Influence of Maturation and Determinants of Repeated Sprint Ability in Youth Basketball Players

ABSTRACT

The main aims of the current study were 1) to determine the main predictors of general and specific repeated-sprint ability (RSA) tests, 2) to analyze the relationships between RSA tests and independent measures of physical performance, 3) to examine whether between-age differences exist, and 4) to assess if maturation affects those mentioned above in young basketball players. Thirty-five young (U-14 to U-16), highly trained basketball players performed a linear sprint test (5, 10, and 25-m), an incremental running test, and two repeated-sprint tests (general [RSG]: 6 x 25-m; specific [RSS]: 6 x 5+5 m with a 45º change of direction and 20 s of passive recovery in both tests). Anthropometric variables were measured and used to calculate age at peak height velocity (APHV), which was used to determine maturation. The main determinants of RSA tests were aerobic performance and linear sprinting for RSS (R^2= 0.84) and adding the percentage of body fat for RSG (R^2= 0.94). Almost perfect relationships (r = 0.93 to 0.99) were found between all RSA variables (i.e., the best [RSGb and RSSb] and mean time [RSGm and RSSm]). As age increased, performance in RSA were evident, as shown by improved best and mean scores. When APHV was controlled for, no significant differences were apparent in the comparison from U-14 and U-16 in 25-m, RSGb, and RSGm. In contrast, significant differences ($p < 0.05$) still were evident with APHV controlled between U-14 and U-16 in 5-m, 10-m, RSSb, and RSSm. In conclusion, maturation positively affects linear sprinting and linear RSA performance, while specific (multidirectional) RSA seems to be related to other factors.

Keywords: multidirectional, team-sports, specificity, aerobic performance, linear sprinting, age differences, growth

INTRODUCTION

Basketball players are required to perform brief, repeated high-intensity actions such as sprints, accelerations, decelerations, and changes of direction (COD) (1). For example, during a basketball match, a short sprint generally takes place every 15-39 s (39), and a high-intensity action is repeated every 10-20 s (1,39). In this regard, players competing at higher levels (i.e., Division I) perform a substantially greater number of high-intensity actions per minute (effect size [ES] = 1.08 to 1.17) in comparison to their lower-level counterparts (i.e., Division II, III, and IV) (15). Furthermore, substantial decrements in high-intensity actions (ES = 0.64 for high-intensity actions, and 0.60 for sprints), mainly at the latter stages of the matches (e.g., second half), have been typically reported in basketball (15). Thus, the ability to maintain high-intensity actions or repeated sprints during a match has been identified as an essential physical fitness component in basketball (15,39).

Repeated sprint ability (RSA) mainly depends on two main determinants: initial sprint performance and recovery between sprints (4). As such, the importance of locomotor factors (i.e., sprinting and peak incremental test speeds) for greater repeated-sprint performance (i.e., mean sprint time) has been provided in team-sports athletes (6). Furthermore, both maximal sprinting and maximal aerobic speed (i.e., aerobic performance) variations highly predict RSA variation (7). The information above related to RSA determinants has been shown in football (38) and rugby (41), finding aerobic performance and linear sprinting as the main determinants for recovery between sprints and initial sprint performance, respectively. In reference to aerobic performance, peak of maximum oxygen consumption (VO_{2peak}) is considered the main indicator of cardiorespiratory fitness, that is, aerobic performance (40). Recent data has shown good predictability to assess VO_{2peak} during the 20-m shuttle run test (r = 0.71 to 0.96), in addition to being an easier, field-based, and more economical tool when assessing a group of athletes (26). Thus, such test can be used as a measurement of aerobic performance in team-sports settings. Additionally, while some studies have analyzed the main predictors of RSA in basketball players (42), no study has included linear sprinting as a possible key factor. In addition, no study has examined the effect of maturation on RSA performance and its key determinants. Thus, it seems necessary to determine their influence on RSA in youth basketball players.

