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ABSTRACT

Repeated-sprint ability is an important physical prerequisite for competitive soccer and deviates for players in various stages of growth and development. Thus, this study investigated reactive repeated-sprint ability in elite youth soccer players in relation to maturation (age at peak height velocity) and its association with performance of other physical tests. Elite male youth players from an English Premier League academy (U12, $n = 8$; U13, $n = 11$; U14, $n = 15$; U15, $n = 6$; U16, $n = 10$; U18, $n = 13$) completed the Reactive Repeated-Sprint Test (RRST; 8 × 30-m sprints with 30-s active recovery), and other physical tests including the Yo-Yo Intermittent Recovery Test Level 2 (Yo-Yo IR2), Arrowhead Agility Test, Counter Movement Jump Test with Arms (CMJA), in addition to 10-m and 20-m straight-line sprints. RRST performance (total time across eight sprints) progressively improved from U12 to U16 ($P < 0.01$; ES: 1.0-1.9), yet with no differences found between U16 and U18. No between-group differences in RRST performance were evident after accounting for age at peak height velocity ($P > 0.05$; ES: <0.3). Correlation magnitudes between performance on the RRST and other tests were trivial to moderate for the Yo-Yo IR2 (r=-0.15-0.42), moderate to very large for the Arrowhead agility test (r=0.48-0.90), moderate to large for CMJA (r=-0.43-0.66) and trivial to large for 10- and 20-m sprints (r=0.05-0.61). The RRST was sensitive at tracking maturation trends in elite youth players, although performance improvements were not as marked from 15-16 years of age. RRST performance correlates with several physical qualities decisive for competitive soccer (agility, speed, power and aerobic endurance).

Key words: Football, directional changes, youth, fitness tests, multiple “all-out” efforts.

INTRODUCTION

The ability to perform repetitive maximal, or near-maximal, multidirectional efforts of short duration (<10 s) with incomplete recovery time (<60 s) is an important prerequisite for competitive soccer (7, 11, 14). Intense match play periods only allow short recovery times between high-intensity bouts of ~30 s or less which subsequently impairs performance of repeated sprints (1, 12, 37).

Maturity status is an important factor in the physical development of youth players, especially in relation to their physical capacities and match running performances (19, 23, 25). Repeated-sprint sequences have been found to decrease throughout the game for U13 to U18 players, and are affected by age and playing position (10). Thus, one would assume that repeated-sprint ability (RSA) is an important determinant of physical performance in youth players due to fatigue development (36). Yet it is surprising that limited information exists on RSA in elite youth soccer players (29). Current literature raises some concerns regarding the validity of this measure for senior soccer as only a few repeated-sprint sequences occur during senior matches (35). Hence, some researchers have hypothesised that the term 'repeated acceleration ability' could more accurately describe the demands of soccer (3). It would therefore be prudent to analyse this physical parameter in soccer populations in various stages of maturation to verify its importance across ages and its relationship with other physical qualities.

Investigating the importance of RSA in youth players, several studies made the interesting observation that adolescents (U12 to U18) have an enhanced ability to recover from high-intensity exercise (15, 34). This has partly been attributed to phosphocreatine (PCr) resynthesis being faster in children (≤12 yr) than young adults (18-29 yr), with a greater reliance on oxidative (20, 39). Given its positive correlation with the rate of PCr resynthesis, a better RSA is expected in children compared to adults. However, the opposite pattern may occur for total and best time during a RSA test, possibly due to maximal anaerobic power and muscle mass being lower in children than young adults (41). RSA performance has been found to correlate with age changes, with U18 and U16 players demonstrating faster mean sprint times than U16 and U14, respectively (27).

RSA associates differently with speed and endurance in trained and untrained soccer players. A large magnitude correlation (r = 0.66) between RSA and 20-m sprints has been reported, but not with 20-m multistage shuttle running (33). This may suggest that RSA is more related to short sprint performance than endurance capacity (27, 33). However, others have reported large magnitude associations with RSA and aerobic fitness (8, 16, 21). Weak relationships between RSA and counter-movement jump height have also been observed (18), suggesting that leg power is not a major determinant of RSA. However, a strong correlation between performance of a straight-line RSA test and vertical jump ability has been reported, suggesting that the changes of direction tests are more complex (40).

