Apunts Med Esport. 2013;**48(178)**:43–48

apunts

MEDICINA DE L'ESPORT

www.apunts/org

ORIGINAL ARTICLE

Physiological and neuromuscular responses in the shuttle and straight line-repeated sprint running

Juliano Dal Pupo[a,*], **Daniele Detanico**[a], **Lorival J. Carminatti**[a,b], **Saray G. Santos**[a]

[a] *Biomechanics Laboratory, Sports Center, Federal University of Santa Catarina, Florianópolis, Brazil*
[b] *Human Performance Research Laboratory, State University of Santa Catarina – SC, Florianópolis, Brazil*

Received 16 August 2012; accepted 27 November 2012
Available online 28 January 2013

KEYWORDS
Repeated sprint ability;
Team sports;
Muscle power;
Blood lactate

Abstract
Introduction: The aim of the present study was to compare and analyze the performance in the shuttle (RSS) and straight line (RSL) repeated sprint running and to compare the physiological and neuromuscular responses obtained post-RSL and post-RSS.
Material and methods: Fourteen male futsal players performed 25 m sprints in a straight line and with a change of direction. The sprint performances (mean time, best time and fatigue index), countermovement jump (CMJ) performance were evaluated before and after both tests, as well as measuring blood lactate concentrations (LAC_{PEAK}) after the sprints.
Results: The mean time (MT) and best time (BT) were lower in the RSL ($P < 0.01$), while the fatigue index was lower in the RSS ($P = 0.02$). Significant correlations were found between MT_{RSL} and MT_{RSS} ($r = 0.79$), as well as between BT_{RSL} and BT_{RSS} ($r = 0.69$). Significant differences in CMJ performance were recorded between baseline and post-RSL ($P = 0.01$), as well as between baseline and post-RSS ($P = 0.02$). No significant differences were found between CMJ performance ($P = 0.08$) and LAC_{PEAK} ($P = 0.09$) and post-RSL and post-RSS.
Conclusions: It was concluded that, despite the differences in BT and MT in the two models of repeated sprints, the MT in both tests correlated well, suggesting that repeated sprint ability is a general quality and independent of changing direction. Moreover, both the glycolytic and neuromuscular demand did not differ between the two sprints models.

PALABRAS CLAVE
Capacidad de esprines repetidos;
Equipo deportivo;
Fuerza muscular;
Lactato en sangre

Respuestas fisiológicas y neuromusculares en esprines repetidos con cambio de dirección y en línea recta

Resumen
Introducción: El objetivo de este estudio fue comparar y relacionar el rendimiento en sprint repetidos con cambio de dirección (ER_{CD}) y en línea recta (ER_{LR}), y comparar las respuestas fisiológicas y neuromusculares obtenidas post-ER_{CD} y post-ER_{LR}.

* Corresponding author.
E-mail address: dalpupo@gmail.com (J. Dal Pupo).

1886-6581/$ - see front matter
http://dx.doi.org/10.1016/j.apunts.2012.11.001

Material y métodos: Formaron parte del estudio 14 jugadores de fútbol sala que realizaron sprint (25 m) con cambio de dirección y en línea recta. Se evaluó el rendimiento en los sprint (tiempo medio, mejor tiempo e índice de fatiga) y el *countermovement jump* (CMJ) antes y después de las 2 pruebas, además de las concentraciones de lactato en sangre (LAC_{PEAK}) después de los sprint.

Resultados: El tiempo medio (TM) y mejor tiempo (MT) fueron más bajos en los ER_{LR} ($p < 0{,}01$), mientras que el índice de fatiga fue más bajo en los ER_{CD} ($p = 0{,}02$). Se observaron correlaciones entre TM_{LR} y TM_{CD} ($r = 0{,}79$), así como entre MT_{LR} y MT_{CD} ($r = 0{,}69$). Se encontraron diferencias en el rendimiento del CMJ entre los valores basales y post-ER_{LR} ($p = 0{,}01$), así como con el post-ER_{CD} ($p = 0.02$). No hubo diferencias entre el rendimiento del CMJ ($p = 0{,}08$) y LAC_{PEAK} ($p = 0{,}09$) entre post-ER_{LR} y post-ER_{CD}.

