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The Reliability, Validity and Sensitivity of an Novel Soccer-Specific Reactive Repeated-Sprint Test (RRST)

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Abbreviation List:

Analysis of variance (ANOVA)

Bangsbo Sprint Test (BST)

Best Time ($RRST_{best}$)

Coefficient of Variation (CV)

Effect Size (ES)

Global Positioning System (GPS)

Horizontal Dilution of Precision (HDOP)

Microelectromechanical System (MEMS)

Reactive Repeated-Sprint Test (RRST)

Repeated Sprint Ability (RSA)

Smallest Worthwhile Change (SWC)

Typical Error of Measurement (TE)

Abstract

Purpose: The aim of this study was to determine the reliability, validity and sensitivity of a Reactive Repeated-Sprint Test (RRST). *Methods:* Elite (n = 70) and sub-elite male (n = 87) and elite female players (n = 12) completed the RRST at set times during a season. Total distance timed was 30 m and the RRST performance measure was the total time (s) across 8 repetitions. Competitive match running performance was measured using GPS and high-intensity running quantified (≥19.8 $km \cdot h^{-1}$). *Results:* Test-retest coefficient of variation in elite U16 and sub-elite U19 players was 0.71 and 0.84%, respectively. Elite U18 players' RRST performances were better (P < 0.01) than elite U16, sub-elite U16, U18, U19 and elite senior female players (58.25 ± 1.34 vs 59.97 ± 1.64, 61.42 ± 2.25, 61.66 ± 1.70, 61.02 ± 2.31 and 63.88 ± 1.46 s; ES: 0.6-1.9). For elite U18 players, RRST performances for central defenders (59.84 ± 1.35 s) were lower (P < 0.05) than full backs (57.85 ± 0.77 s), but not attackers (58.17 ± 1.73 s) or central and wide midfielders (58.55 ± 1.08 and 58.58 ± 1.89 s; ES: 0.7-1.4). Elite U16 players demonstrated lower *(P* < 0.01) RRST performances during the preparation period versus the start, middle and end of season periods (61.13 ± 1.53 vs 59.51 ± 1.39, 59.25 ± 1.42 and 59.20 ± 1.57 s; ES: 1.0-1.1). Very large magnitude correlations (P < 0.01) were observed between RRST performance and high-intensity running in the most intense 5-min period of a match for both elite and sub-elite U18 players (r = -0.71 and -0.74), with the best time of the RRST also correlating with the Arrowhead agility test for elite U16 and U18 players (r = 0.84 and 0.75). *Conclusion*: The data demonstrate that the RRST is a reliable and valid test that distinguishes between performance across standard, position and seasonal period.

Introduction

Soccer is a complex sport with unpredictable movement patterns with players performing repetitive maximal, or near-maximal, multidirectional sprints of short duration (<10 s) during a match (Bradley et al. 2009; Carling 2010; Di Salvo et al. 2007). The ability to sprint repeatedly with minimal recovery is widely accepted as an important component of physical performance in soccer (Bishop et al. 2001; Chaouachi et al. 2010; Rampinini et al. 2007; Wragg et al. 2000). Recent findings using time-motion analysis indicate the high demands placed on the modern player (Barnes et al. 2014; Bush et al. 2015). This is particularly evident during intense periods of matches, as players perform twice as much high-intensity running (~ ≥15 $km \cdot h^{-1}$) when compared to the match average (Bradley et al. 2009, 2010; Mohr et al. 2003). High-intensity running also doubled to ~6% of total time during the most intense 5-min period from the match average (Di Mascio and Bradley 2013). The use of soccer-specific tests that incorporate several sprints interspersed with brief recovery periods (<60 s), rather than a single linear sprint, would be expected to mimic the physiological responses that occur in the most intense periods during match-play (Spencer et al. 2005; Wragg et al. 2000). Muscle metabolite accumulation and reductions in pH that occur during intense periods of matches are indicative of muscle acidosis and could be contributory factors to fatigue. Concomitant declines in muscle phosphocreatine, peak blood lactate concentrations reaching 10-14 $mmol \cdot L^{-1}$ and heart rates of ~95% HR_{max} clearly highlight that the aerobic and anaerobic systems are highly taxed during intense periods of match-play (Krustrup et al. 2006). Phosphocreatine utilization seems to be an important determinant of the ability to reproduce performance in subsequent sprints following intense actions and, therefore, can have a large effect on repeated-sprint ability