General repeated sprint tests (RSG) in team sports have been based on performing six linear sprints between 20-35 m with 15-25 s of recovery (2). However, basketball players can perform up to 835 turns throughout a game (34), the mean linear sprint distance is approximately 5 meters (e.g., 1-2 s) (12), and the most usual cutting angle during match play is about 45º (+/-15º) (13). Based on these specific demands, including an RSA test with comparable movement patterns seems appropriate. Indeed, several basketball specific repeated-sprint tests have been proposed based on the most common playing demands (9,44) such as a test compounded by 10 repetitions x 15+15 m with 30 s of passive recovery (9). Previously, Carling et al., (8) have reported that RSG have been generally designed to replicate a highly stressful period of play during a match and measure the ability to resist fatigue and maintain high performance levels. They concluded that repeated sprint tests should consider specific demands in terms of frequency, distance, and duration of high-intensity actions to their ecological design. Nevertheless, whether specific repeated-sprint tests can bring new or different information to the team and individual players still needs to be answered. Therefore, the comparison of the main determinants between general and specific RSA tests should be developed as, to the authors' knowledge, it has not been evaluated before. Thus, the main aims of this study were: 1) to determine the main predictors of general and specific repeated-sprint tests, 2) to analyze the relationships between anthropometrics, linear sprinting, incremental running speed test, and repeated-sprint tests, 3) to examine whether between-group (U-14, U-15 and U-16) differences exist in young basketball players, and 4) to assess if maturation affects the predictors, relationships and between-group differences.

METHODS

Experimental approach to the problem

Players performed a series of sprint assessments over five testing sessions. The assessments were performed during the last month of the competitive season (i.e., June) and at the same time of day (17:00 to 19:00). Subjects were familiar with all testing protocols as they are used within their routine testing battery, which is repeated 5 times per season. Between-session recovery was 72 hours (from test session 2 to test session 5). All tests were executed on an indoor wooden basketball court where the ambient temperature ranged from 20 to 24°C. Subjects were told not to exercise the day before each testing session and to consume their last meal (caffeine free) at least 3 hours before the scheduled test time.

Subjects

An a priori power analysis was conducted to determine the appropriate sample size using G*Power (version 3.1.9.3, Düsseldorf, Germany). Considering the study design, a within-group design looking at differences, an effect size at 0.5, an alpha level of 0.05, and a required power of 80%, a total sample of 27 participants was required. Thirty-five subjects were included in the current study resulting in the current power of 89%. Highly trained male basketball players (age: 14.1 ± 1.22, training experience: 6.76 ± 1.42) voluntarily participated in this study. Subjects were divided into three age groups (U-14 [*n* = 15], U-15 [*n* = 11], and U-16 [*n* = 9]) (Table 2). Maturity offset was predicted using a non-invasive method appropriate for the age range of the sample, considering anthropometric data (leg length and sitting height), and chronological age (Maturity offset = -9.236 + 0.0002708 x Leg Length and Sitting Height interaction -0.001663 x Age and Leg Length interaction + 0.007216 x Age and Sitting Height interaction + 0.02292 x Body mass by Height ratio) (27). This measure was previously validated in a male longitudinal study in the range of 8 to 18 years old (24). Age at peak height velocity (APHV) was calculated by subtracting maturity offset from the chronological age. All players were training in a basketball club for at least five years and belonged to a club academy squad in the first Top Spanish Division (Endesa League). They participated on average in approximately 14 hours of combined basketball (5-6 sessions), strength and power training (2 sessions), injury prevention training (i.e., isometric and eccentric hip, knee, and ankle exercises, CORE, and sensorimotor exercises) (1 session), and two competitive matches per week. At the time of the study, all players were competing at the national and international level categories (i.e., Spanish Basketball National League, and European and World Basketball Championship). Furthermore, nine players (*n* = 9) are currently competing at a professional level (i.e., NBA, Euroleague, Top Spanish Division, and 2nd Spanish Division). Written informed consent was obtained from both the players and their parents before the investigation. The present study was approved by the institutional research ethics committee and conformed to the recommendations of the Declaration of Helsinki.

Procedures

Prior to the physical testing, all players performed a typical pre-game warm-up, including low-intensity jogging (10 minutes), dynamic stretches (lunges, single-leg deadlifts, lateral squats) (8 repetitions x leg x exercise) (5 minutes), and moderate to high-intensity activities such as high-knees, butt kicks, cariocas, accelerations, decelerations, linear sprints and changes of direction (5 minutes).

