

EFFECT OF THE NUMBER OF SPRINT REPETITIONS ON THE VARIATION OF BLOOD LACTATE CONCENTRATION IN REPEATED SPRINT SESSIONS

■ Accepted
for publication
11.01.2014

AUTHORS: Gharbi Z.^{1,2}, Dardouri W.³, Haj-Sassi R.⁴, Castagna C.⁵, Chamari K.^{1,6}, Souissi N.¹

¹ Tunisian Research Laboratory "Sport Performance Optimisation", National Center of Medicine and Science in Sports (CNMSS), Tunis, Tunisia

² High Institute of Sports and Physical Education, University of Gafsa, Gafsa, Tunisia

³ Department of physical Education, University of Hail-College of Education, Hail, Kingdom of Saudi Arabia

⁴ Research Unit "School and University Sportive Practices and Performance", High Institute of Sports and Physical Education, University of Jendouba, Kef, Tunisia

⁵ Football Training and Biomechanics Laboratory, Italian Football Federation (FIGC), Technical Department, Coverciano (Florence), Italy

⁶ Athlete Health and Performance Research Centre, ASPETAR, Qatar Orthopaedic and Sports Medicine Hospital, Doha, Qatar

Reprint request to:

Zied Gharbi

High Institute of Sports and Physical Education of Gafsa,

University of Gafsa, Gafsa, Tunisia.

Tel: +216 24 56 86 42.

Fax: +216 76 211 616

E-mail: zied1976@yahoo.fr

ABSTRACT: The aim of the present study was to examine the effect of number of sprint repetitions on the variation of blood lactate concentration (blood [La]) during different repeated-sprint sessions in order to find the appropriate number of sprint repetitions that properly simulates the physiological demands of team sport competitions. Twenty male team-sport players (age, 22.2 ± 2.9 years) performed several repeated-sprint sessions (RSS) consisting of 1, 2, 3, 4, 5, 9, or 10 repetitions of 30 m shuttle sprints (2×15 m) with 30 s recovery in between. The blood [La] was obtained after 3 min of recovery at the end of each RSS. The present study showed that for RSS of 3 sprints (RSS3) there was a high increase ($p < 0.001$) in blood [La], which reached approximately fivefold resting values (9.4 ± 1.7 mmol \cdot l⁻¹) and then remained unchanged for the RSS of 4 and 5 sprints (9.6 ± 1.4 and 10.5 ± 1.9 mmol \cdot l⁻¹, $p = 0.96$ and 0.26 , respectively). After RSS9 and RSS10 blood [La] further significantly increased to 12.6 and 12.7 mmol \cdot l⁻¹, $p < 0.001$, respectively. No significant difference was found between RSS3, RSS4 and RSS5 for the percentage of sprint speed decrement (Sdec) (1.5 ± 1.2 ; 2.0 ± 1.1 and $2.6 \pm 1.4\%$, respectively). There was also no significant difference between RSS9 and RSS10 for Sdec ($3.9 \pm 1.3\%$ and $4.5 \pm 1.4\%$, respectively). In conclusion, the repeated-sprint protocol composed of 5 shuttle sprint repetitions is more representative of the blood lactate demands of the team sports game intensity.

KEY WORDS: repeated shuttle sprint, lactate, speed decrement, team sports

INTRODUCTION

The ability to repeatedly sprint with a relatively short time interval is considered as a relevant fitness pre-requisite in team sports [12, 21, 24]. Although there seems to be common agreement in repeated-sprint ability (RSA) testing protocols regarding the sprint distance and time of recovery in between sprints, the sprint number seems to be indiscriminately chosen. Indeed, the number of sprint repetitions reported in RSA protocols varies greatly, from 5 to 15 sprints, even when the sample of studies is limited to those that selected sprint durations ranging from 5 to 6 seconds, which has been suggested as relevant to field-based team-sport performance [25]. This large variance regarding the number of sprint repetitions can affect the contribution of aerobic and anaerobic systems in RSA testing [25].