(RSA) during matches (Girard et al. 2011). Due to the comparative nature, assessing players' RSA is now increasingly popular in soccer and as such more research should be devoted to this topic (Psotta et al. 2005; Reilly et al, 2000; Spencer et al. 2005; Svensson and Drust 2005).

Given the importance of RSA for players during matches, it would seem vital that valid, reliable and sensitive tests are developed in order to monitor training interventions and changes in physical capacity (Bishop et al. 2001; Rampinini et al. 2007). However, despite there being several RSA tests (Fitzsimmons et al. 1993; Gabbett 2010; Impellizzeri et al. 2008; Wragg et al. 2000), very few have been assessed for reliability and validity in relation to soccer. Rampinini et al. (2007) reported moderate correlations for the mean time of a RSA test (6 x 40 m, 20 s passive recovery) as an indicator of match-related physical performance, suggesting that it would be useful for the physical assessment of soccer players. It would appear that the most intense period during a match could be the only time that players tax their physical capacities (Di Mascio and Bradley, 2013) and this should, therefore, be of importance when considering RSA test protocols. Average distances, recovery periods and movement patterns gained from match-play should also be included to assess players' RSA (Bloomfield et al. 2007; Mohr et al. 2003). Although various RSA tests have been developed (Baker et al. 1993; Balsom 1994; Bangsbo 1994; Gabbett 2010; Mujika et al. 2000; Wadley and Le Rossignol 1998), the validity of most current tests is based on logical validity and these often assume that they can measure match-related physical performance (Impellizzeri et al. 2005; Wragg et al. 2000), and have also failed to take into account the most extreme match-specific demands, including the reactive element in soccer (Psotta et al. 2005). Moreover, to the authors' knowledge, only one test has been modified to include a random direction change that would closer simulate match-play (Wragg et al. 2000). Limited research exists that has quantified the construct validity of RSA tests (Impellizzeri et al. 2008; Rampinini et al. 2007) particularly relating RSA to intensified periods of match-play. Rampinini et al. (2007) demonstrated that large magnitude correlations exist between high-intensity running and sprinting and the mean performance of a RSA test (6 x 40 m with 20 s passive recovery), highlighting the comparison between RSA and intense periods during the match. Tests for RSA have also been found to discriminate between performance levels, highlighting differences between elite vs sub-elite (Reilly et al. 2000) and elite vs amateur players (Sampaio and Macas 2003). For a test to be applicable, it must also be reliable. This is important for coaches and sport scientists that want to detect changes due to training interventions or following a period of inactivity. Wragg et al. (2000) found that the coefficient of variation (CV) for the Bangsbo Sprint Test (BST) was 1.8%, suggesting that it was highly reliable. However, the BST was created in 1994, and modified in 2000, and was developed using distances that were subjective and not based on time-motion analysis. Modern semi-automated tracking devices, with high resolutions (10-25 Hz), can now provide accurate measurements to develop improved RSA tests.

Although RSA tests do exist, none have included data gained from the most intense period of a match, where overload seems apparent (Krustrup et al. 2006). Therefore, the aims of this study were to (1) determine the reliability of the Reactive Repeated-Sprint Test (RRST) developed using variables from the most intense period of a match using semi-automated tracking devices, (2) assess the relationship between the RRST and running performance during a full match and the most intense period, (3) assess the relationship between the RRST and other testing modalities, and (4) quantify the sensitivity of the RRST to detect seasonal changes and discriminate between standard and position across elite and sub-elite soccer populations.