Conclusiones: A pesar de las diferencias entre MT y TM en las 2 pruebas de sprint repetidos, el TM presentó gran correlación, sugiriendo que la capacidad de sprint repetidos es una calidad general y no depende de los cambios de dirección. Además, tanto la demanda glucolítica como la neuromuscular no fueron diferentes entre las 2 pruebas de sprint.

Introduction

Futsal is an intermittent and acyclic sport, in which several types of actions demanding the contribution of the different energy systems are performed.[1–3] Considering the total time of effort, the predominant metabolism during a futsal game is the aerobic, however, in the decisive actions that is needed perform short and intense efforts, the anaerobic metabolism is the main source to the energy supply.[1,4]

Time-motion analysis of team sports has revealed that decisive moments in a match are often preceded by short, high-intensity sprints in the range of 10–30 m or 2–4 s.[4] Besides, a recent study has showed that professional futsal players during actual match spent 5–12% of game-time sprinting and performing high-intensity running (speed >15 km h^{-1}).[1] The ability to repeat these sprints of high-intensity and short duration following short recovery periods has been called repeated sprint ability (RSA),[5] and has been considered as one of the main components of physical fitness in team sports.[4–6]

In order to evaluate the physiological demand in the RSA, several tests have been proposed. In futsal it is possible find tests ranging sprint distance, number of repetitions, duration of the interval between sprints and characteristic of recovery (active or passive). In addition, the ability to change direction has also been considered as an important prerequisite for performance in team sports.[7–8] In this sense, changes of direction have been introduced in some RSA tests and during repeated sprint training sessions.[9–12]

Despite presenting more specificity about the actions of the game, the RSA tests with directional changes have been questioned due to the high neuromuscular demand imposed,[10] which could be a limiting factor or conflict in order to evaluate anaerobic fitness. As mentioned by Brughelli et al.[7] and Young et al.,[13] since each change of direction requires a braking force followed by a propulsive force, muscle power levels may determine the performance test. In addition, data obtained in field tests suggest that when changes of direction are introduced, lactate concentrations seem to increase after exercise, indicating an increase in the glycolytic metabolism.[14] That is why some researchers have questioned that straight line running speed and change of direction ability may represent distinct physical qualities.[7,10,15]

Although there are several models of validated RSA tests, there are no conclusive evidences that indicate whether there are differences in metabolic and mainly in neuromuscular responses in the RS models performed in straight line and with directional changes in futsal. Moreover, it is important to highlight if responses in isolated sprints also are applied to RSA. Based on these assumptions, the objectives of this study were: (i) to compare and relate the performance in the shuttle (RSS) and straight line (RSL) repeated sprint running; and (ii) to compare the physiological responses (blood lactate concentration) and neuromuscular (lower limbs muscle power) obtained post-RSS and post-RSL.

Material and methods

Design

This study was classified as descriptive since it was analyzed the physiological and neuromuscular responses in the shuttle RSA test and compared with the traditional straight line RSA test. Besides, this study tried to verify if straight line and shuttle running may represent similar or distinct physical qualities correlating variables of performance (best time and mean time) between RSA tests.

Participants

Fourteen male futsal players at regional level of the category U17 (height: 1.70 ± 0.06 m; body mass: 63.34 ± 7.73 kg) from a Florianopolis-Brazil team took part in this study. This sample size, with α error probability equal to 0.05 and given an effect-size, presented a mean power of 0.98 for correlation analysis and 0.84 for comparative analysis.

Subjects have been involved in regular futsal training sessions (physical + technical/tactical training) four days a week. Subjects selection was intentional non-probabilistic, considering the following criteria: they must not have any kind of muscle–skeletal disorders or any injury; present a medical certificate ensuring that they are in good health and able to participate in the test. Written informed consent was received from all participants and legal guardians of underage players after a brief but detailed explanation about the aims, benefits, and risks involved with this investigation. All procedures were approved by the ethics committee of local University in accordance with the Helsinki declaration. Participants were told that they would be free to withdraw from the study at any time.