Substantial variation was found between RSA and agility throughout a range of age groups (38). Although trivial correlations were found for the U15, U16 and U17 groups, there was a very large correlation for the U18 group. The RSA test in this study was designed to minimise coordination or any skill component and these differences may suggest that maturity and training had a small effect on the outcome. Importantly, the agility test was very technical, requiring good coordination and the lack of a significant relationship may be related to a disruption in motor coordination during the developmental period.

Although all of these tests aim to provide the applied sports scientist with relevant information on physical capacities, the physical overlap between these qualities is substantial. As such the practitioner must decide which tests to include in testing batteries given time constraints. Therefore, the aim of this study was to determine the nature of the relationship of reactive RSA (RRSA) with aerobic endurance, agility, power and speed in elite youth soccer players from U12 to U18. We hypothesised that reactive RRSA would improve from U12 to U18 playing age groups, and correlate with other physical qualities.

METHODS

Experimental Approach to the Problem

Traditional tests for the evaluation of soccer-related physical performance are very general, including continuous running and straight line repeated-sprint ability. Therefore, these do not mimic the movements that occur in soccer. The Reactive Repeated-Sprint Test (RRST) was used to compare different age groups (U12 to U18). We compared the RRST with other physical performance tests, including the countermovement jump (with arms), 10- and 20-m sprints, the Arrowhead agility test and the Yo-Yo IR2.

Participants

A total of 63 elite male youth soccer players participated in this study, representing all playing positions, and were grouped according to their respective under age team (U12, *n* = 8; U13, *n* = 11; U14, *n* = 15; U15, *n* = 6; U16, *n* = 10; U18, *n* = 13). Players belonged to the same English Premier League club, and were involved in regular U12 to U18 competition. The duration of all training sessions was 90-120 min and encompassed individual preparation/warm up activities, technical and tactical skill development, physical conditioning and regeneration modalities. All groups undertook 3-5 training sessions per week and played a single 60-90 min match per week. Players that participated in this study performed minimal exercise outside of training and playing soccer. Players' characteristics are presented in Table 1. The study was approved by the institution's ethical committee, the testing procedure was explained to the players and a written consent was obtained from the club, the players and their parents.

Design

Testing was performed between the start and middle phases of the season, and all trials were conducted within the same training week to reduce the impact of seasonal variation on physical performance. Players were familiar with the testing protocols (as part of their regular physical performance assessment). Testing was always carried out on an artificial surface at the same time of day (5 to 8 pm) following a standardised warm up. Controls for their diet matched that of the typical training week at the professional club, as all players receive diet plans and recommendations for their season. Each player was verbally encouraged throughout testing.

Maturity Status

Pubertal timing was estimated according to the biological age of maturity of each player (28). Age of maturity (yr) was calculated by subtracting the chronological age at the time of the measurement from the peak velocity age (5). Peak height velocity (PHV) is defined as the period where maximum rate of growth occurs. Body mass (kg) (Seca, α 700 digital low form scale, Birmingham, UK) and stature (m) (Seca, α 220 digital low form scale) were measured to the nearest 0.1 kg and 0.01 m. Players were measured barefoot while wearing light training clothing. From this, body mass index (BMI) was calculated (body mass·stature^{-2}; kg·m^{-2}).

Reactive Repeated-Sprint Test (RRST)

The RRST configuration was based on the most intense 5-min period in elite soccer matches (13) and its reliability and validity has been verified (12). The RRST lasts for ~5 min and consists of 8 maximal efforts interspersed with 30 s of active recovery (walking pace back to the start). 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^{TM}, Queensland, Australia) placed 0.7 m above the ground and 4 m from the starting position, which started a digital timer (the drill option used on Smartspeed was a 1-1-2 Auto Start Cut). 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 (Figure 1). Each individual sprint was 6 m and the right or left turn was dictated by the random signal. Total distance timed was 30 m and RRST performances were reported as the total time (s; $RRST_{TT}$) and the best time (s; $RRST_{best}$) as the percentage decrement is highly variable (31).