Methods

Subjects

A total of 169 soccer players participated in the study. The sample of players consisted of elite English Premier League U18's (*n* = 28), English League One U18's (*n* = 15) and English Premier League U16's (*n* = 27), sub-elite seniors (*n* = 12), U19's (*n* = 14), U18's (*n* = 37) and U16's (*n* = 24), and elite female seniors (*n* = 12). See Table 1 for physical characteristics and Table 2 for the number of players contained in each subsection of the study. Written consent was obtained from the players, parents/guardians or the football club. The study was approved by the appropriate institutional ethical committees.

Reactive Repeated-Sprint Test (RRST)

The RRST configuration was based on the most intense 5-min period in elite soccer matches (Di Mascio and Bradley, 2013). Eight high-intensity bouts were performed per 5-min and ~30 s recovery was needed between bouts. The test lasts for a total of ~5 min and consists of 8 maximal efforts interspersed with 30 s of active recovery. Each sprint was initiated by a green LED and from an individually chosen standing position. Upon initiation of each run, players passed through a timing gate (Fusion Sport Smartspeed™, Queensland, Australia) placed 0.7 m above the ground and 4 m from the starting position, which started a digital timer. The acceleration phase before the timing started was based on the acceleration of 3.8 $m \cdot s^{-2}$ and the distance it took to reach 19.8 $km \cdot h^{-1}$ (Bradley et al. 2010). Additional timing gates were placed at 1.5 m, which triggered the right or left turn, and at the end of the sprint, both on the right and left side (Fig. 1). Each sprint was 6 m and the right or left turn was dictated by the random signal. The turns during the test were based on those found by Bloomfield et al. (2007), where the most frequent at high-intensity were directly forward, forward diagonal and arc forward; these were included in this order. Total distance timed was 30 m and performance was measured as the total time (s) for RSA (Gabbet 2010; Impellizzeri et al. 2008; Oliver 2009) and best time (s; $RRST_{best}$). A limitation of using distances covered in various speed categories to determine the physical demands of the RRST, is they fail to account for demanding activities such as accelerations/decelerations and multi-directional movements, thus these were quantified using a global positioning system (GPS).

Physiological response of RRST

Heart rate was quantified in 5-s intervals using radio telemetry (Polar Team System, Oy, Kempele, Finland) from a monitor placed around the chest for continuous recordings throughout the RRST. HR_{max} was determined by performing the YYIR1. Capillary blood samples were obtained from a finger and analysed immediately for lactate concentration using an automated analyser (Lactate Pro, Arkray, Kyoto, Japan). The blood samples were collected before, immediately after the RRST and 5-min post. This analyser was cleaned, calibrated and operated in accordance with the manufacturer's instructions.

Arrowhead agility test

Some players also completed the Arrowhead agility test course, which consisted of two trials; one right and one left. Cones are placed in an arrowhead shape, and one set of cones to indicate the start and finish line. The best time (s) to complete the test for the right and left trials are recorded. All testing sessions were performed on artificial surface, marked out with training poles and cones. The Arrowhead test was used to determine relationships with agility.

Test-retest of RRST and Arrowhead agility test performances

Elite U16 (*n* = 29) and sub-elite (*n* = 15) carried out the RRST on two separate occasions interspersed by 7 days. Moreover, elite U18 players (*n* = 10) also performed the arrowhead test twice to quantify its reproducibility. All testing sessions were conducted at the same time of day on the same surface.