Procedures

On two distinct occasions (separated 48 h) participants performed, in a randomized order, two tests of six repeated maximal 25 m sprints, performed in straight line or with change of direction (180°). Lower limbs muscle power through countermovement jump (CMJ) performance was evaluated, before and after both repeated sprints (RS) tests, besides measurements of blood lactate concentrations after RS. Before the experiments, the subjects were familiarized with the testing procedures and performed a warm up, that consisted in 5 min of low intensity running (jogging), followed by 5 progressive sprints (~25 m). All tests were performed in a futsal court where ambient temperature ranged from 24 to 26 °C. Athletes were assessed during the regular competitive season and they were instructed to refrain from any high intensity training during the data collection period.

Repeated sprint ability assessment

The athletes performed the RSA protocol as described by Buchheit et al.,[10] which consisted in two sets of six repeated maximal 25 m sprints: (i) repeated straight line-sprint (RSL – 6 m × 25 m); (ii) repeated shuttle-sprint (RSS – 6 × [2 × 12.5 m]), changing 180° the direction. Among each sprint there was 10 s of active recovery and five seconds prior to the beginning of each sprint, subjects were asked to be ready and await the start signal. Participants were instructed to complete all sprints as fast as possible, and strong verbal encouragement was provided to each subject during all sprints. The sequence of tests (1st day × 2nd day) was randomized.

Two electronic photocells (Speed Test 4.0 – CEFISE, Brazil) were used for time record in the sprints, placed 25 m each other in the RSL and 12.5 m in the RSS. The following variables were obtained from RSA tests: best time (BT), mean time (MT) and fatigue index (FI), calculated according the equation: $FI = [(\Sigma \times /6 \times BT) - 1] \times 100$.[16]

Lower limbs muscle power assessment

To measure the lower limbs muscle power, athletes performed three CMJ on a piezoelectric force platform (QUATTRO JUMP, model 9290AD, Winterthur, Switzerland), operating at a frequency of 500 Hz. From the ground reaction vertical force measured by the platform it was possible to obtain the jump height (considered as the best indicator of lower limbs muscle power),[17] by double integration method. The average height of the three jumps was selected for using in the analyses. In order to verify the effect of repeated sprints in the muscle power levels, the CMJ was performed in three moments: in the first day, baseline measures before a randomly selected test (RSL or RSS) and 1 min after the selected sprint test; in the second day 1 min after the sprint test (RSL or RSS).

Blood lactate concentrations measurements

To estimate the glycolytic pathway contribution in the repeated sprint ability tests (RSL and RSS), a sample of 25 μl of blood was collected from the earlobe, using a heparinized capillary tube in the 3rd, 5th, 7th, 9th and 11th min of recovery for blood lactate measurements. Blood samples were stored in 1.0 ml sealed polyethylene tubes with 50 μl solution (sodium fluoride, 1%), and were analyzed afterwards using an electrochemical analyzer YSI 2700 model Stat Select (YSY Incorporate, Yellow Springs, USA). The equipment was calibrated before each measurement according to the manufacturer's instructions. The highest blood lactate concentration (LAC_{PEAK}) during the recovery period was analyzed.

Statistical analysis

The distribution of each variable was examined with the Shapiro–Wilk normality test; the homogeneity of variance was verified by Levene test. Descriptive data were presented as means and standard deviation. Analysis of variance of repeated measures and Bonferroni post hoc were used to compare lower limbs muscle power among baseline, post-RSL and post-RSS. In addition, a paired *t*-test was used to compare LAC_{PEAK} between post-RSL and post-RSS. Pearson's linear correlation was used to determine the individual relationship between the performance variables (mean time and best time) in RSL and RSS. The following criterion was adopted for interpreting the magnitude of correlation: <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.[18] The level of significance adopted was set at $p < 0.05$.

Results

The performance variables in the RSL and RSS are presented in Table 1. The athletes presented lower mean time (MT) and best time (BT) in the RSL, however the fatigue index was lower in the RSS.