Previous studies demonstrated that after performing RSA tests, players achieved high concentrations of blood lactate values ranging

from 10 to 15 mmol \cdot l⁻¹ [4, 6, 18]. These reported blood lactate levels are mainly higher than the mean values reported during actual game play [5]. Indeed, mean blood lactate values collected during basketball, field hockey, rugby league, and soccer competition, for instance, are in the range of 3 to 10 mmol \cdot l⁻¹ [4, 10, 27]. On the other hand, Buchheit et al. [3] performed more detailed investigations of the specific sprint patterns during competitive games in highly trained young soccer players. They reported a relatively small number of sprints per sequence or set of repeated sprints (2.7 ± 0.3). This is in agreement with the data of Gabbett et al. [15], who reported an average of 4.8 repeated-sprint sets per player per match, with each set comprising three to six sprints during international matches analysed in elite women soccer players. This is also in line with the mean number of sprints (4 ± 1) reported during a repeated-sprint bout in

field-hockey games [26]. Such observations might also question the logical validity of some RSA protocols widely employed in team sports when using more than 6 sprints. Coaches and fitness trainers continually seek to identify and use tests that can closely reproduce the physical and physiological demands of the competition. Therefore, the aim of the present study was to examine the effect of variation in number of sprint repetitions on post-test blood lactate concentration during different repeated-sprint sessions; this would allow us to find the appropriate number of sprint repetitions that properly simulates the physiological demands of team sport competitions.

MATERIALS AND METHODS

Participants. Twenty male physical education students (age, 22.2 ± 2.9 years; body mass, 70.2 ± 11.6 kg; height, 180 ± 1 cm; % fat mass, $12 \pm 4\%$; VO_{2Peak} , 54.6 ± 5.2 mL · kg⁻¹ · min⁻¹) volunteered to participate in the study. At the time of the study, they were all licensed in various team sports: soccer (n=11), basketball (n=5), and handball (n=4). Subjects were selected from their team sport experience (each subject had at least 5 years of training experience). None was a highly trained competitive athlete and therefore subjects could be described as sub-elite. In addition to their training schedule with their teams, they also performed ~ 16 h · wk⁻¹ of various physical activities as part of their university course. All the participants provided written consent after being informed of the aims, benefits and risks involved with this investigation. The local University Ethics Committee approved this study protocol design that respected the principles of the Declaration of Helsinki (1975).

Experimental procedures

All tests were performed indoors at the sport university gymnasium on a synthetic floor. Before testing, subjects were allowed 15 minutes to complete a standardized individual warm-up, including 5 minutes of light jogging, then 5 minutes of exercise involving dynamic stretching and 3 single 2×15 m shuttle sprints (30 m with 180° change of direction [COD]) with 2 minutes of passive recovery in between. All sessions were performed at the same time of day from 10 am to 12 noon to minimize the effects of diurnal variations on the measured variables. Each subject was asked to maintain their normal diet and to take a standardized breakfast ~ 2 h before undertaking any repeated-sprint session. The subjects were also instructed to abstain from caffeine intake on the test days. The subjects were instructed to refrain from other intense physical exercise 48 h before all repeated-sprint sessions.

Repeated-sprint sessions (RSS)

All repeated-sprint sessions (RSS) were conducted in a randomized, counterbalanced order over a two-week period. Only one RSS (of 1, 2, 3, 4, 5, 9 or 10 sprints) was carried out on any given day, and each session was separated by at least 24 hours not including any further physical activity to ensure adequate recovery. Consistent strong vocal encouragement was given throughout the assessments.