Repeated sprint specific test

A new repeated-sprint specific test was developed. The test is based on repeating the same number of repetitions as typical general RSA tests (i.e., 6), the mean linear sprint found in the literature (i.e., 5 m) (the test is compounded by 5 + 5 m) (12), and the most usual cutting angle (i.e., 45º) (13). In addition, with high-intensity activities being repeated between 10-39 s (we used 20 s between sprints as it is within the range found and it is similar to general repeated tests), and we used only one COD to test repeated sprint specific test rather than repeated COD ability where we would employ a greater number of CODs. The first and second testing sessions were used to analyze its reliability separated by five to seven days. The repeated specific sprint test involved six repetitions of maximal 5+5 m sprints with a 45° COD (Figure 1). Players had 20 s of passive recovery between each sprint. During the recovery, players were required to stand passively. Three seconds before starting each sprint, the subjects were asked to assume the start position and await the start signal. The front foot was placed 0.5 m before the first timing gate whilst adopting a 2-point staggered stance. Time was recorded with photoelectric cells (*Witty, Microgate, Bolzano, Italy*). Timing gates were placed at 0.75 m height and 1.5 m distance between each other (18). Strong verbal encouragement was provided to each subject during all sprints. Three scores were calculated for the repeated specific sprint test: the best sprint time (RSS_b), the mean sprint time (RSS_m), and the percentage of decrement ($\%Dec_{RSS}$) calculated as follows: (100 x (mean time/best time)) – 100.

***** Insert Figure 1 near here*****

Anthropometric measurements

Anthropometric measurements were executed during the third testing session. Such selection was based on their strong impact on RSA in other team-sports such as football (25). Each player was weighed (in kg) using a scale (*Seca Instruments Ltd., Hamburg, Germany*), and his stature and arm span were measured (in cm) with a stadiometer (*Holtain Ltd., Crymych, UK*) and anthropometric tape *(W606PM Lufkin1, Cooper Industries, Lexington, SC)*, respectively. Skinfold measurements (in mm) were taken at seven sites (triceps, subscapular, biceps, supraspinal, abdominal, front thigh, and medial calf) using a Harpenden caliper (*Baty International, Burgess Hill, UK*). All skinfold measurements were taken on the right side of the body. %BF was calculated from skinfold thickness as follows: Body density (BD) = 1.0988 – [0.0004 x (sum of 7 skinfolds); %BF = (495/BD) - 450 (43). The length of the femur (trochanterion-tibiale laterale) and of the tibia (tibiale laterale) were measured (in cm) with a segmometer *(Rosscraft)*. The sum of the length of the femur and the length of the tibia was used to calculate leg length. All measurements were taken by the same person, who holds an International Society for the Advancement of Kinanthropometry (ISAK) qualification (Level 2).

Speed tests

Running speed was evaluated by 25-m sprint times (standing start) with 5-m and 10-m split times during the third testing session after carrying out the anthropometric measurements. Linear sprinting has been considered as one of the most important indicators of repeated-sprint performance in several team-sports (6), though no information is presented in basketballers. Furthermore, those improvements achieved in sprinting ability have been directly related to RSA (7). Consequently, linear sprinting ability was selected to analyze its influence on RSA in basketball players. The front foot was placed 0.5 m before the first timing gate whilst adopting a 2-point staggered stance. Time was recorded with photoelectric cells (*Witty, Microgate, Bolzano, Italy*). Timing gates were placed at 0.75 m height and 1.5 m distance between each other (18). The 25-m sprint was performed twice, separated by at least 3 min of passive recovery, and the best time was registered to analyze. Verbal encouragement was provided throughout the whole sprint from the tester and provided the following instructions: run as fast as possible.

Repeated sprint general test

RSA general test was executed during the fourth testing session. The RSG test involved six repetitions of maximal 25-m linear sprints with 20 s of passive recovery between sprints. During the recovery, players were required to stand passively. Three seconds before starting each sprint, the subjects were asked to assume the start position and await the start signal. The front foot was placed 0.5 m before the first timing gate whilst adopting a 2-point staggered stance. Time was recorded with photoelectric cells (*Witty, Microgate, Bolzano, Italy*). Timing gates were placed at 0.75 m height and 1.5 m distance between each other (18). Strong verbal encouragement was provided to each subject during all sprints. Three scores were calculated for the RSG test: the best sprint time (RSG_b), the mean sprint time (RSG_m), and the percentage of decrement ($\%Dec_{RSG}$) calculated as follows: (100 x (mean time/best time)) – 100.