Figs. 1 and 2 show the correlations of the MT and BT, respectively, between two models of RS. Significant correlations between MT_{RSL} and MT_{RSS} ($r = 0.79$; $p < 0.01$), as well as

Table 1 Variables of performance (mean time, best time, fatigue index) recorded in the repeated straight line-sprint (RSL) and repeated shuttle-sprint (RSS) ability tests.

	RSL	RSS	*p*
Mean time (s)	3.98 ± 0.20	5.34 ± 0.23	<0.01
Best time (s)	3.80 ± 0.18	5.17 ± 0.23	<0.01
Fatigue index (%)	4.67 ± 1.95	3.24 ± 1.38	0.02

RSL, repeated straight-line sprints; RSS, repeated shuttle-sprint.

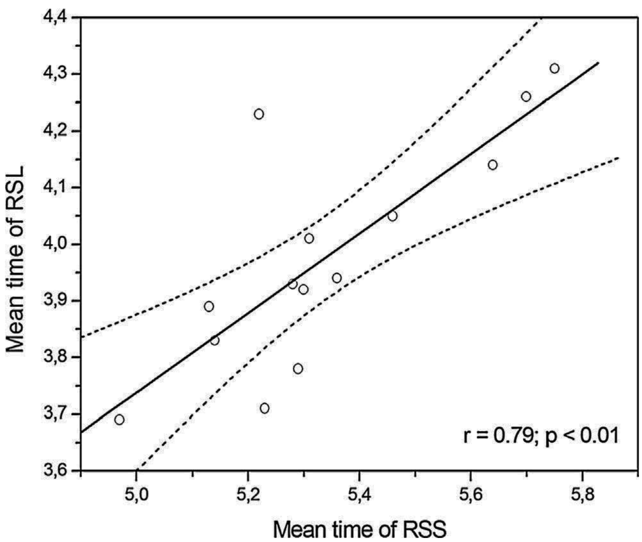

Figure 1 Relationship between mean sprint times recorded during the repeated straight line-sprint (RSL) and repeated shuttle-sprint (RSS) ability tests.

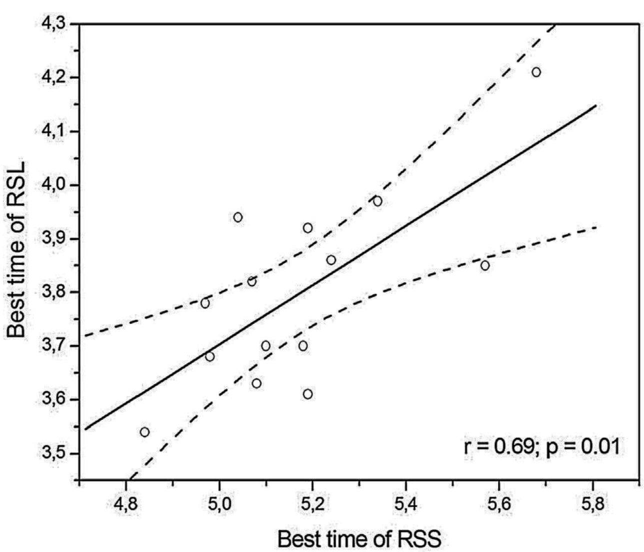

Figure 2 Relationship between best sprint times recorded during the repeated straight line-sprint (RSL) and repeated shuttle-sprint (RSS) ability tests.

between BT_{RSL} and BT_{RSS} ($r = 0.69$; $p = 0.01$) were found. The magnitude of first correlation was classified as ''very large'' and the second correlation was ''large''.

In Table 2 is presented the comparison of the CMJ performance in three moments: baseline, 1 min post-RSL and 1 min post-RSS. Significant differences between baseline and post-RSL ($p = 0.01$) as well as between baseline and post-RSS ($p = 0.02$) were observed. No significant difference of the CMJ performance between post-RSL and post-RSS ($p = 0.08$) was found. Post-exercise blood lactate concentrations also are presented in Table 2. No significant differences ($p = 0.09$) in the LAC_{PEAK} during the recovery period after RSL and RSS were found.