Match running performance

Activity profiles of English Premier League U18 (*n* = 17), English Football League U18 (*n* = 15) and sub-elite U18 (*n* = 16) players were quantified during competitive matches via microelectromechanical system (MEMS) devices (minimaxX V4.0, Catapult Innovations, Scoresby, VIC, Australia). MEMS devices contain a GPS processor with a sample frequency of 10 Hz, were harnessed between the shoulder blades and anchored using an undergarment to restrict movement artefact. Only files from players who completed the full match were included and taken at similar periods of the season as testing occurred (2-5 matches, median = 4, within 2 weeks). Total distance represented the overall distance covered during the match. High-intensity running consisted of any speed ≥19.8 $km \cdot h^{-1}$ (Carling et al. 2012; Di Mascio and Bradley 2013). The most intense period of the match was classified as the predefined 5-min period that contained the most high-intensity running in a match (Di Mascio and Bradley 2013; Varley et al. 2012a). Validity and reliability of the GPS system has been reported elsewhere for acceleration, deceleration and constant motion (Varley et al. 2012b). The 10 Hz GPS units have been found to be reliable for measuring velocity (CV 1.9-6.0%) and have sufficient sensitivity for detecting changes in performance in soccer. Data were analysed using proprietary software (Sprint 5.0, Catapult Innovations, Melbourne, Australia). Data sets were verified for satellite signal (11 ± 2) and horizontal dilution of precision (HDOP); (mean = <1.0) before being included in the analysis.

Statistical analysis

All analyses were conducted using statistical software (SPSS Inc., Chicago, USA). Descriptive statistics were calculated on each variable and z-scores used to verify normality. Changes in heart rate and blood lactate concentrations as a result of the RRST were evaluated using a one-way analysis of variance (ANOVA) with repeated measures, with Bonferroni's test used for post-hoc comparison. A one-way ANOVA was used to evaluate differences between players at different performance levels, various playing positions and intra-season variations for the RRST and match performances. In the event of a difference occurring, Tukey's HSD post-hoc tests were used to identify any localised effects. Relationships between RRST performance and selected variables were evaluated using Pearson's product moment test. The magnitudes of the correlations were considered as trivial ($r \leq 0.1$), small (r > 0.1-0.3), moderate (r > 0.3-0.5), large (r > 0.5-0.7), very large (r > 0.7-0.9), nearly perfect ($r > 0.9$), and perfect ($r = 1.0$) in accordance with Hopkins et al. (2009). The CV and typical error of measurement (TE) was determined to assess reliability (Atkinson and Nevill 1998; Hopkins et al. 2001). Furthermore, a threshold of 1.5 – 2.0 times the TE was used to indicate a systematic change in performance for elite and sub-elite players (Hopkins, 2000). To complement TE, the smallest worthwhile change (SWC) was computed by multiplying the smallest worthwhile effect (0.2) by the between player standard deviation (Hopkins, 2004). The effect size (ES) was calculated from the ratio of the mean difference to the pooled standard deviation. The magnitude of the ES was classified as trivial (≤ 0.2), small (> 0.2-0.6), moderate (> 0.6-1.2), large (> 1.2-2.0) and very large (> 2.0) based on guidelines from Batterham and Hopkins (2006). Statistical significance was set at $P < 0.05$. Values are presented as mean and standard deviations unless otherwise stated.

Results

Test-retest reliability and smallest worthwhile change of the RRST

No difference was found for elite U16 and sub-elite U19 players when the RRST was performed on two separate occasions interspersed by 7 days (n = 29), with a combined CV, TE and SWC of 0.77%, 0.60 s and 0.39 s, respectively (Fig. 2). CV, TE and SWC for elite U16 and sub-elite U19 was 0.71%, 0.44 s and 0.32 s, and 0.84%, 0.75 s and 0.47 s. $RRST_{best}$ had a combined CV, TE and SWC of 1.05%, 0.10 s and 0.05 s, respectively. CV, TE and SWC for elite U16 and sub-elite U19 was 1.04%, 0.08 s, 0.04 s, and 1.06%, 0.10 s and 0.05 s. Additionally, for elite U18 players, the test-retest CV, TE and SWC for the Arrowhead agility test was 0.79%, 0.07 s and 0.03 s.