20-m shuttle run test

The 20-m shuttle run test was performed during the fifth testing session. The final speed reached in such test ($V_{20\text{-m ST}}$) has been highly related (very large to almost perfect correlations) to VO_{2peak} (26). As it is considered as the main indicator of aerobic performance (40), and its impact on RSA performance is very high (6), the 20-m shuttle run test was selected. The protocol used was proposed by Léger and colleagues (21). Subjects were required to run between two lines 20 m apart while keeping pace with audio signals from a pre-recorded CD. The initial speed was set at 8.5 km · h-1, which was increased by 0.5 km · h-1 each minute (one-minute equals one stage). Subjects were instructed to run in a straight line, pivot and turn on completing a shuttle, and pace themselves under the audio signals. The test ended when the participant stopped due to fatigue or failed to reach the end lines concurrent with the audio signals on two consecutive occasions. The subjects were constantly encouraged to run for as long as possible throughout the test. The last completed half-stage of the 20-m shuttle run test was recorded (e.g., if five stages plus a half-stage were completed: 5.5) as the final speed reached ($V_{20\text{-m ST}}$).

Statistical Analyses

Data are presented as mean ± standard deviation (SD). Normality was assessed using the Shapiro-Wilk test and all data were normally distributed. To examine reliability, pairwise comparisons were first applied. Between-session reliability analysis was computed using: i) a 2-way random intraclass correlation coefficient (ICC) with an absolute agreement and 90% confidence intervals, and ii) the coefficient of variation (CV). The smallest worthwhile change (SWC) was calculated as 0.2 multiplied by the between-subject SD ($SWC_{0.2}$), 0.6 ($SWC_{0.6}$) or 1.2 ($SWC_{1.2}$) to detect small, moderate, or large effects, respectively. The test was rated as depending on typical error of measurement was below (rated as “Good”), equal to (“OK”) or higher than (“marginal”) SWC. Pearson’s correlation coefficients were calculated to establish the relationships between every variable and RSG_m and RSS_m (within U-14, U-15, U-16, and pooled data). Multiple linear regression models (stepwise backward elimination procedure) with RSG_m and RSS_m as the dependent variables were also used. Independent variables were anthropometry, linear straight sprinting, and a 20-m shuttle run test. In the backward procedure, variables with p-value > 0.05 were removed from the model. The magnitude of the correlation (*r* (90% CL)) between variables was assessed with the following thresholds: ≤ 0.1 = trivial; > 0.1–0.3 = small; > 0.3–0.5 = moderate; > 0.5–0.7 = large; > 0.7–0.9 = very large; and > 0.9–1.0 = almost perfect (20). If the 90% confidence interval (CI) overlapped small positive and negative values, the magnitude of the correlation was deemed unclear; otherwise, the magnitude was deemed to be the observed magnitude (20). The standardized difference or effect size (ES, 90% CI) was calculated using the pooled SD. Threshold values for Cohen *d* ES statistics were > 0.2 (small), > 0.6 (moderate), and > 1.2 (large) (20). Furthermore, a one-way ANOVA was conducted to determine between-age group significant differences ($p < 0.05$). Bonferroni’s test was developed to establish post-hoc comparisons. Finally, to examine the influence of maturation on between-group differences ($p < 0.05$), an analysis of covariance (ANCOVA) was conducted using APHV as a covariate (SPSS for MAC, Version 28.0; SPSS Inc, Chicago, IL, USA).

RESULTS

Reliability of the repeated sprint specific test

There were no substantial between-trial differences in any variable (i.e., ES < 0.2). All the other measures of reliability are presented in Table 1. The changes in performance to be considered small, moderate, and large are also displayed in Table 1.

***** Insert Table 1 near here*****

Between-age differences

Between-group differences (Table 2) showed substantially better performance in the older groups (U-14<U-15<U-16) in linear sprinting (ES: 0.64 to 1.44) and each RSA variable (ES: 0.59 to 1.77), except for $\%Dec_{RSG}$ and $\%Dec_{RSS}$ that was substantially better in the U-14 group in comparison to U-15 ($\%Dec_{RSS}$, ES: -0.6) and U-16 ($\%Dec_{RSG}$, ES: -0.62 and $\%Dec_{RSS}$, ES: -0.63). Substantially greater performance was found in U-15 (ES: 0.46) and U-16 (ES: 0.67) compared to U-14 in the $V_{20\text{-m ST}}$.

***** Insert Table 2 near here*****

When APHV was controlled, significant differences ($p > 0.05$) no longer apparent in the comparison from U-14 and U-16 in 25-m, the best and mean time in the general RSA test while remained ($p < 0.05$) in 5-m, 10-m, and the best and mean time in the specific RSA test. Furthermore, significant differences ($p < 0.05$) were also maintained when U-14 and U-15 were compared in the best time and the mean time in the general and specific RSA tests, respectively.