Discussion

We investigated in the present study the differences in performance, neuromuscular and metabolic responses in the SR tests performed in straight line and with change of direction 180° in futsal players. As expected, the mean time and best time were higher in RS with change of direction. This higher time (25.46% for MT and 26.49% for BT) was similar to found by Buchheit et al.[10] and is related to deceleration, braking and reacceleration performed during changing direction sprints.[7,13,15]

The correlation analysis between the performance variables of RS aimed to verify if the BT and MT in the RSL would be valid for evaluating these same variables in the RSS, or vice versa. Regarding to the MT, considered an indicator of anaerobic capacity, the correlation ''very large'' between the two RS models suggests that this physical quality seems to be evaluated similarly in both RS tests, regardless of the direction change. Correlations above 0.71 (i.e. $r^2 > 0.5$) allow to say that MT is considered a ''general quality'' because at this level the common variance is higher than 50%. Regarding BT, the correlation between the RS tests, although significant, was of lesser magnitude (large) and lower than 0.71 (i.e. common variance < 50%), thus considered a ''specific quality''.[10] This means that athletes evaluated in the RSL often might not present similar performance (for best time) when measured in the RSS, suggesting that other components such as coordination, balance and muscle power are related to the BT in the RSS.[7,13,15] On the other hand, Glaister et al.[19] found large correlations of both MT ($r = 0.83$) and BT ($r = 0.83$) between straight line versus change of direction, which reflects great similarity in the neuromuscular and metabolic demands in both models of sprints. This question, however, requires further investigation to obtain more conclusive results.

Fatigue index was lower during the shuttle protocol, inducing $3.24 \pm 1.38\%$ increase in time compared to the $4.67 \pm 1.95\%$ obtained in RSL. Despite the lower exposure time to exercise, the greater running speed obtained in the RSL may explain the highest fatigue generated, as evidenced also in the study of Buchheit et al.[10] The performance decrement at the end of RS seems inevitable because there is a rise in fatigue. Several causes of fatigue during multiple sprint work have been suggested, including a lack of available phosphocreatine[20–21] and several other mechanisms and metabolic processes that can affect central nervous system and muscles.[22] It is known that accumulation of metabolic byproducts from the glycolytic pathway as blood lactate might reduce the skeletal muscle contractile capacity and power generation ability,[23] affecting performance. In this sense, Gaitanos et al.[24] affirmed that LAC_{PEAK} would be positively associated with FI, therefore, could be expected highest LAC_{PEAK} values at the end of the RSL, in which occurred the highest FI. However, further studies will be necessary to elucidate the relationship between fatigue and lactate production.

Glycolytic metabolic response in RS was estimated in the present study by blood lactate concentration measured post exercise, a technique commonly used for this purpose.[25] The values obtained in the RSS ($12.23 \pm 3.32\,mmol\,L^{-1}$) did not differ from RSL ($11.15 \pm 2.4\,mmol\,L^{-1}$). These results were similar to those found by Buchheit et al.[10] in the

Table 2 Comparison of the CMJ and blood lactate peak among the baseline and post repeated straight line-sprint (RSL) and repeated shuttle-sprint (RSS) ability tests.

	Baseline	Post-RSL	Post-RSS
CMJ (cm)	43.52 ± 1.48[a]	41.68 ± 1.25[b]	40.37 ± 1.28[b]
LAC_{PEAK} (mmol L^{-1})	–	11.15 ± 2.4[a]	12.23 ± 3.32[a]

RSL, repeated straight-line sprints; RSS, repeated shuttle-sprint.
Different letters show significant differences (comparison within lines).

same RS models, showing that the change of direction does not increase the glycolytic participation during the test. On the other hand, Dellal et al.[26] found higher blood lactate concentrations after sprints with change of direction of 180° compared to straight line sprints, suggesting a greater metabolic demand in the first model. According to the authors, this aspect may be explained due the additional muscle actions recruitment in the change of direction during sprints. However, a limitation of the study of Dellal et al.[26] was that blood collection was performed only in the 3rd min post exercise, which may not coincide with lactate peak during the recovery period. In our study, lactate peak occurred, in average, in the 7th minute of recovery, both post RSL and RSS.