The RSS consisted of 1, 2, 3, 4, 5, 9, or 10 repetitions of 30 m shuttle sprints (15 + 15 m) interspersed with 30 s of passive recovery. Each sprint shuttle was performed with one change of direction (180° turn) and was timed using a photocell system (Brower Timing System, Salt Lake City, 174 UT, USA; accuracy of 0.01 s). This distance and exercise mode were chosen as time-motion analysis indicated 15 m shuttle runs as the upper-range distance covered at a high intensity during a game by team sport players [6,25]. Subjects were encouraged to decelerate as soon as possible after passing over the finish line and to reach the starting line walking back slowly and waiting still for the next sprint on the starting line set exactly 50 cm before the line covered by the first photocell beam. All the sprints were timed with the subjects starting 50 cm before the first photocell beam. The photocell beam was placed at a height of 1 m and the subjects had to cross the 15 m line and place at least one foot behind this line before sprinting back to the 0 m beam gate. The rule was that if a subject did not cross the 15 m line, his test was stopped and postponed to a subsequent day. During the experiment, no subject was excluded for this reason or for any other reason including injury. Subjects were instructed before all RSS to produce maximal effort for each 30 m shuttle sprint and were wearing the same sport shoes for all testing sessions. The choice of the latter equipment was made in order to allow subjects to run and perform changes of direction without any inappropriate sliding.

The following variables were derived from all RSS:

Peak time (PT): The best time of each RSS; (b) Total time (TT): The sum of all RSS sprint times; (c) the percentage speed decrement (Sdec): The Sdec was calculated as recommended by Fitzsimons et al. [14] for sprint running performance using the following formula:

$$Sdec (\%) = \left\{ \frac{TT}{PT \times \text{nombre of sprints}} - 1 \right\} \times 100$$

Three minutes after the end of each RSS, blood lactate concentration (blood [La]) was obtained from the fingertip of the left hand, with the players in a seated position. At the end of the last RSS sprint, the subjects were instructed to decelerate, and then walk back to near the starting line to sit and wait for the fingertip sampling. Indeed, Taoutaou et al. [28] reported that post-exercise peak [La] was attained at approximately 3 min post-exercise when no active recovery was performed. Blood lactate concentration (in mmol · l⁻¹) was measured with a portable analyser (Lactate Pro, Arkray, Japan). Before each testing session and before each blood sampling, the Lactate Pro system and reagents were calibrated and used according to manufacturer guidelines. To avoid any possible effect of perspiration on the measurements, the finger was cleaned with alcohol and dried immediately before each measurement.

Statistical analysis

Means and standard deviations were calculated for each dependent variable. One-sample Kolmogorov-Smirnov test confirmed normal distributions. Blood [La], PT and Sdec scores of each RSS were compared using a one-way ANOVA with repeated measures. An

alpha value of $p < 0.05$ was assumed to check statistical significance, and all multiple comparisons were adjusted using the Bonferroni method. All statistical analyses were performed using SPSS for Windows (version 15.0, Chicago, IL).

RESULTS

The mean results for both the peak time (PT), the total time (TT) and the percentage speed decrement (Sdec) are summarized in Table 1. The recorded PT during each RSS did not change significantly for any of the study subjects, indicating that subjects generated a maximal intensity effort on each visit assessment.

The blood [La] and Sdec achieved after repeated-sprint sessions (RSS) with 1, 2, 3, 4, 5, 9, and 10 sprints are presented in Figure 1. The averaged blood [La] measured after completion of one repetition

TABLE 1. PEAK TIME (PT), TOTAL TIME (TT) AND PERCENTAGE SPEED DECREMENT (SDEC) DURING ALL RSS

	PT § (s)	TT (s)	S _{dec} (%)
1 sprint	6.31 ± 0.20	6.31 ± 0.20	
2 sprints	6.26 ± 0.24	12.63 ± 0.47	1.0 ± 0.7
3 sprints	6.18 ± 0.23	18.75 ± 0.61	1.5 ± 1.0
4 sprints	6.17 ± 0.21	25.05 ± 0.81	2.0 ± 1.1
5 sprints	6.29 ± 0.20	32.36 ± 1.23	2.6 ± 1.4
9 sprints	6.28 ± 0.23	58.68 ± 2.38	3.9 ± 1.3
10 sprints	6.23 ± 0.23	64.96 ± 2.57	4.5 ± 1.4

Note: PT: peak time; TT: total time; S_{dec}: percentage speed decrement; §: no significant difference

of 15 + 15 m sprint increased from a pre-exercise value of $1.8 \pm 0.6 \text{ mmol} \cdot \text{l}^{-1}$ to $4.7 \pm 1.5 \text{ mmol} \cdot \text{l}^{-1}$ and was not different from the blood [La] of RSS with 2 repetitions (RSS2) ($5.7 \pm 1.2 \text{ mmol} \cdot \text{l}^{-1}$, $p = 0.80$).