Physiological response to the RRST

For English Premier League U18 players (n = 22), heart rate was 58 ± 11% HR_{max} before the test and increased (P < 0.01) to 82 ± 5, 87 ± 3, 88 ± 4, 89 ± 4, 90 ± 4, 90 ± 3, 91 ± 3 and 92 ± 3% HR_{max} after each repetition (ES: 0.3-1.8). During the recovery period, heart rate decreased (P < 0.05) to 70 ± 9, 57 ± 5 and 56 ± 8% HR_{max} after 1, 2 and 5 min (ES: 0.3-1.3), respectively. Furthermore, heart rate increased (P < 0.01) from 52 ± 8% HR_{max} to 71 ± 9, 79 ± 7, 82 ± 8, 84 ± 6, 86 ± 6, 89 ± 5, 91 ± 3 and 95 ± 2% HR_{max} after each repetition (ES: 0.3-1.9) for sub-elite U19 players. During the recovery period, heart rate decreased (P < 0.01) to 47 ± 7 % HR_{max} after 5 min (ES: 1.4). For sub-elite U19 players (n = 14), blood lactate concentration was 1.2 ± 0.4 $mmol \cdot L^{-1}$ before the test and increased to 12.5 ± 1.6 and 11.4 ± 2.3 $mmol \cdot L^{-1}$ 1 and 5 min after (ES: 1.9), respectively (Fig. 3).

RRST performance in relation to competitive level, position and phase of season

Differences ($P < 0.01$) were observed in the RRST, were English Premier League U18 ($n = 28$) and English Football League U18 ($n = 15$) were faster than elite U16 ($n = 27$), sub-elite U19 ($n = 14$), U18 ($n = 37$), U16 ($n = 24$) and elite senior female players ($n = 12$) during the start of season period (3.0, 4.8, 5.9, 5.4 and 9.7%, and 1.7, 3.5, 4.6, 4.1 and 8.3%, respectively; ES: 0.6-1.9). Sub-elite senior players ($n = 12$) performed better ($P < 0.01$) in the RRST than sub-elite U18, U16 and elite senior female players (ES: 0.9-1.7). Furthermore, elite senior female players were outperformed ($P < 0.01$) by the elite and sub-elite male population (ES*:* 1.1-1.9; Fig. 4).

For elite U18 players ($n = 43$), it was observed that central defenders had a lower RRST performance ($P < 0.05$) than full backs (3.3%; ES: 1.4), but not central midfielders (2.2%), wide midfielders (2.1%) or attackers (2.8%; ES: 0.7-1.0; Fig. 5). Interestingly, full backs had the lowest intra-positional variability (56.54-58.54 s) while wide midfielders had the highest (56.01-62.77 s). As a result of a low sample size, no positional subset analysis was conducted on elite U16, sub-elite and elite female players.

For elite U16 players ($n = 18$), RRST performance was found to be 2.7, 3.1 and 3.2% longer ($P < 0.01$) during the preparation period (August) compared with the start (October), middle (December) and end (April) of season periods, respectively (ES: 1.0-1.1; Fig. 6). For sub-elite U18 players, RRST performance was found to be 0.9, 1.0 and 0.8 s longer during the preparation period (August) compared with the start (October), middle (January) and end (April) of season periods, respectively (62.55 ± 1.83 vs 61.62 ± 1.84, 61.53 ± 2.03 and 61.75 ± 1.96 s; ES: 0.4-0.5).

Relationships between RRST performance, match running performance and the Arrowhead agility test

A relationship was observed between RRST performance and high-intensity running in the most intense 5-min period for English Premier League U18 (n = 17; r = -0.71; P < 0.01; Fig. 7a), English Football League U18 (n = 15; r = -0.55; P < 0.05; Fig. 7b) and sub-elite U18 players (n = 16; r = -0.74; P < 0.01; Fig. 7c) during competitive matches. Correlations were also observed between RRST performance and high-intensity running during a match for English Premier League U18 (n = 17; r = -0.56; P < 0.05), English Football League U18 (n = 15; r = -0.55; P < 0.05) and sub-elite U18 players (n = 16; r = -0.67; P < 0.01) during competitive matches. Furthermore, a relationship was found between RRST performance and total distance covered during a match for English Football League U18 players (n = 15; r = -0.66; P < 0.01), but not for English Premier League U18 (n = 17; r = -0.25) and sub-elite U18 players (n = 16; r = -0.36). A very large correlation was obtained (n = 31; r = 0.82; P < 0.01; Fig. 7d) between $RRST_{best}$ and the Arrowhead agility test for English Premier League U18 (n = 11; r = 0.75; P < 0.01) and elite U16 (n = 20; r = 0.84; P < 0.01) players.