In order to assess the neuromuscular response in the shuttle and straight line-repeated sprint running, we compared the CMJ performance in two situations: (i) baseline vs. post RS; (ii) post RSL vs. post RSS. The athletes presented as acute effect of intermittent exercise a reduction in CMJ performance after both RS models compared to baseline. This decrement in muscle power can be considered a sign of fatigue. It has been related to several factors that causes damage in the contractile mechanism of musculoskeletal fibers[21,22] and consequently in muscle power production.

In a similar study[27] CMJ performance was analyzed before and after a repeated straight-line sprint running protocol in professional soccer players. Unlike to the results obtained in the present study, muscle power was not reduced after the repeated sprints. The authors reported that this maintenance was possible probably due to tolerance to fatigue and buffering capacity of the metabolic acidosis, caused by imbalance between production and consumption of H^+ ions resulting from the exercise.[28] The efficiency of this mechanism is considered an important attribute for RSA.[6] However, this mechanism may not be well developed in young athletes of this study because they are still in a development period of some physical qualities as anaerobic capacity, which may explain our results.

According to the results of the present study, there was no difference in CMJ performance obtained 1 min post-RSL and RSS, showing that the acute effects (muscle power decrement) from the change of direction did not differ from the straight-line traditional model. As mentioned by Brughelli et al.,[7] since each change of direction requires a braking force followed by a propulsive force (deceleration and acceleration), there will be an increase in exercise intensity in RSS, resulting in metabolic and neuromuscular demands higher than that of the RSL. Based on this aspects could be hypothesized that in the present study the CMJ performance could suffer greater decrements after the RSS. On the other hand, in the straight line running, due to biomechanical aspects such as higher stride length and better use of the stretch-shortening cycle,[29] are developed higher running speed, requiring high muscle actions too.

Further studies are needed to monitor the electromyographic activity in order to analyze muscle recruitment during repeated sprints for more conclusive results about neuromuscular aspects.

Conclusions

We conclude that despite of differences in performance variables (best time and mean time) in the two models of repeated sprints (with or without change of direction), the mean time in both tests are largely correlated, suggesting that the repeated sprint ability is a general quality and independent of change of direction. Moreover, from our results it is possible conclude that glycolytic and neuromuscular demand did not differ between the two models of sprints performed by futsal players.

These information can aid futsal coaches in the design of intermittent training exercise programs that induce different training responses using classical (straight line) or a specific form (shuttle) of intermittent exercise.

Acknowledgements

The authors wish to acknowledge all the athletes of the FUCAS for their collaboration and the Biomechanics Laboratory group (LABIOMEC-UFSC) and Physical Effort Laboratory group (LAEF-UFSC) for their support.

The results of the present study do not constitute endorsement of the product by the authors or the journal.

References

1. Barbero-Alvarez JC, Soto VM, Barbero-Alvarez V, Granda-Vera J. Match analysis and heart rate of Futsal players during competition. J Sports Sci. 2008;26:63–73.
2. Castagna C, D'Ottavio S, Vera JG, Alvarez JC. Match demands of professional Futsal: a case study. J Sci Med Sport. 2009;12:490–4.
3. Rebelo AN, Oliveira J. Association between speed, agility and muscular power of pro soccer players. Port J Sports Sci. 2006;6:342–8.
4. Spencer M, Bishop D, Dawson B, Goodman C. Physiological and metabolic responses of repeated-sprint activities: specific to field-based team sports. Sport Med. 2005;35:1025–44.
5. Impellizzeri FM, Rampinini E, Marcora SM. Physiological assessment of aerobic training in soccer. J Sports Sci. 2005;23:583–92.