Physical Performance Tests

Leg power was determined from countermovement jumps with free arms use (CMJA, cm). During each CMJA trial, Players started from a standing position on a rubber mat, squatted down and then extended maximally their knees in one continuous movement (Just Jump System, Probotics, Huntsville, AL). The micro switches embedded in the mat (0.69 by 0.69 m) timed the interval between players' lift-off from the mat and landing (24). The mat was attached to a hand-held computer that recorded time off the ground and determined CMAJ jump height. Players executed 3 maximal trials (60 s of rest between jumps), and the average of three jumps was retained (cm). Nearly perfect correlations between the jump mat and a 3-camera motion analysis system indicate that the system is valid (31), while its test-retest reliability has also been verified (30).

Players were asked to run 10-m and 20-m maximal sprints (3 trials with 3 min recovery for each sprint distance, and the average performance was kept for analysis). Linear sprinting time was measured to the nearest 0.01 s using digital timing gates

(Brower Timing System, Draper, UT). Players were instructed to adopt a forward lean and start voluntarily, with no sway. Single-sprint tests have been reported to demarcate between players of various competitive standards and playing positions (22).

The Arrowhead agility test was used to determine the players' ability to change direction (12). The Arrowhead course consists of two trials; one right and one left. Cones were placed in an arrowhead shape, and one set of cones to indicate the start and finish line. The average time (s) to complete the test for the right and left trials were recorded. Players recovered sufficiently between trials (180 s of rest) and were able to give a maximal effort. Research has reported that this test is reproducible (12).

The Yo-Yo IR2 consisted of repeated 2 x 20-m shuttle runs performed at progressively increasing velocity, interspersed with 10 s of active recovery, controlled by audio signals. The test was terminated when a player failed twice to reach the end line in time with the bleep. The total distance covered during the test was the outcome. The Yo-Yo IR2 test provides a valid and sensitive way to assess intense intermittent exercise performance (2). Only the U13 to U18 age groups completed the Yo-Yo IR2.

Statistical Analysis

All analyses were conducted using statistical software (SPSS Inc., Chicago, USA). Descriptive statistics (mean and standard deviations unless otherwise stated) were calculated on each variable and z-scores used to verify normality. A one-way analysis of variance (ANOVA) was used to evaluate differences between players in various age groups for the RRST. In the event of a difference occurring, Tukey's HSD post-hoc tests were used to identify any localised effects. Between-group differences in the

RRST were assessed using a one-way analysis of covariance (ANCOVA) in separate phases; (1) no covariate, (2) age at PHV. The magnitude of the differences of each covariate effect was assessed (pairwise comparisons) using standardized mean differences on the adjusted means. Statistical significance was set at $P < 0.05$. Effect sizes (ES) were 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 previous guidelines (4). Relationships between RRST performance and selected variables were evaluated using Pearson's product moment correlation analysis. The correlation coefficients (*r*) were interpreted in accordance with the following scale of magnitude: 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 ($r = 1.0$).

RESULTS

RRST

For $RRST_{best}$, U12 to U14 players were different to all other groups ($P < 0.01$; ES: 0.8-1.9). U15 players were also slower than the U18 age group ($P < 0.01$; ES: 1.7). Improvements in $RRST_{best}$ were evident as age progressed. U12 to U13 (2.5 ± 2.7%), U13 to U14 (2.1 ± 3.0%), U14 to U15 (2.6 ± 2.3%) and U15 to U16 (2.4 ± 2.1%) showed differences although the least pronounced difference was between U16 to U18 players (1.8 ± 2.3%; $P < 0.01$; ES: 1.0-1.9).

$RRST_{TT}$ progressively decreased from U12 to U16, yet with no significant differences found between U16 and U18 (U12 to U13 = 2.0 ± 2.7%, U13 to U14 = 2.0 ± 3.0%, U14 to U15 = 2.8 ± 2.3%, and U15 to U16 = 2.0 ± 2.1; $P < 0.01$; ES: 1.0-1.9; Figure 2). No between-group differences were evident after adjustment for age at PHV ($P > 0.05$; ES: <0.3). For U13, U14 and U15 players, $RRST_{TT}$ performances were slower than U16 and U18 players, and between-group effect sizes were substantially lower when age at PHV was included as a covariate (ES: 0.0-0.6).

