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ABSTRACT

The aim of this study was to examine the usefulness and reliability characteristics of a repeated sprint ability test considering 5 line sprints of 30-m interspersed with 30-s of active recovery in non-elite outfield young male soccer players. Twenty-six (age 14.9±1.2 years, height 1.72±0.12 cm, body mass 62.2±5.1 kg) players were tested 48 hours and 7 days apart for 5x30-m performance over 5 trials (T1-T5). Short- (T1-T2) and long-term reliability (T1-T3-T4-T5) were assessed with Intraclass Correlation Coefficient (ICC) and with typical error for measurement (TEM). Short- and long-term reliability ICCs and TEMs for total sprint time and best sprint performance were nearly perfect and satisfactory, respectively. Usefulness (as smallest worthwhile change and TEM ratio) resulted acceptable (i.e =1) and good (i.e >1) for total sprint time and best sprint performance, respectively. The present study revealed that the 5x30-m sprint test is a reliable field test in the short and long-term when the sum of sprint times and the best sprint performance are considered as outcome variables. Sprint performance decrements variables showed large variability across trials.

Keywords: Association football, talent detection, anaerobic fitness, team sports, intermittent high-intensity exercise.

INTRODUCTION

Soccer is an intermittent high-intensity team sport with players performing as much as 150-200 high speed bouts interspersed with activities of lower intensity or rest (2). In an average competitive soccer-match sprinting accounts for 1-11% of total match-time depending on the arbitrary speed thresholds considered for detecting sprint performance (5). Additionally, players are reported to perform 1000-1400 changes of activity at different speeds with turns and changes of directions according to match progress (32). Indeed, during a soccer match, players may sprint with change of direction to gain ball possession or better positioning (28). However, a recent study showed that line sprints led more frequently to a scored goal than other match activities performed with different speeds and exercise modes (i.e. heading, turning, change of direction, etc.) (12).

Match analysis using the arbitrary speed-thresholds method have reported sprint distances in the range of 15-20-m during a competitive match (32). However, this method does not consider the acceleration phases that lead the run into the chosen sprint speed-threshold category and may therefore, underestimate the actual sprint-bout distance covered by players during the match (21). Given this, longer than usually reported sprint-bouts should be considered, with 30-m suggested as a relevant paradigm to test line-sprint performance in soccer (6, 11, 32).

The ability to perform repeat sprint bouts with short recovery time (repeated sprint ability, RSA) was reported to be relevant for soccer performance and worth being evaluated and trained in elite soccer (6, 27, 32). Furthermore, RSA test paradigms showed to discriminate between competitive levels and age groups in youth football, and to serve as a predicting variable in talent detection, selection and development (3, 24, 30). Despite the various forms of RSA protocols proposed, the only paradigm that was tested for match sprint-fatigue considered 5 sprints of 30-m each (5x30-m) repeated after 25-s of active recovery (20). This protocol profiled temporary and cumulative fatigue during the first and second halves of a soccer match respectively, showing its validity in tracking relevant physiological phenomena of competitive soccer (20). Moreover, with the same RSA protocol, Mohr et al. (23) were able to follow-up the recovery of RSA performance during the hours following an experimental match in male professional soccer-players. Interestingly, a shorter version, using only three 30-m sprints, described the effect of muscle temperature on RSA performance in soccer players after the match interval (22). Chaouachi et al. (6) reported in professional players that 5 bouts of 30-m was the minimum sprint number to detect significant RSA performance changes when an active recovery of 25-s was considered. Additionally, this test has shown to be associated with relevant match performance in elite assistant referees during competitive matches (19).

The reliability of RSA tests is of fundamental importance in sports science as no RSA gold standard are currently available (6, 25, 27, 30, 31, 35). Detailed information about test score stability is of particular interest when dealing with young soccer players that usually train few times per week across the competitive season and RSA tests are used to track individual changes for talent detection, selection, and later development (9, 10, 17). For a comprehensive figure of data reproducibility either at individual or group level, relative and absolute reliability need to be assessed (17). In this regard, multiple research designs are deemed as ideal in evaluating the learning effect (i.e. short-term reliability) and physiological stability of RSA test variables across the time (i.e. long-term reliability) (1, 16) However, long-term reliability studies are difficult to be carried out in the training set-up, discouraging strength and conditioning coaches in implementing these time consuming evaluation procedures, forcing them to consider day-to-day designs at best (1, 16).