For RSS3 there was a much larger increase ($p < 0.001$) in blood [La], which reached $9.4 \pm 1.7 \text{ mmol} \cdot \text{l}^{-1}$, approximately five times the pre-exercise value, and then remained unchanged compared to the RSS of 4 and 5 sprints ($p = 0.96$ and $p = 0.26$, respectively). Figure 1 shows that the blood [La] values were highly and significantly elevated ($p < 0.001$) for RSS9 and RSS10, with similar levels of 12.6 ± 2.3 and $12.7 \pm 1.0 \text{ mmol} \cdot \text{l}^{-1}$, respectively.

DISCUSSION

The aim of the present study was to examine the effect of the variation of the number of repetitions of repeated-sprint testing sessions on post-exercise blood lactate concentration. This was done in order to find the appropriate number of sprint repetitions that more closely simulates the physiological demands of team sport competitions. The main finding in the present study was that the RSS with 3, 4, or 5 sprints (15 + 15 m with 30 s recovery in between) induced no significant difference in Sdec and produced similar blood [La] around $9 \text{ mmol} \cdot \text{l}^{-1}$, closely representing what is observed in team sport competition.

After only one sprint repetition (RSS1), approximately a threefold accumulation of blood [La] compared to pre-exercise values was observed (from 1.8 ± 0.6 to $4.7 \pm 1.5 \text{ mmol} \cdot \text{l}^{-1}$), reflecting the contribution of the anaerobic glycolysis energy system to the 30 m shuttle sprint. In accordance with the present study findings, Dawson