Multiple regression analyses

Stepwise multiple regression analyses (Table 3) showed that the mean time general RSA predictors (model *r* = 0.97) were 25-m sprint time, the $V_{20\text{-m ST}}$, and the percentage of body fat. The mean time in the specific RSA test was explained (model *r* = 0.91) through 25-m sprint time and the $V_{20\text{-m ST}}$.

***** Insert Table 3 near here*****

Relationships between anthropometric and physical test performance with repeated sprint performance

Correlation coefficients between anthropometric and physical test performance with repeated sprint performance (the mean time in both RSA tests) in the pool data are illustrated in Figure 2 and Figure 3, respectively.

***** Insert Figure 2 near here*****

***** Insert Figure 3 near here*****

Within group correlational analyses are presented in Table 4. Interestingly, almost perfect correlations (*r* range: 0.94 to 0.99) were found between RSA variables (i.e., RSG_b, RSG_m, RSS_b, and RSS_m).

***** Insert Table 4 near here*****

Similar relationships (i.e., same threshold) were found in the correlational analyses of the mean time in the RSA specific test after using APHV and body mass as covariates in each group and the pool data, except for the U-16 group controlled by body mass. Specifically, moderate to very large correlations were found between RSSm and the $V_{20\text{-m ST}}$ (r = -0.43), 5-m (r = 0.67), 10-m (r = 0.56), 25-m (r = 0.51), and RSSb (r = 0.73). On the other hand, only the relationships between the mean time in the RSA general test and MAS (r = -0.50) and 5-m (r = 0.55) were modified after controlling the body mass in the U-16 group.

DISCUSSION

The main aims of the present study were 1) to analyze the main predictors of two different repeated-sprint tests (general and specific), 2) to determine their relationships with other tests, 3) to establish the between-group differences in several age groups (U-14, U-15, U-16), and 4) to examine the influence of maturation on the predictors, relationships, and between-group differences. The main findings were: 1) in agreement with previous literature, the main determinants of repeated-sprint performance were linear sprinting (the main determinant) and aerobic performance in RSS_m, as well as % BF in RSG_m, 2) both general and specific repeated-sprint tests seem to assess a similar physical ability, 3) as age increased, greater performance in the best and mean scores in RSA appear to be evident, while %Dec seems to be worse, and 4) maturation influenced the ability to perform maximal long sprints (25-m) and the ability to repeat linear sprints over time (RSG_m), while not in the ability to repeat short sprints with changes of direction (RSS_m).

In line with previous investigations (4,6,22), linear sprinting and aerobic performance were the main determinants of both RSG and repeated specific sprint tests in the current study. When considering prior research, one study analyzed the main predictors of general RSA tests in team sport athletes, showing the best time (i.e., linear sprinting) and the final speed reached in an incremental test (i.e., aerobic performance) as the major predictors (6). The relevant finding from our investigation is the inclusion of %BF within the RSG model, but not in the repeated specific sprint test model. However, there was a very small difference using one predictor (25-m sprint) (R^2= 0.89) compared to two predictors (25-m sprint and %BF) (R^2= 0.92) to predict RSG performance. It suggests that %BF might not be the main predictor of RSA performance. Looking at the correlations, there were very large to almost perfect relationships between %BF and both RSA performances. Thus, it seems that %BF might be an important variable to consider for improving repeated sprinting, which is most likely related to the increased energy requirements when fatigue sets in. From a speculative point of view, in an in-depth analysis of several studies on team sports (19,30,36), maturation seems to be a key factor to consider the %BF in overall COD ability (speculatively repeated specific sprint). While COD performance was directly influenced by fat mass in pre-puberal team sports athletes (19,30), post-pubertal or adults depend on other variables to explain COD ability performance (19,36). Our basketball players were mid- and mainly post-pubertal, which is similar to the aforementioned data. It may be possible that anthropometric variables are important to change direction in pre-puberty, whereas post-puberal athletes may affect their performance through technical factors (i.e., foot placement, stride adjustment, and/or body lean and posture) rather than anthropometry. Nonetheless, maturation should be considered to avoid misinterpretation of the major predictors in RSA.