Test usefulness of a test was defined as the ratio between the estimation of the smallest worthwhile change (i.e. test signal) and the typical error of the measurement (i.e. test noise) (25, 26). Usefulness is ideally an "a priori" indicator of test sensitivity and together with relative reliability a proof of test feasibility as it evaluates the familiarization capacity of subjects and thus the ability to provide stable between subjects test scores across the trials (25, 26).

Despite the interest of RSA test in the form of 5x30-m with 25-30-s recovery between sprint bouts, no study has yet addressed any form of reliability of the 5x30-m test in young soccer players. Information in this regard would be of great interest for the assessment of RSA for talent detection, selection and development.

Therefore, the aim of this study was to examine various forms of reliability of the 5x30-m test in young soccer-players. Specifically, the interest was in evaluating short- and long-term relative and absolute reliability together with test usefulness of 5x30-m (4, 26). In this study, the usefulness and relative and absolute good reliability of the 5x30-m test were considered as work hypothesis.

METHODS

Experimental Approach to the Problem

In this study the considered RSA test consisted of five 30-m line-sprints performed with 30-s of recovery (5x30-m) according to the procedures developed by Chaouachi et al. (6). This recovery time was chosen as it permitted young players to comfortably reach the start line before the next sprint, though not allowing full recovery. Sprint number for the RSA test was assumed according to the suggestions provided by Chaouachi et al. (6) and preliminary testing with young soccer-players of similar characteristics to those participating in this study. In this study the RSA paradigm (i.e. 5x30-m) short- and long-term reliability were evaluated according to general procedures suggested by Impellizzeri et al. (18). The 5x30-m was tested for short- and long-term reliability with the involved players performing the 5x30-m after 48-h (i.e. short-term reliability, T2) and at one-week interval from first (T1) testing session (T3), 2-weeks (T4) and 3-weeks (T5), respectively (31). Data collection was performed over three training weeks during the competitive season.

Short-term reliability was assessed with all players having no training session during the 48-h re-test time. The aim of this procedure was to evaluate the 5x30-m performance consistency (i.e. learning effect) without the influence of possible confounding variables such as match and training fatigue (18, 23). Long-term reliability was assessed to test 5x30-m for sensitivity across the time, with measures being taken always during the first training session of each studied week, that was carried out at least 48-h after the last match (23). This testing design was considered in order to avoid, as much as possible, the effect of possible post-match cumulative fatigue on 5x30-m performance, nevertheless providing ecological validity on testing procedures according to this study aims (18, 20, 23).

During this study design testing period, no modification of the usual training schedule as per training content and match fixture was performed by coaches and fitness trainers. In order to warrant this study ecological validity, all the testing procedures took place at the beginning of the training session.

Subjects

Participants were 26 young outfield male soccer players (age 14.9±1.2 years, height 1.72±0.14 cm, body mass 62.2±5.1 kg) with at least 4 years of experience in soccer competitions and training. At the time of the study the players trained 3 times per week with a competitive match performed during the weekend. All the procedures involved in this study were carried out during the competitive season of players' regional-level federal championship (Italian Football Federation, FIGC). Written informed consent was obtained from of each of the players and parents or guardians after a detailed verbal and practical explanation of the benefits and potential risks of the testing procedures considered in this study. The players were aware that they could withdraw from the study at any requested time without any penalty. All the procedures used in this study were approved from the Institutional Internal Research Board before the commencement of this study.