Accelerations, anthropometric profile and lateral dominance

For sub-elite U18 players (n = 19), maximal accelerations were 3.8 ± 0.5, 3.7 ± 0.4, 3.7 ± 0.5, 3.7 ± 0.5, 3.7 ± 0.6, 3.6 ± 0.5, 3.5 ± 0.4 and 3.4 ± 0.5 $m{\cdot}s^{-2}$ during each repetition of the RRST. Maximal decelerations were -1.5 ± 0.4, -1.2 ± 0.4, -1.2 ± 0.3, -1.1 ± 0.4, -1.3 ± 0.5, -1.4 ± 0.5, -1.2 ± 0.3 and -1.3 ± 0.6 $m{\cdot}s^{-2}$ during each repetition. No correlations were observed between RRST performance and height and body mass for English Premier League U18 (n = 28; r = 0.47 and r = 0.38, respectively) and elite U16 players (n = 29; r = 0.00 and r = 0.04, respectively). No differences were found between dominant and non-dominant sprints during the RRST (average time) for sub-elite senior (n = 12; 7.41 ± 0.20 vs 7.46 ± 0.19 s; ES: 0.3) and elite female senior players (n = 12; 7.93 ± 0.18 vs 8.04 ± 0.20 s; ES: 0.6).

Discussion

The ability to repeatedly produce high-intensity efforts is essential in soccer (Bradley et al. 2009, 2010; Di Mascio and Bradley 2013; Mohr et al. 2003). It is, therefore, vital to measure players' fitness levels in order to cope with such demands. The present data indicates that the RRST is reliable and test performance is closely related to running performance during competitive matches. The RRST was also found to differentiate between performance levels, playing positions and phases of season for elite and sub-elite soccer players. The $RRST_{best}$ was also closely related to the Arrowhead agility test, suggesting the RRST has the ability to measure both RSA and agility. The study also revealed that $\%HR_{max}$ and blood lactate concentrations were similar to that found during the most intense period of matches (Krustrup et al. 2006), and accelerations were similar to that found by Bradley et al. (2010).

Reliability of the RRST

The relatively low CV, TE and SWC for the RRST and $RRST_{best}$ suggest very good sensitivity for measuring changes in physical performance. However, total time was the parameter with the greatest reliability compared to $RRST_{best}$ (CV: 0.77 vs 1.05 %). The CV found in this study for the RRST is similar to the values reported by Fitzsimons et al. (1993) and Impellizzeri et al. (2008) who both reported a CV of 0.8% for the total and average time, respectively. Furthermore, the $RRST_{best}$ CV of 1.04% was found to be similar to that reported (1.3%) by Impellizzeri et al. (2008). However, the protocols included 6 x 40 m sprints (30 s recovery) and 6 x 40 m sprints with 180° turns after 20 m (20 s passive recovery) and do not reflect the protocol for the RRST, which includes random direction changes. A greater CV (1.8%) was reported when the protocol more closely resembled the RRST used in this study. Wragg et al. (2000) modified the RSA test proposed by Bangsbo (1994), which included 7 x 34.2 m sprints with direction changes. Moreover, the TE of 0.44 s is similar to the value reported (0.3 s) for the recently developed repeated sprint test for female soccer players (Gabbett, 2010). This highlights the low test-retest variability and that a performance deviation of 1.5-2.0 times the TE (0.90-1.20 s) or a SWC >0.3-0.5 s would be classified as a systematic and worthwhile change in performance (Hopkins, 2000). The slight deviation in TE values compared to previous literature could be attributed to the total time of sprints during both tests, whereby the RRST is nearly three times the duration (~60 vs ~22 s), in addition to gender specificity as this protocol was developed from women's competitive time-motion analysis data. Thus, the relative TE % of 1.0 is lower than that reported (1.5%) by Gabbett (2010). Even though the RRST has random direction changes and is reactive, it is highly reliable and can be used to measure the RSA of soccer players due to its low CV and TE values.