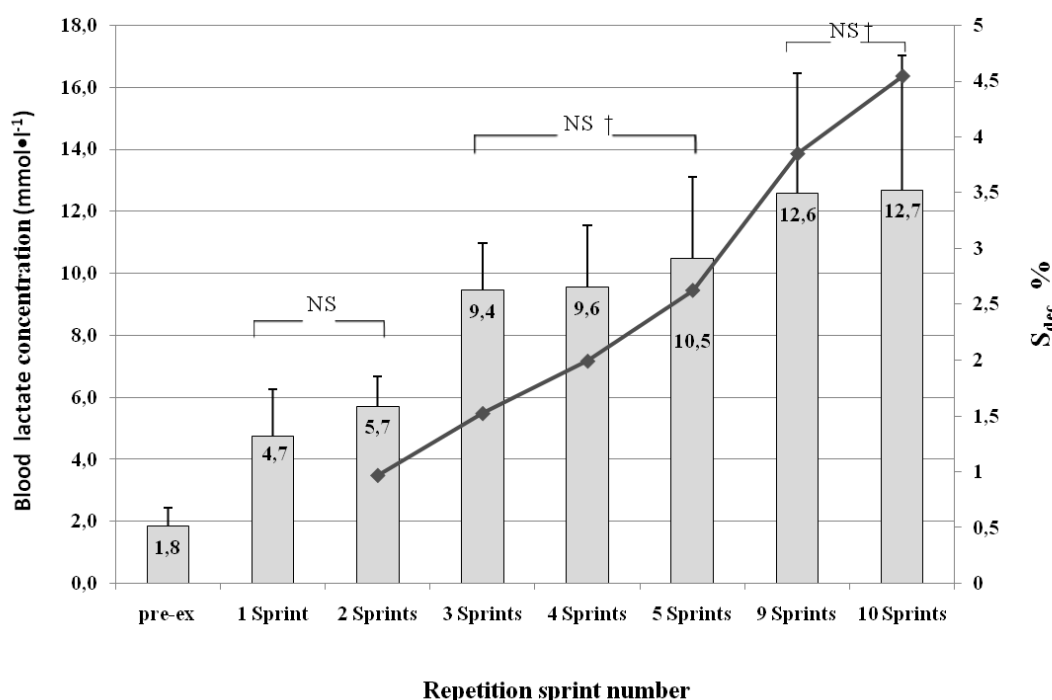


FIG. 1. MEAN AND ± SD VALUES FOR BLOOD LACTATE CONCENTRATION (BLOOD [La]) (COLUMNS) AND THE PERCENTAGE SPEED DECREMENT (S_{DEC}) (LINE) ACHIEVED AFTER REPEATED-SPRINT SESSIONS (RSS) WITH 1, 2, 3, 4, 5, 9 AND 10 SPRINTS

Note: *: no significant difference in blood [La]. †: no significant difference in S_{dec}

et al. [13] recorded after single 6 s cycle sprint a threefold increase in muscle [La] from the pre-exercise level (from 6.8 ± 1.9 to 20.9 ± 5.0 $\text{mmol} \cdot \text{kg}^{-1} \text{DM}$). This confirms therefore that only one short 6 s sprint needs a high energy demand exceeding the aerobic and alactic anaerobic capacity of the muscle cells, and a large fraction of the ATP required will come from anaerobic glycolysis, therefore resulting in relatively high levels of [La] [20,29]. These results are also in accordance with those previously reported by Gaitanos et al. [16], who estimated at 44.1% the glycolysis contribution rate to ATP production within the first sprint of ten repeated 6 s cycle sprints, and therefore leading to lactate formation. After RSS2 no significant change in blood [La] concentration was detected ($p = 0.67$) compared to RSS1. This result may be explained by the good level replenishment of phosphocreatine (PCr) stores after the first sprint. Indeed, Dawson et al. [13] found that PCr repletion was approximately 70% of the pre-exercise values after 30 s of recovery following single 6 s maximal cycle sprint.

The second significant increase of blood [La] values was observed in RSS3 ($p < 0.001$). It should be noted that the blood [La] of RSS with 3, 4, and 5 repetitions did not vary significantly (9.4 ± 1.7 , 9.6 ± 1.4 and 10.5 ± 1.9 $\text{mmol} \cdot \text{l}^{-1}$, respectively). We speculated that the reasons for these steady lactate levels during RSS3, RSS4 and RSS5 may be attributable to a greater aerobic intervention which maintained the blood [La] at a similar level [17]. This intervention of the aerobic metabolism could have (1) increased lactate clearance during recovery and (2) increased the aerobic contribution to sprint energy supply, dampening the glycolytic contribution to the energy production during the sprints [7,8,16]. The blood [La] measured in RSS5 increased six-fold compared to pre-exercise level (1.8 vs. 10.5 $\text{mmol} \cdot \text{l}^{-1}$). Similarly, Gaitanos et al. [16] reported a blood [La] of 9.2 $\text{mmol} \cdot \text{l}^{-1}$ immediately after the fifth sprint of 6-sec cycle sprints (with 30 s of recovery in between). On the other hand, Dawson et al. [13] found a nine-fold increase in muscle [La] from the pre-exercise level (from 6.8 ± 1.9 to 62.5 ± 20.4 $\text{mmol} \cdot \text{kg}^{-1} \text{DM}$). This difference might be due to differences in exercise mode and also to the fact that here the comparison is made between local muscle concentrations and haematological ones. The muscle [La] is a direct measure but remains highly invasive when it involves muscle biopsies. Measuring blood lactate is much less invasive, especially when it involves finger pricks. In this context, it has widely been shown that muscle lactate is released into the blood stream, where it will be removed by the resting muscles and the heart [2]. This might be a major cause of the higher lactate increase observed in the study of Dawson et al. [13] compared to the present study. Also, the cycling exercise generates more local fatigue [14,22] and then causes a greater disturbance to muscle homeostasis than sprint running exercise. Interestingly, it has been observed that the stability of blood [La] over RSS3, RSS4 and RSS5 is associated with no significant difference in Sdec. Sprint decrements were $1.5 \pm 1.0\%$, $2 \pm 1.1\%$ and $2.6 \pm 1.4\%$, respectively.