Procedures

The players were familiarized with the test procedures with two training sessions performed in the week before the commencement of the study. During these sessions the players practised subjective maximum speed sprints over 30-m with full recovery and repeated sprinting over the same distance using the considered RSA protocol (6). Great emphasis was provided on players' maximal-effort production over each of the sprint considered in this study (i.e. 2x30-m sprints with full recovery for reference and 5x30-m sprints with 30-s between bouts recovery). Testing procedures took place at the same time of the day (3-5 p.m.) in order to avoid possible circadian bias (6). Before each test session the players performed a standardized warm-up consisting in 10 min self-paced jogging (score 2 of CR10 Borg scale average intensity), followed by 2-min of skipping and striding exercises over 10 and 30-m, respectively. After the standardized warm-up, the players actively rested for two minutes before starting the testing procedures. During the first testing session, 5-min before the 5x30-m test, the players performed two maximal 30-m sprints interspersed with 3-min of passive recovery to establish maximum-performance reference after the standardized warm-up. In all testing trials players had to, at least, cover the first 5x30-m sprint in a time no slower than 5% of the individual reference maximum-performance over 30-m (14). In case of failure players had to repeat the RSA 10 min later as a rule. However, no players violated the assumed test criteria for RSA in this study. In order to avoid sprint pacing, maximal effort was stressed in each of the 5x30-m bouts with strong verbal encouragements provided by coaches and peers during all the test sprints. Calculations for either short and long-term 5x30-m reliability were performed using the following outcome variables (25, 31):

- Best 5x30-m sprint (i.e. the fastest 30-m test-sprint, BS);
- Total sprint time as sum of the time in the 5 sprints (TT);
- Percentage of change from the ideal total time (ITT), calculated as the fastest sprint of the 5 repetitions multiplied by 5 (i.e. %ITT) (31);

- Percentage of change from the first to the last sprint (%First-Last).

All the test procedures were performed with wind absence and similar environmental conditions (i.e. 23-26°C temperature, 50-60% humidity). The 5x30-m performance was assessed using a telemetric photocells system (Witty System, Microgate, Bolzano, Italy). In order to avoid undue switch-on of the timing system players had to position the front foot immediately before a line set 50-cm from the first photocell beam. The photocell beam was positioned at 0.5-m height and 1.5-m apart (6). All players performed the 5x30-m test with a self-administered first sprint start and successive 30-s recovery time timed with a computerized count-down (Witty System, Microgate, Bolzano, Italy). After each sprint the players were requested to decelerate and slowly jog back to the starting line in 25-s to in order to position in time for the next sprint bout. Each player was tested singularly and over the same artificial-turf soccer pitch and wearing football boots. In order to avoid possible bias on sprint time related to starting technique all players had to maintain a split stance position standing start position throughout the test and the testing sessions.

Statistical Analyses

Results are expressed as means ± standard deviations and 95% confidence intervals (95% CI). Normality assumption was verified using the Shapiro-Wilk W-test. A one-way repeated measurements analysis of variance with post-hoc Bonferroni tests was used to compare testing occasions (T1 to T5). The Cohen's *d* was used to evaluate the effect size (7) with values above 0.8, between 0.8 and 0.5, between 0.5 and 0.2 and lower than 0.2 considered as large, moderate, small, and trivial, respectively (7). The IntraClass Correlation Coefficient ($ICC_{3,1}$) was used to assess 5x30-m relative reliability and rated according to Hopkins et al. (15, 17, 34). A paired successive-comparison design was used for ICCs (i.e. T1vT2, T1vT3, T3vT4 and T4vT5) according to Hopkins et al. (17) Absolute reliability was assessed calculating the Typical Error of Measurement (TEM), that was reported as row data and as % of coefficient of variation (%CV) according to

Hopkins et al. (17). Satisfactory reliability was assumed for variables with TEM as %CV < 5% (17). Test usefulness (signal-to-noise ratio) was assumed as smallest worthwhile change (0.2 x standard deviation, SWC) and the TEM ratio (17). The usefulness was rated as marginal, useful and good when the SWC/TEM was below, equal or higher than 1, respectively (26). Significance was set at 5% (p≤ 0.05).

RESULTS

The values of the variables considered in this study to characterize the 5x30-m performance are presented in table 1. The best sprint-time BS at T1 was significantly lower (p<0.003) from those at T3 (95%CI -0.152, -0.0384; *d*=1.36), T4 (95%CI -0.144, -0.030; *d*=1.23) and T5 (95%CI -0.132, -0.018; *d*=1.09). No between T1 and T2 significant differences were reported for BS (p=0.08, 95%CI -0.111, 0.003; *d*=0.82). Total time at T1 was significantly lower (p<0.004) than at T2 (-0.701, -0.088; *d*=1.02), T3 (-0.956, -0.344; *d*=1.56), T4 (-0.850, -0.237; *d*=1.67) and T5 (-0.827, -0.215; *d*=0.81) for TT. No significant differences were found across the trials for %IT (p>0.24, 95%CI -1.467 – 1.039; *d*=0.39–0.63) and %First-Last (p>0.07, 95%CI -0.032 – 0.100; *d*=0.24 – 0.51) variables.