Validity of the RRST

The RRST must have high validity based on various models to be classified as a valid tool to monitor soccer players. As well as the RRST being based on measurements from the most intense 5-min period during competitive matches (logical validity), the validity of the RRST was assessed by evaluating match running performance (concurrent validity). Large to very large correlations were found between RRST performance vs high-intensity running in the most intense period (r = -0.55-0.74) and during a match (r = -0.55-0.67) for two elite U18 squads playing in the English Premier League and Football League, and one sub-elite U18 squad, respectively. High-intensity running has been shown to have great importance for performance in soccer due to differences between performance level and playing positions (Bradley et al. 2009, 2010; Mohr et al. 2003), and has been used to validate tests (Bradley et al. 2011; Impellizzeri et al. 2008; Rampinini et al. 2007). However, it has been suggested that rolling, rather than predefined, periods are used when determining specific match intervals because of improved accuracy and a clearer representation of high-intensity distance covered (Varley et al. 2012a). Furthermore, a major limitation of quantifying high-intensity running is the high match-to-match variability (Gregson et al. 2010) due to factors such as playing position, tactics, opponent, situation and degree of motivation. Using match running performance as an indicator of physical fitness is complex and should be considered. Bradley et al. (2013) and Di Salvo et al. (2013) have reported that players in the lower leagues perform more high-intensity running distance and actions than their Premier League counterparts, suggesting that players may not be running to their physical capacity. Nonetheless, players may be experiencing overload during the most intense period of a match due to the large decline in the subsequent 5-min period (Bradley et al. 2010; Mohr et al. 2003; Di Mascio and Bradley 2013). The very large magnitude relationship between the RRST and high-intensity running in the most intense period suggests that the RRST provides a valid measure of RSA in soccer.

Validity was also evaluated by measuring its sensitivity to a variety of performance levels (construct validity). It has been demonstrated that high-intensity running is a distinguishing characteristic of players at various performance levels, whereby elite players perform 28% more than their sub-elite counterparts (Mohr et al. 2003). RRST performance differed markedly between levels with elite U18 players outperforming elite U16 and sub-elite players. Furthermore, sub-elite senior performed better than other sub-elite players and elite senior female were outperformed by all male counterparts. Superior RRST performance in elite U18 players may be explained by their training status and that they are full-time, showing greater fitness levels and improved ability to repeatedly perform short duration high-intensity bouts. The present data supports other studies that have found better RSA in professional and semi-professional vs amateur (Aziz et al. 2008), adult professional vs amateur (Abrantas et al. 2004) and elite vs sub-elite junior players (Reilly et al. 2000). Thus, the present findings indicate that the RRST is superior in teams performing professionally and at a higher level of performance.

In addition to RRST performance, $RRST_{best}$ performance was assessed by its relationship to the Arrowhead agility test (criterion validity), which is the test used for youth players throughout the English Premier and Football League via Nike SPARQ. An excellent relationship was found in this study with a very large correlation between the Arrowhead agility test and $RRST_{best}$ from English Premier League U18 and U16 players. The present study found that the Arrowhead agility test was reliable with a CV, TE and SWC of 0.79%, 0.07 s and 0.03 s, respectively. Agility is an important component for soccer and has been suggested to be a specific quality (Little and Williams 2005; Sheppard et al. 2006). Several other tests have been developed (Balsom Agility Test, Balsom 1994; Illinois Agility Test, Getchell 1979; T-Test, Semenick 1990) that assess soccer players' agility and that make up a battery of fitness tests for soccer players. However, the RRST has the ability to assess both RSA and agility and, therefore, has the advantage of measuring two qualities at the same time. The data demonstrates that this test is a useful monitoring tool for soccer players for both RSA and agility.