In the present study, the third significant level of blood [La] values

was observed after RSS9 and remained at a similar level after RSS10 (12.6 ± 2.3 $\text{mmol} \cdot \text{l}^{-1}$ and 12.7 ± 1.0 $\text{mmol} \cdot \text{l}^{-1}$ respectively, $p = 0.084$). It is interesting to note that Sdec shows in the same way a greater increase after repetition of 9 sprints ($3.9 \pm 1.3\%$) compared to RSS5, with no significant variation observed between RSS9 and RSS10. The unchanged blood [La] in RSS10 supports previous work of Gaitanos et al. [16] showing that the contribution of anaerobic energetic resources is limited during the tenth sprint. Indeed, Gaitanos et al. [16] reported that during a 10×6 s sprint separated with 30 s rest, the contribution from glycolysis to ATP production for the 10th sprint was negligible. They suggested then that during the last sprint (10th sprint) the ATP re-synthesis was mainly derived from PCr degradation and oxidative metabolism. This apparent inhibition of glycolysis with repeated sprints probably occurred in the present study.

On the other hand, the high blood [La] values measured after 9 and 10 repetitions of sprint are in accordance with those previously reported in the same RSA protocol that was used by Caprino et al. [4] (12.4 ± 2.8 $\text{mmol} \cdot \text{l}^{-1}$). However, after 10 sprints of 30 m shuttle running sprints with 30 s recovery in between, Castagna et al. [5] found a high blood [La], being around 1.3 $\text{mmol} \cdot \text{l}^{-1}$ above the values of the present study (14.1 ± 3.5 $\text{mmol} \cdot \text{l}^{-1}$). Previous research also showed a high mean blood [La] above 12 $\text{mmol} \cdot \text{l}^{-1}$ after performing repeated-sprint protocols [11,19]. These recorded blood lactate levels are well above the upper average range of those reported to occur during actual game play [5,27]. Consequently, the present study authors suggest that RSS with 3 to 5 sprints would appear sufficient to replicate similar physiological responses to competition demands in team sports. In that regard, several studies have proposed a reduction of the number of sprint bouts in RSA protocols to avoid a pacing strategy that is used by subjects when performing numerous repeated supposed all-out sprints [14,25,30]. In fact, Fitzsimons et al. [14] suggested that an RSA test should not involve more than 8–10 sprint bouts when short recovery times (20–30 s) are used. In addition, Chaouachi et al. [9] indicate that for RSA protocols involving 30 m with 25 s recovery, 5 sprint bouts should be sufficient as the sprint decrement percentage is similar to that of longer protocols. For instance, a number of repetitions around 5 to 6 would certainly achieve both goals of (1) replicating the lactate observed during a game and (2) being related to some game performances, and thus representing ecological validity. In this context, Rampinini et al. [23] have indeed shown that the performance of an RSA test composed of 6 shuttle sprints of 40 m (2×20 m with 180° COD) with 20 s recovery in between was correlated with on-field official match performance. RSA tests composed of a low number of repetitions would induce low lactate values, and others with too many repetitions would induce too high lactate values showing low logical validity with respect to the assessment of team sports athletes.

In light of this study's findings and the match analysis literature reporting no more than five sprints per sequence during the game and also the peak lactate observed during the game, it appears that the repeated-sprint protocols including 5 sprint repetitions are more

representative of the blood lactate demands of the team sport game. It may therefore be of interest to adopt a novel approach for the development of future RSA protocols. We propose completing a smaller number of sprint repetitions (not more than 5 sprints) and performing more than one repeated-sprint set to simulate the repeated-sprint demands of team sport competitions. It is therefore suggested that future RSA tests composed of multiple sets of 5 sprint repetitions could be developed in order to match not only the repeated-sprint ability over a few intensive sporting actions, but also the repetition of such "intense" sets of actions over time during the team sport games [24].