The short- (i.e. T1vT2) and long-term (i.e. T1vT3, T3vT4, T4vT5) reliability ICCs were nearly perfect for BS and TT variables (Table 2). The ICC ranged from small-to-moderate for %IT and %FLS in either the reliability categories (i.e. short and long-term reliability). The %CV for the BS and TT were lower than 2% either in the short and long-term reliability conditions. Huge variability in %IT and %FLS were detected with %CV ranging from 32.4 to 78.2% across the reliability conditions. The SWC for the TT and BS were 0.32 and 0.06s, respectively. The signal-to-noise ratio for TT and BS were 1.23 and 1.00, respectively.

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DISCUSSION

This is the first study that addressed the reliability characteristics and usefulness of the 5x30-m sprint test in youth male soccer. The main finding of this research was the excellent (i.e. nearly perfect) relative and the satisfactory absolute reliability of the 5x30-m sprint test when performance outcome was expressed as TT (8). Similar reliability values were found for BS showing maintenance of within and between subjects' variability in maximal effort across the trials considered in this study. Interestingly, the usefulness of the 5x30-m resulted "good" when the TT was considered as outcome variable (26).

The ability to repeat sprint during the match has been reported of relevance in male soccer performance (27, 30, 32). Despite the consensus over the interest of RSA in soccer performance, only few RSA test paradigms were examined for reliability with a systematic approach. Impellizzeri et al. (18) reported a satisfactory absolute reliability in male professional soccer players in the short- (48-h apart) and long-term (seasonal changes) when using a 20-m shuttle run to be repeated every 20-s for six times. Indeed, short-term RSA test mean and best sprint-time showed a TEM as %CV of 0.8% and 1.3% respectively, with similar results for the long-term reliability sub-study (18). The authors reported a very large ICC for mean RSA sprint-time (0.81; CI90% 0.64–0.90) in the short-term reliability study, but a small to large inter-subject consistency in either reliability conditions (i.e. short- and long-term) for best sprint and sprint performance decrement (ICC from 0.15 to 0.63). Wragg et al. (35) using a supposed soccer relevant RSA test, consisting of seven 34.2-m sprints with change of directions and 25-s of active recovery in-between, reported a %CV of 1.8% across the 6 trials that they used to test absolute reliability (long-term reliability). Unfortunately, Wragg et al. (35) did not report any measure of relative reliability and provided results using a small simple size (n=7). With the considered 7x34.2-m test, the players showed performance stability only after 3 test sessions, suggesting practical issues for this test applicability under field conditions even in professional soccer (35). Spencer et al. (31) investigated long-term reliability (re-test 7 days apart) in 10 highly-trained male field-hockey players using 6x30-m sprint with 25-s of active recovery. The test showed very good absolute reliability for TT (i.e. TEM as %CV, 0.7%) and satisfactory usefulness (i.e. signal-to-noise ratio=1). However, also in this study the authors failed to report any relative reliability information questioning the test-retest inter-individual consistency (i.e. rank order) of test performance (17). In a longitudinal RSA development study, Valente-dos-Santos et al. (33) reported for the 7x34.2-m sprint test reliability (i.e. 7 day apart retest) coefficients of 0.86 and 0.91 for ideal time and total sprint time, respectively, in regional level young soccer players.

This study results are in line with absolute reliability reported by other authors with young soccer players using RSA testing protocols (6, 18, 33). However, the 5x30-m showed higher relative reliability supporting the fair potential of this RSA paradigm in tracking individual changes across the testing trials. Given this, 5x30-m may be considered as a valuable research tool to assess the ability to repeat sprint in young soccer players in the initial stages of their training career. This finding is of specific interest as RSA was deemed to discriminate between competitive level and chronological ages in young soccer players, suggesting consideration for RSA in developmental soccer (13, 24, 29).