Other Physical Performance Tests

All performances improved from U12 to U18 for the 10-and 20-m sprints (U12: 2.07 ± 0.08 and 3.60 ± 0.15, U13: 2.01 ± 0.10 and 3.50 ± 0.20, U14: 1.88 ± 0.10 and 3.23 ± 0.20, U15: 1.89 ± 0.10 and 3.23 ± 0.10, U16: 1.89 ± 0.10 and 3.15 ± 0.10, U18: 1.74 ± 0.07 and 2.99 ± 0.08 s), U13 to U18 for the Arrowhead agility test (U13: 9.00 ± 0.50, U14: 8.51 ± 0.40, U15: 8.49 ± 0.40, U16: 8.29 ± 0.10, U18: 7.94 ± 0.23 s) and the Yo-Yo IR2 (U13: 19.3 ± 0.7, U14: 20.1 ± 0.5, U15: 20.4 ± 0.6, U16: 20.6 ± 0.8, U18: 21.0 ± 0.6), but only from U12 to U16 for CMJA (U12: 46.7 ± 3.3, U13: 48.1 ± 5.1, U14: 53.6 ± 6.6, U15: 57.2 ± 5.2, U16: 59.8 ± 5.4, U18: 58.9 ± 5.0 cm). In general, the correlation magnitudes between $RSST_{TT}$ and CMJA were moderate to large and trivial to large with 10- and 20-m sprints, moderate to very large with the Arrowhead agility test and trivial to moderate with the Yo-Yo IR2 (Table 2). The relationships between $RSST_{best}$ and CMJA were trivial to very large and trivial to large with the 10- and 20-m sprints, moderate to very large with the Arrowhead agility test and trivial to moderate with the Yo-Yo IR2 (Table 2).

DISCUSSION

This study is the first to investigate RRSA in U12 to U18 players and its relationships with other physical performance tests. The present data demonstrate that RRSA progressively improved from the U12 to U18, with more marked changes evident between U12 and U15 groups. However, no differences were observed for RRSA when adjusted for age at PHV, suggesting that this is a general physical quality in adolescents and adaptations occur with generic soccer training as players mature. The present data further revealed that RRSA correlated with other physical performance indices such as the Yo-Yo IR2, the Arrowhead agility test, CMJA, and 10- and 20-m sprint tests, but the magnitude of these relationships are test and age dependent.

The differences in $RRST_{TT}$ and $RRST_{best}$ across age groups are similar to other investigations (29, 41), whereby performance was greater as playing age group increased. These are likely, in most circumstances, to be attributed to maturation rather than training (25). The most marked $RRST_{TT}$ performance differences were between U14 to U15 age groups, during and following PHV, whereas the least pronounced performance differences were between U16 to U18 age groups (2.6 *vs.* 1.8%). The slowdown in RRSA progress as players mature could be linked with the glycolytic capacity and peak muscle fibre size plateauing at 16 years of age (17). Differences between U12 to U16 players were observed, although no further improvements between U16 and U18 were evident. This may suggest that it is training, not maturation, that improves performance after U16. With the possible exception of U12 players being inferior to U16 and U18 players, between-group effect sizes were substantially lower when age at PHV was included as a covariate.

For $RRST_{best}$, U12 to U14 performances were slower than older age groups, showing that greater power produced over a sustained period of time develops with age up until PHV. Research has demonstrated differences between youth soccer populations, where there was an improvement in RRSA (6 × 30 m) in U11 to U18 age groups (29). However, the present study is the first to investigate soccer-specific RSA, given that the $RRST_{TT}$ has been designed to mimic the most intense periods of match play and uses a reactive stimulus to replicate game situations (12, 13).