CONCLUSIONS

The results of the present study show that performing RSS with 3, 4, or 5 shuttle sprints (15+15 m with 30 s recovery in between) does not induce any significant difference in Sdec and does display similar blood lactate concentrations (around $9 \text{ mmol} \cdot \text{l}^{-1}$) compared to what is observed in team sport competition. We propose then a

reduction of the number of sprint repetitions (not more than 5 sprints) in RSA testing and training sessions. Such a number of repetitions reduces blood lactate concentrations (compared to 9 and 10 repetitions), allowing us to respect the recommended training rules concerning training intensity and volume applied in better training adaptations [1]. For that reason it could be more pertinent for coaches and fitness trainers to select about 5 sprint repetitions for testing or training sessions; this may better prepare athletes for the physiological demands of team sport competitions. Lastly, future applied research should experiment with multiple sets of 5 RSA efforts to get closer to team sport efforts.

Acknowledgments

This study was financially supported by the Ministère de l'Enseignement Supérieur et de la Recherche Scientifique, Tunisia. The authors thank all subjects for their enthusiasm and commitment.

Conflict of interest: The authors declare no conflict of interest.

REFERENCES

1. Billat V.L., Slawinski J., Bocquet V., Chassaing P., Demarle A., Koralsztein J.P. Very short (15s-15s) interval-training around the critical velocity allows middle-aged runners to maintain VO_2 max for 14 minutes. *Int. J. Sports Med.* 2001;22:201-208.
2. Brooks G.A. Current concepts in lactate exchange. *Med. Sci. Sports Exerc.* 1991;23:895-906.
3. Buchheit M., Bishop D., Haydar B., Nakamura F.Y., Ahmaidi S. Physiological responses to shuttle repeated-sprint running. *Int. J. Sports Med.* 2010;31:402-409.
4. Caprino D., Clarke N.D., Delextrat A. The effect of an official match on repeated sprint ability in junior basketball players. *J. Sports Sci.* 2012;30:1165-1173.
5. Castagna C., Abt G., Manzi V., Annino G., Padua E., D'Ottavio S. Effect of recovery mode on repeated sprint ability in young basketball players. *J. Strength Cond. Res.* 2008;22:923-929.
6. Castagna C., Manzi V., D'Ottavio S., Annino G., Padua E., Bishop D. Relation between maximal aerobic power and the ability to repeat sprints in young basketball players. *J. Strength Cond. Res.* 2007;21:1172-1176.
7. Chamari K., Ahmaidi S., Blum J.Y., Hue O., Temfemo A., Hertogh C., Mercier B., Prefaut C., Mercier J. Venous blood lactate increase after vertical jumping in volleyball athletes. *Eur. J. Appl. Physiol.* 2001;85:191-194.
8. Chamari K., Ahmaidi S., Fabre C., Ramonatxo M., Prefaut C. Pulmonary gas exchange and ventilatory responses to brief intense intermittent exercise in young trained and untrained adults. *Eur. J. Appl. Physiol. Occup. Physiol.* 1995;70:442-450.
9. Chaouachi A., Manzi V., Wong del P., Chaalali A., Laurencelle L., Chamari K., Castagna C. Intermittent endurance and repeated sprint ability in soccer players. *J. Strength Cond. Res.* 2010;24:2663-2669.
10. Coutts A., Reaburn P., Abt G. Heart rate, blood lactate concentration and estimated energy expenditure in a semi-professional rugby league team during a match: a case study. *J. Sports Sci.* 2003;21:97-103.