The ability to repeat sprint was defined as the players' capacity of performing maximal sprints over time with incomplete active or passive recovery (i.e. ≤30s) (30). Thus, promoting the use of sprint decrement variables to describe the cumulative fatigue built-up experienced by players during repeated sprinting (25). This issue was of specific interest in young soccer with authors reporting no variation of %IT across the ages despite age-dependent changes in TT (6, 18, 24, 33). Nonetheless, the considered papers used a cross-sectional design not providing information whether the reason(s) for a stable %IT across the ages was a statistical artefact or an effect of maturation (24, 31).

Furthermore, the 6x30m test used by the cited authors was not tested for any kind of reliability in the population of interest (24, 31).

The scientific literature that studied the reliability of RSA paradigms has shown poor absolute and relative reliability of sprint decrement variables across testing trials (18, 31). The findings of the present study strongly confirmed previous investigations suggesting the use of global performance variables to track individual and group changes across the trials. Indeed, in our study the ICC for %IT and %First-Last were moderate to small with huge, and thus practically not acceptable %CV (i.e. from 32.4 to 78.2%).

Usefulness is a key issue for assessing test quality and together with short-term reliability can be used to evaluate test protocol practical interest (4, 26). In the present study, the 5x30-m has shown to possess good applicability resulting from a SWC higher than TEM and a nearly perfect association between TT at T1 and T2. These findings are in line with other studies that used RSA paradigms similar to the 5x30-m sprint test (31).

In this study, control on possible confounding variables was performed looking for standard test conditions to avoid possible effect of variations in circadian rhythms, climatic conditions, training/match cumulative strain (i.e. test performed at least 48-h from training/matches), players' equipment and venue conditions (23). Despite this, significant and practical differences in performance were detected across the trials with respect to T1. Indeed, the TT scores were lower at T1 than in T2 (large effect), T3-T5 (large effect) and for the BS difference emerged from the T3 trial (large effect). It could be speculated that this was the effect of a cumulative training and match fatigue, that may have affected 5x30-m performance progressively during the study course (23, 33). In line with this Mohr et al. (23) reported RSA performance impairment in the 2 post-match days of an experimental friendly match in male professional adult players using the 5x30-m test. Additionally, Valente-dos-Santos et al. (33) documented a cumulative effect of long-term training load on RSA in young regional-level soccer players. Unfortunately, this study design did not involve any form of training load assessment to evaluate the actual possible effect of acute/cumulative fatigue on this population of soccer players_ENREF_36. Future studies investigating on the effect of young soccer training on long-term variation of 5x30-m test are warranted.

This study reported for the first time the reliability characteristics and usefulness of a test that was reported to be convenient for tracking soccer related RSA fatigue such as 5x30-m (20, 23). The reported findings suggested that the 5x30-m even in an ecological set-up (i.e. Academy development activity) can be successful considered for tracking RSA performance in young non-elite soccer players (20, 33). In this regard, Valente-dos-Santos et al. (33) using the multilevel approach reported that RSA performance was independent from chronological age and maturation. Given that, the interest of a reliable and useful test for RSA like 5x30-m in talent detection procedures (i.e. talent identification, detection and development) in soccer seems warranted. Future studies are needed addressing further aspects of reliability (i.e. test sensitivity) and ecological validity of the 5x30-m sprint test in young soccer players.

Practical Applications

Information related to test short- and long-term reliability are of great practical interest for the strength and conditioning coach as they are an expression of test applicability (i.e. learning time) and sensitivity (i.e. stability of metric result over time), respectively. This allowing the calculation of the minimum detectable change on individual base (e.g. short-term reliability) and the estimation of the sample sizes necessary to evaluate meaningful changes (e.g. long-term reliability) in response to training interventions (18).

In this study the most accredited metrics of RSA performance such as speed decrements in the form of ratio between ideal and actual performance time, difference between fastest and slowest sprint performance and total sprint time (25, 26, 31) were tested for short- and long-term reliability.

