 4v4 soccer games, whereas subjective appreciation of "moderate" fatigue recorded during both RSS2 and RSS4 was comparable to that recorded during 6v6 and 8v8 soccer training drills.

CONCLUSIONS

Our data demonstrated the considerable effect of between-set recovery durations on RSS performance indices, mean HR and RPE. In fact, 1 min of recovery between sets is sufficient to ensure a significant decrease in performance in the second set, while 2 min and 4 min of recovery were sufficiently long to provide appropriate intracellular restitution and maintenance of high intensity work in the second set. In addition, our results indicated that blood lactate was independent of recovery durations, and the decrease of Δ [Lac] in the second set of RSS4 suggests that other factors may be more reliant on fatigue during RSS exercise. These findings would be useful for coaches and sport scientists when attempting to assess repeated sprint abilities and performance enhancement in young soccer players. Thus, coaches and physical conditioning trainers should take into account these results when attempting to assess or to develop repeated sprint performance in soccer players.

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