11. da Silva J.F., Guglielmo L.G., Bishop D. Relationship between different measures of aerobic fitness and repeated-sprint ability in elite soccer players. *J. Strength Cond. Res.* 2010;24:2115-2121.
12. Dawson B. Repeated-sprint ability: where are we? *Int. J. Sports Physiol. Perform.* 2012;7:285-289.
13. Dawson B., Goodman C., Lawrence S., Preen D., Polglaze T., Fitzsimons M., Fournier P. Muscle phosphocreatine repletion following single and repeated short sprint efforts. *Scand. J. Med. Sci. Sports* 1997;7:206-213.
14. Fitzsimons M., Dawson B., Ward D., Wilkinson A. Cycling and running tests of repeated sprint ability. *Aust. J. Sci. Med. Sport.* 1993;25:82-82.
15. Gabbett T.J., Mulvey M.J. Time-motion analysis of small-sided training games and competition in elite women soccer players. *J. Strength Cond. Res.* 2008;22:543-552.
16. Gaitanos G.C., Williams C., Boobis L.H., Brooks S. Human muscle metabolism during intermittent maximal exercise. *J. Appl. Physiol.* 1993;75:712-719.
17. Glaister M. Multiple sprint work. *Sports med.* 2005;35:757-777.
18. Glaister M., Witmer C., Clarke D.W., Guers J.J., Heller J.L., Moir G.L. Familiarization, reliability, and evaluation of a multiple sprint running test using self-selected recovery periods. *J. Strength Cond. Res.* 2010;24:3296-3301.
19. Haj-Sassi R., Dardouri W., Gharbi Z., Chaouachi A., Mansour H., Rabhi A., Mahfoudhi M.E. Reliability and validity of a new repeated agility test as a measure of anaerobic and explosive power. *J. Strength Cond. Res.* 2011;25:472-480.
20. Hirvonen J., Rehunen S., Rusko H., Harkonen M. Breakdown of high-energy phosphate compounds and lactate accumulation during short supramaximal exercise. *Eur. J. Appl. Physiol. Occup. Physiol.* 1987;56:253-259.
21. McGawley K., Bishop D. Reliability of a 5 x 6-s maximal cycling repeated-sprint test in trained female team-sport athletes. *Eur. J. Appl. Physiol.* 2006;98:383-393.
22. Meckel Y., Machnai O., Eliakim A. Relationship among repeated sprint tests, aerobic fitness, and anaerobic fitness in elite adolescent soccer players. *J. Strength Cond. Res.* 2009;23:163-169.
23. Rampinini E., Bishop D., Marcora S.M., Ferrari Bravo D., Sassi R., Impellizzeri F.M. Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. *Int. J. Sports Med.* 2007;28:228-235.
24. Serpiello F.R., McKenna M.J., Stepto N.K., Bishop D.J., Aughey R.J.

- Performance and physiological responses to repeated-sprint exercise: a novel multiple-set approach. *Eur. J. Appl. Physiol.* 2011;111:669-678.
25. Spencer M., Bishop D., Dawson B., Goodman C. Physiological and metabolic responses of repeated-sprint activities: specific to field-based team sports. *Sports med.* 2005;35:1025-1044.
26. Spencer M., Fitzsimons M., Dawson B., Bishop D., Goodman C. Reliability of a repeated-sprint test for field-hockey. *J. Sci. Med. Sport.* 2006;9:181-184.
27. Stolen T., Chamari K., Castagna C., Wisloff U. Physiology of soccer: an update. *Sports Med.* 2005;35:501-536.
28. Taoutaou Z., Granier P., Mercier B., Mercier J., Ahmaidi S., Prefaut C. Lactate kinetics during passive and partially active recovery in endurance and sprint athletes. *Eur. J. Appl. Physiol. Occup. Physiol.* 1996;73:465-470.
29. Westerblad H., Allen D.G., Lannergren J. Muscle fatigue: lactic acid or inorganic phosphate the major cause? *News Physiol. Sci.* 2002;17:17-21.
30. Wragg C.B., Maxwell N.S., Doust J.H. Evaluation of the reliability and validity of a soccer-specific field test of repeated sprint ability. *Eur. J. Appl. Physiol.* 2000;83: 77-83.