Despite the interest of speed decrements for RSA performance the evaluation of this supposed relevant variable have shown to provide unreliable results (18, 25). The present study showed that this was the case also with young soccer players over controlled repeated testing trails using 5x30-m as RSA paradigm. Given that, the longitudinal assessment of RSA performance should be preferably undertaken using the sum of sprint times or sprints' average (31). These findings suggest that speed decrements are, at best, temporary indicators of RSA fitness level in young soccer players (31). The detected nearly perfect reproducibility of the BS notation may be used by strength and conditioning coaches operating in soccer academies to estimate the RSA ability of young soccer player across the competitive season with a single sprint bout. Indeed, in this study BS performance showed to be near-perfectly associated with TT (r= 0.96–0.99, nearly perfect) and occurring always as the first or second sprint across the testing trials. This finding may suggest the use of 30-m BS as reference of sprint abilities in young soccer players with a less demanding test protocol, therefore enabling a "non-invasive" longitudinal measurement option in club academies (13).

Given this study results, the 5x30-m test should be considered a useful and reliable test to evaluate RSA in male young soccer players. This with a very limited learning time on part of players. In light of this findings, strength and conditioning professionals may consider the 5x30-m test scores as representative of their players individual RSA performance since their first data collection.

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References

1. Atkinson, G. and A.M. Nevill. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*. 26(4):217-238. 1998.

2. Bangsbo, J., F.M. Iaia, and P. Krustrup. Metabolic response and fatigue in soccer. *Int J Sports Physiol Perform*. 2(2):111-27. 2007.

3. Bidaurrazaga-Letona, I., H.M. Carvalho, J.A. Lekue, J. Santos-Concejero, A.J. Figueiredo, and S.M. Gil. Longitudinal field test assessment in a Basque soccer youth academy: a multilevel modeling framework to partition effects of maturation. *International journal of sports medicine*. 36(3):234-40. 2015.

4. Buchheit, M., M. Spencer, and S. Ahmaidi. Reliability, usefulness, and validity of a repeated sprint and jump ability test. *Int J Sports Physiol Perform*. 5(1):3-17. 2010.

5. Carling, C., J. Bloomfield, L. Nelsen, and T. Reilly. The role of motion analysis in elite soccer: contemporary performance measurement techniques and work rate data. *Sports Med*. 38(10):839-62. 2008.

6. Chaouachi, A., V. Manzi, P. Wong del, A. Chaalali, L. Laurencelle, K. Chamari, and C. Castagna. Intermittent endurance and repeated sprint ability in soccer players. *Journal of strength and conditioning research / National Strength & Conditioning Association*. 24(10):2663-9. 2010.

7. Cohen, J. *Statistical power analysis for the behavioral sciences*. 2nd ed. ed. Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.

8. Coppieters, M., K. Stappaerts, K. Janssens, and G. Jull. Reliability of detecting 'onset of pain' and 'submaximal pain' during neural provocation testing of the upper quadrant. *Physiother Res Int*. 7(3):146-56. 2002.

9. Deprez, D., J. Fransen, M. Lenoir, R.M. Philippaerts, and R. Vaeyens. A retrospective study on anthropometrical, physical fitness and motor coordination characteristics that influence drop out, contract status and first-team playing time in high-level soccer players, aged 8 to 18 years. *Journal of strength and conditioning research / National Strength & Conditioning Association*. 2014.

10. Deprez, D., J. Valente-Dos-Santos, M.J. Silva, M. Lenoir, R. Philippaerts, and R. Vaeyens. Multilevel Development Models of Explosive Leg Power in High-Level Soccer Players. *Medicine and science in sports and exercise*. 2014.

11. Di Salvo, V., W. Gregson, G. Atkinson, P. Tordoff, and B. Drust. Analysis of high intensity activity in Premier League soccer. *International journal of sports medicine*. 30(3):205-12. 2009.

12. Faude, O., T. Koch, and T. Meyer. Straight sprinting is the most frequent action in goal situations in professional football. *J Sports Sci*. 30(7):625-31. 2012.

13. Figueiredo, A.J., M.J. Coelho e Silva, and R.M. Malina. Predictors of functional capacity and skill in youth soccer players. *Scandinavian Journal of Medicine & Science in Sports*. 21(3):446-54. 2011.

14. Girard, O., A. Mendez-Villanueva, and D. Bishop. Repeated-sprint ability - part I: factors contributing to fatigue. *Sports Med*. 41(8):673-94. 2011.

15. Hopkins, W.G. Measures of reliability in sports medicine and science. *Sports Medicine*. 30(1):1-15. 2000.

16. Hopkins, W.G., E.J. Schabort, and J.A. Hawley. Reliability of power in physical performance tests. *Sports Med.* 31(3):211-234. 2001.