In line with previous literature, trivial (U12, U13, U16, U18) to moderate (U14, U15) magnitude correlations were found between $RRST_{TT}$ and the Yo-Yo IR2 (21, 38). Ingebrigtsen et al. (21) investigated the relationships between commonly employed field tests in elite and sub-elite soccer players and demonstrated that Yo-Yo IR2 performances were moderately correlated with 35 m linear sprinting and RSA. As the Yo-Yo IR2 test has been shown to highly tax the aerobic energy system (2), the magnitude of the correlation in the present study is understandable as RSA performances are only partially influenced by aerobic capacity. Research has reported that RSA protocols that have shorter sprints (20 m) tax the anaerobic energy system to a greater extent (33) and given that each RRST bout was 6 m (total of 30 m), this further reflects the differences between testing modes. With blood lactate concentrations of ~13 mmol/L immediately post-RRST, this test highly taxes the glycolytic system (12). The protocol used for RSA should be sport-specific, provide a similar physiological response and mimic the most intense period of the game (12, 13).

Large to nearly perfect correlations were evident between $RRST_{TT}$ and $RRST_{best}$ *vs.* the Arrowhead agility test. Both tests include change of directions, although the RRST included more turns than the Arrowhead test, and it has been reported that performance during repeated-sprints are angle-dependent (9). However, both took ~7-8 s per bout for elite male youth populations. There was a lowering of the correlation coefficient with the U16 playing age group for $RRST_{TT}$, and in the U15 and U16 groups for $RRST_{best}$. This period of maturation may also be related to disproportional growth in leg length relative to trunk length (25). However, performance deficits that occur during maturation between 14-16 yr are known to dissipate by the age of 18 (6).

All playing age groups demonstrated moderate to large correlations between RSST total time and CMJA (r = −0.43-−0.66), with $RRST_{best}$ *vs*. CMJA demonstrating a moderate to very large correlation (r = −0.40-−0.73), with the exception of the U15 group (r = 0.21). A temporary decline in jumping ability may occur the year after PHV (U14), as RSA seems to continue to improve across age groups. Spencer et al. (2011) reported large correlations between countermovement jump with and without arms *vs*. RSA (6 × 30 m), with the exception of U14, with U18 players having a very large correlation. mromore, mean power, but not peak power, was found to be strongly correlated (r = −0.5) with RSA total time but varied with RSA fastest time depending on the protocol (6 × 40 m, r = −0.4; 12 × 20 m, r = −0.3). However, power was measured in the study by the Wingate Anaerobic Test (26).

The trivial to large correlations of RSA with 10- and 20-m sprints are consistent with previous findings for some playing age groups, but not others (27, 33, 38). Mendez-Villanueva et al. (27) found moderate to nearly perfect correlations between RSA *vs.* 10-m sprint and 20-m flying sprint for U14 (r = 0.76 and 0.91), U16 (r = 0.55 and 0.96) and U18 (r = 0.66 and 0.74) playing age groups. Contrastingly, Spencer et al. (38) found large to very large correlations between RSA and 15 m sprint times for U11 to U18 highly trained players. The moderate to large correlations between RSA *vs*. 10- and 20-m sprints in U12 to U14 groups became trivial to moderate in U15 to U18 groups. In support, performance in a 30-m sprint showed an inverse relationship before PHV, but performance improved at and after PHV (32). Beunen and Malina (6) suggested that it could be a disruption of motor coordination and is highly dependent on the individual player.

The present study showed for the first time that the $RRST_{TT}$ and $RRST_{best}$ improved progressively from the U12 to U18 age groups, while no differences were observed when adjusting for age at PHV. Moreover, RRST was highly correlated with other aspects of physical performance, although consistency varied between components of fitness and group. Moderate to large correlations were evident with CMJA and the Arrowhead agility test, but varied for the 10 and 20 m sprints and Yo-Yo IR2, suggesting it could also be used to assess agility from U12 onwards. The RRST has also illustrated that it can differentiate between adolescents at different development stages and provides guidance on the implementation of training programmes to best improve match physical performance.

Practical Applications

Given that RRST is sensitive enough to identify difference across maturation trends, it could be a valuable tool to assist practitioners in developing individualised training methods for elite youth players. For instance, repeated shuttle sprint training could be utilised when players are at U15 level as this improves the ability to change direction with more generic training with a technical element adopted for U12 and U14 players. It is important that coaches and practitioners are educated on the deficiencies that players may experience during the U15 and U16 playing age groups. The RRST was sensitive at tracking maturation trends in elite youth players. Given its reactive stimulus, it could be an important test to include within academy testing batteries.

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