Playing position and phase of the season

Several studies have found a substantial difference between playing position and high-intensity running during a match (Bradley et al. 2009, 2010; Di Mascio and Bradley 2013; Di Salvo et al. 2007, 2009; Mohr et al. 2003), where central defenders have covered less distance than all other playing positions in domestic and European competitions. In the present study, it was observed that central defenders had a lower RRST performance than all other positions (ES: 0.7-1.4), suggesting a very similar pattern to match running performance. However, it must be acknowledged that the sample used was low (*n* = 43) and that a larger sample may show more differences between playing positions. These findings are similar to differences in other performance tests (Intermittent Endurance Test, Bangsbo and Lindquist 1992; Yo-Yo IE2 test, Bradley et al. 2011). More specifically, comparable differences were observed with other RSA tests, where Impellizzeri et al. (2008) reported defenders having the lowest performance in best and mean time compared to full backs, midfielders and attackers. Furthermore, full backs were reported to have the best times for both the best and mean, which is similar to the present study. These findings suggest that central defenders are likely to have the least physically demanding role or their positional characteristics do not require RSA as much as other positions.

It was observed that RRST performance was 1.6, 1.9 and 1.9 s longer during the preparation phase compared with the start, middle and end of the season, respectively, for elite U16 players. This showed an improvement of 2.6, 3.1 and 3.1%, respectively. Furthermore, differences of 0.9, 1.0 and 0.8 s were also found between the preparation vs start, middle and end of the season, respectively, for sub-elite U18 players. This data is supported by Impellizzeri et al. (2008) where the RSA test mean time was 2.2, 1.4 and 1.6% lower during the first week of pre-season training compared to the start, middle and end of the season for professional players (7.32 ± 0.13 vs 7.16 ± 0.15, 7.22 ± 0.14 and 7.20 ± 0.13, respectively). Thus, it appears that the RRST is also a sensitive tool that can differentiate RSA in various phases of the season as differences were found for both elite and sub-elite players.

Physiological responses, accelerations, anthropometric profile and lateral dominance

The RRST is similar to intense periods during a match due to its HR's and blood lactate concentrations throughout. $\%HR_{max}$ was observed to reach 92 ± 3 and 95 ± 2, for elite and sub-elite players, and blood lactate values reaching 12.7 ± 1.8 $mmol \cdot L^{-1}$ for sub-elite players. This was similar to peak values found during a match, where blood lactate concentrations and heart rate measurements reached 10-14 $mmol \cdot L^{-1}$ and ~95% HR_{max}, respectively, during intense periods (Krustrup et al. 2006). Maximal accelerations reached 3.8 $m \cdot s^{-2}$, which was similar to those found during a match (Akenhead et al. 2013). Furthermore, accelerations declined slightly from the first to the last rep (3.8 ± 0.5 vs 3.4 ± 0.5 $m \cdot s^{-2}$) and decelerations varied throughout (-1.1--1.5 $m \cdot s^{-2}$), signifying accelerations were affected by fatigue through the RRST. RRST performance was unaffected by height and body mass for elite players, whereby performance was most likely dictated by quality of player and their conditioning rather than anthropometric profile. No differences were found between dominant and non-dominant sprints during the RRST average time for sub-elite senior (7.41 ± 0.20 vs 7.46 ± 0.19 s), although a small to moderate effect size (ES: 0.6) was observed for elite female senior players (7.93 ± 0.18 vs 8.04 ± 0.20 s). This implies that a minimal effect occurs between dominant and non-dominant direction sprints, providing further reason to the high reliability of the RRST even though it is reactive in nature.

Summary

The data clearly demonstrate that the RRST is reliable and can be used as an indicator of match-specific physical capacity of elite and sub-elite players. The RRST illustrates high sensitivity by differentiating between performance levels, playing positions and phases of the season. Furthermore, physiological responses and accelerations were similar to those found during intense periods of a match. Finally, the RRST may also be used to test agility due to its strong relationship to the Arrowhead agility test.

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