17. Hopkins, W.G., S.W. Marshall, A.M. Batterham, and J. Hanin. Progressive statistics for studies in sports medicine and exercise science. *Medicine and science in sports and exercise*. 41(1):3-13. 2009.

18. Impellizzeri, F.M., E. Rampinini, C. Castagna, D. Bishop, D. Ferrari Bravo, A. Tibaudi, and U. Wisløff. Validity of a repeated-sprint test for football. *Int J Sports Med*. 29(11):899-905. 2008.

19. Krustrup, P., M. Mohr, and J. Bangsbo. Activity profile and physiological demands of top-class soccer assistant refereeing in relation to training status. *J Sports Sci*. 20:861-871. 2002.

20. Krustrup, P., M. Mohr, A. Steensberg, J. Bencke, M. Kjaer, and J. Bangsbo. Muscle and blood metabolites during a soccer game: implications for sprint performance. *Med. Sci. Sports Exerc.* 38(6):1165-1174. 2006.

21. Manzi, V., F. Impellizzeri, and C. Castagna. Aerobic fitness ecological validity in elite soccer players: a metabolic power approach. *Journal of strength and conditioning research / National Strength & Conditioning Association*. 28(4):914-9. 2014.

22. Mohr, M., P. Krustrup, L. Nybo, J. Nielsen, and J. Bangsbo. Muscle temperature and sprint performance during soccer matches – beneficial effect of re-warm-up at half-time. *Scand J Med Sci Sports*. 14:156-62. 2004.

23. Mohr, M., D. Draganidis, A. Chatzinikolaou, J.C. Barbero-Alvarez, C. Castagna, I. Douroudos, A. Avloniti, A. Margeli, I. Papassotiriou, A.D. Flouris, A.Z. Jamurtas, P. Krustrup, and I.G. Fatouros. Muscle damage, inflammatory, immune and performance responses to three football games in 1 week in competitive male players. *European journal of applied physiology*. 2015.

24. Mujika, I., M. Spencer, J. Santisteban, J.J. Goiriena, and D. Bishop. Age-related differences in repeated-sprint ability in highly trained youth football players. *Journal of Sports Sciences*. 27(14):1581-90. 2009.

25. Oliver, J.L. Is a fatigue index a worthwhile measure of repeated sprint ability? *J Sci Med Sport*. 12(1):20-3. 2009.

26. Pyne, D.B. Interpreting the results of fitness testing. In: *Gastrolyte VIS international science and football symposium*. Melbourne, Australia: Victorian Institute of Sport.2003. pp.

27. Rampinini, E., D. Bishop, S.M. Marcora, D. Ferrari Bravo, R. Sassi, and F.M. Impellizzeri. Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. *International journal of sports medicine*. 28(3):228-35. 2007.

28. Rampinini, E., F.M. Impellizzeri, C. Castagna, A.J. Coutts, and U. Wisloff. Technical performance during soccer matches of the Italian Serie A league: effect of fatigue and competitive level. *Journal of science and medicine in sport / Sports Medicine Australia*. 12(1):227-33. 2009.

29. Reilly, T., J. Bangsbo, and A. Franks. Anthropometric and physiological predispositions for elite soccer. *J Sports Sci*. 18(9):669-83. 2000.

30. SPENCER, M., D. BISHOP, B. DAWSON, and C. GOODMAN. Physiological and Metabolic Responses of Repeated-Sprint Activities Specific to Field-Based Team Sports. *Sports Med.* 35(12):1025-1044. 2005.

31. SPENCER, M., M. FITZSIMONS, B. DAWSON, D. BISHOP, and C. GOODMAN. Reliability of a repeated-sprint test for field-hockey. *Journal of science and medicine in sport / Sports Medicine Australia*. 9(1-2):181-4. 2006.

32. STØLEN, T., K. CHAMARI, C. CASTAGNA, and U. WISLØFF. Physiology of Soccer: An Update. *Sports Med.* 35(6):501-536. 2005.