6. Bishop D, Edge J, Goodman C. Muscle buffer capacity and aerobic fitness are associated with repeated-sprint ability in women. Eur J Appl Physiol. 2004;92:540–7.
7. Brughelli M, Cronin J, Levin G, Chaouachi A. Understanding change of direction ability in sport: a review of resistance training studies. Sports Med. 2008;38:1045–63.
8. Castagna C, Barbero-Alvarez JC. Physiological demands of an intermittent futsal-oriented high-intensity test. J Strength Cond Res. 2010;24:2322–9.
9. Bravo DF, Impellizzeri FM, Rampinini E, Castagna C, Bishop D, Wisloff U. Sprint vs. interval training in football. Int J Sports Med. 2008;29:668–74.
10. Buchheit M, Bishop D, Haydar B, Nakamura FY, Ahmaidi S. Physiological responses to shuttle repeated-sprint running. Int J Sports Med. 2010;31:402–9.
11. Buchheit M, Mendez-Villanueva A, Delhomel G, Brughelli M, Ahmaidi S. Improving repeated sprint ability in young elite soccer players: repeated shuttle sprints vs. explosive strength training. J Strength Cond Res. 2010;24:2715–22.
12. Impellizzeri FM, Rampinini E, Castagna C, Bishop D, Bravo D, Tibaudi A, et al. Validity of a repeated-sprint test for football. Int J Sports Med. 2008;29:899–905.
13. Young WB, James R, Montgomery L. Is muscle power related to running speed with changes of direction? J Sports Med Phys Fitness. 2002;43:282–8.
14. Ahmaidi S, Collomp K, Prefaut C. The effect of shuttle test protocol and the resulting lactacidaemia on maximal velocity and maximal oxygen uptake during the shuttle exercise test. Eur J Appl Physiol. 1992;65:475–9.
15. Chaouachi A, Vincenzo M, Chaalali A, Wong DP, Chamari C, Castagna C. Determinants analysis of change of direction ability in elite soccer players. J Strength Cond Res. 2012 [ahead of print].
16. Fitzsimmons M, Dawson B, Ward D, Wilkinson A. Cycling and running tests of repeated sprint ability. Aust J Sci Med Sport. 1993;25:82–7.
17. Knudson DV. Correcting the use of the term ''power'' in the strength and conditioning literature. J Strength Cond Res. 2009;23:1902–8.
18. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009;41:3–13.
19. Glaister M, Hauck H, Abraham CS, Merry KL, Beaver D, Woods B, et al. Familiarization, reliability, and comparability of a 40-m maximal shuttle run test. J Sports Sci Med. 2009;8:77–82.
20. Bogdanis GC, Nevill ME, Boobis IH. Contribution of phosphocreatine and aerobic metabolism to energy supply during repeated sprint exercise. J Appl Physiol. 1996;80:876–84.
21. Glaister M. Multiple sprint work: physiological responses, mechanisms of fatigue and the influence of aerobic fitness. Sports Med. 2005;35:757–77.
22. Leppik JA, Aughey RJ, Medved I, Fairweather I, Carey MF, McKenna MJ. Prolonged exercise to fatigue in humans impairs skeletal muscle Na^+ K^+ ATPase activity, sarcoplasmic reticulum Ca^{2+} release, and Ca^{2+} uptake. J Appl Physiol. 2004;97: 1414–23.
23. Fitts RH. Cellular mechanisms of fatigue muscle. Physiol Rev. 1994;74:49–94.
24. Gaitanos GC, Williams C, Boobis LH, Brooks S. Human muscle metabolism during intermittent maximal exercise. J Appl Physiol. 1993;75:712–9.
25. Di Prampero PE, Ferretti G. The energetics of anaerobic muscle metabolism: a reappraisal of older and recent concepts. Respir Physiol. 1999;1:10–5.
26. Dellal A, Keller D, Carling C, Chaouachi A, Wong DP, Chamari K. Physiologic effects of directional changes in intermittent exercise in soccer players. J Strength Cond Res. 2010;24: 3219–26.
27. Dal Pupo J, Almeida CMP, Detanico D, Silva JF, Guglielmo LGA, Santos SG. Muscle power and repeated sprint ability in soccer players. Braz J Kinanthropom Hum Perform. 2010;12:255–61.
28. Robergs RA, Ghiasvand F, Parker D. Biochemistry of exercise-induced metabolic acidosis. Am J Physiol Regul Integr Comp Physiol. 2004;287:502–16.
29. Smirniotou A, Katsikas C, Paradisi G, Argeitaki P, Zacharogiannis E, Tziortzis S. Strength-power parameters as predictors of sprinting performance. J Sports Med Phys Fit. 2008;48: 447–54.