33. VALENTE-DOS-SANTOS, J., E.S.M.J. COELHO, V. SEVERINO, J. DUARTE, R.S. MARTINS, A.J. FIGUEIREDO, A.T. SEABRA, R.M. PHILIPPAERTS, S.P. CUMMING, M. ELFERINK-GEMSER, and R.M. MALINA. Longitudinal study of repeated sprint performance in youth soccer players of contrasting skeletal maturity status. *Journal of sports science & medicine*. 11(3):371-9. 2012.

34. WEIR, J.P. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J. Strength Cond. Res.* 19(1):231-40. 2005.

35. WRAGG, C.B., N.S. MAXWELL, and J.H. DOUST. Evaluation of the reliability and validity of a soccer-specific field test of repeated sprint ability. *Eur J Appl Physiol*. 83(1):77-83. 2000

Legend of Tables and Figures

Table 1. Mean values of the repeated sprint ability (RSA) variables considered in this study (see methods) across the testing occasions (T1-T5).

Table 2. Relative and absolute reliability variables across repeated sprint ability (RSA) trials.

Table 1.

Variable	T1	T2	T3	T4	T5
Best Sprint (s)	4.63±0.30	4.69±0.30	4.73±0.30**	4.72±0.30**	4.71±0.30**
Total Time (s)	23.58±1.60	23.98±1.60**	24.23±1.80**	24.13±1.70**	24.10±1.60**
%Ideal Time	1.86±1.00	2.38±1.30	2.52±1.10	2.29±1.20	2.43±1.30
%First-Last	-0.19±0.10	-0.22±0.10	-0.25±0.10	-0.22±0.10	-0.23±0.10

Table 2.

Trials	**T2-1**	**T3-1**	**T4-3**	**T5-4**
ICC Best Sprint	0.97 (0.93–0.99)	0.97 (0.94–0.99)	0.98 (0.95–0.99)	0.94 (0.88–0.97)
TEM raw (s)	0.06 (0.05–0.08)	0.06 (0.05–0.08)	0.06 (0.04–0.08)	0.08 (0.07–0.11)
TEM as %CV	1.2 (0.9–1.7)	1.1 (0.9–1.7)	1.2 (0.9–1.7)	1.9 (1.4–2.8)
Change in Mean (s)	0.05 (0.02–0.09)	0.10 (0.06–0.13)	-0.01 (-0.04–0.02)	-0.01 (-0.06–0.04)
ICC Total Time	0.98 (0.95–0.99)	0.96 (0.92–0.98)	0.98 (0.95–0.99)	0.93 (0.86–0.96)
TEM raw (s)	0.26 (0.22–0.35)	0.36 (0.29–0.47)	0.29 (0.24–0.39)	0.47 (0.38–0.61)
TEM as %CV	1.2 (1.0–1.7)	1.5 (1.2–2.1)	1.4 (1.1–1.9)	1.7 (1.4–2.3)
Change in Mean (s)	0.39 (0.27–0.52)	0.65 (0.48–0.82)	-0.11 (-0.25–0.03)	-0.02 (-0.24–0.20)
ICC % Ideal Time	0.34 (0.02–0.60)	0.52 (0.23–0.72)	0.38 (0.07–0.63)	0.27 (-0.05–0.55)
TEM raw (s)	0.94 (0.76–1.22)	0.76 (0.62–0.99)	0.94 (0.77–1.24)	1.11 (0.90–1.45)
TEM as %CV	66.1 (49.6–100.4)	46.5 (35.4–68.7)	45.3 (34.5–66.8)	78.2 (58.2–120.7)
Change in Mean (s)	0.52 (0.07–0.96)	0.65 (0.29–1.01)	-0.22 (-0.67–0.22)	0.14 (-0.38–0.67)
ICC % First-Last	0.24 (-0.09–0.52)	0.30 (-0.02–0.57)	0.33 (0.01–0.59)	0.07 (-0.26–0.38)
TEM raw (s)	0.08 (0.06–0.10)	0.07 (0.06–0.09)	0.08 (0.07–0.11)	0.10 (0.08–0.13)
TEM as %CV	43.1 (32.9–63.4)	43.5 (33.2–64.0)	40.6 (31.0–59.4)	70.2 (52.6–107.3)
Change in Mean (s)	0.03 (0.00–0.07)	0.06 (0.03–0.10)	-0.03 (-0.07–0.01)	0.01 (-0.03–0.06)