One of the most interesting findings was the almost perfect (r = 0.93 to 0.99) relationships between the best and the mean time in both RSA tests. These results are very similar to those found in a group of junior basketball players (in addition to other sports players) who performed two RSA tests (i.e., linear [RSG] and COD [repeated specific sprint test]) (best times r = 0.74; mean times r = 0.74) (31). Although correlations do not imply a cause-effect relationship, it may indicate that both tests (i.e., general, and specific RSA tests) assess a similar ability or at least share similar performance factors despite between-test differences in drill design. From a time-efficient point of view, it seems that there is no need to use both tests in a talent ID setting. However, some small differences in the main performance predictors and the influence of maturation on between-age differences might influence a practitioner's decision, as to how useful one is over the other. Furthermore, as linear sprinting distance increases (i.e., 5-10-25 m), greater relationships were found with the mean time in RSA tests. These results are in line with those reported across various group ages (38) and in young football players (25), where the mean RSA time was strongly related to maximum running (i.e., 20 m flying) than to acceleration (i.e., 10 m). In the same line as previous studies (4,6), there was a very large relationship between aerobic performance, and RSA mean time in both tests (i.e., repeated specific sprint test and RSG). Despite there being some evidence (10,16) that shows non-significant correlations between RSA and aerobic performance in basketball players (14,20), a follow-up study of two competitive seasons in youth basketballers (U-14 to U-19) found a significant contribution of aerobic performance on RSA development (x^2 [1] = 4.89; $p < 0.05$) (42). Additionally, those young team-sport players who have a greater aerobic performance before starting RSA training show significant positive adaptations in RSA performance in comparison to those players who had a lower aerobic performance at the beginning of the study (35). It is worth noting that depending on the metric used to quantify aerobic performance (i.e., $VO2_{max}$, maximal aerobic speed, final speed reached at the end of the endurance test, etc.) this might influence the relationship between measurements. As studies have used different metrics to assess aerobic performance based on the very close relationship between variables (r = 0.70 to 0.96), such small differences can affect the correlation magnitude as the unique direct aerobic performance measurement is VO_{2peak}. Thus, despite all metrics being strongly related to aerobic performance, caution should be taken into consideration when correlations are analyzed, as this is not causative. Notwithstanding, it seems logical to state that being fitter aerobically as well as sprinting faster might help to heighten your RSA performance.

To the best of our knowledge, the present study is the first time RSA age-related differences have been examined in youth basketball players. Previously, there were several assessments of youth football players showing better RSA performance (i.e., mean and best times) as age increases (25,38). Such tendencies are similar irrespective of assessing RSG or repeated specific sprint test. Interestingly, the U-16 *vs.* U-14 comparison showed the greatest differences (ES = 1.21 to 1.77; $p < 0.05$) in the mean and best times in both RSA tests. Despite no significant differences being found between U-16 *vs.* U-15 (repeated specific sprint test and RSG) and U-14 *vs.* U-15 (RSG), practical differences were still moderate to large (ES = 0.59 to 0.99) between each age category. These results are expected as physical performance increases significantly with age (37) through greater motor unit recruitment and muscle size (related to hormones such as testosterone), which directly impacts force production capability, greater anaerobic peak power or mechanical efficiency which affects speed performance, and higher aerobic peak power directly influencing aerobic performance (32). Specifically, RSA performance improves during adolescence, although a plateau occurs from the age of 15 (29) mainly due to players almost reaching full maturation. Thus, it seems logical that no significant differences were present between U-16 and U-15 players.

Regarding linear sprinting times, the current results are supportive of previously published research in young basketball players (11,17). It is worth noting that players with greater sprinting ability, irrespective of the age category (U-14, U-16, and U-18), performed a greater distance per minute of high-speed running during games (11). Despite maximal sprinting being considerably influenced by age (25,29,38), training focusing on linear sprinting enhancement should be considered for athletes of all ages, as its development may directly impact specific movement game demands. Finally, the final speed reached in the incremental running test was not significantly different between age groups. This was expected as aerobic performance may be attributed to unique match roles which are position-dependent, rather than age category per se (28). Similarly, neither %DecRSG nor %DecRSS showed significant between-group differences, albeit they did increase as age increased. The hypothetical relationship between aerobic performance and the %Dec (9) may explain the non-significant results. Furthermore, endurance capacity and muscle fatigability closely linked to aerobic performance seem very similar in prepubertal children and well-trained endurance athletes (33). Specifically, work capacity per anaerobic contribution, VO_2 constant, muscle phenotype, PCr recovery rate, pH recovery rate, and muscle fatigability are similar physiological variables (33). Therefore, the above results suggest that age influences RSA and linear sprinting, while fatigue and aerobic performance may not be age dependent.

Physical performance is commonly used to either select or not select players to be part of important competitions or teams. With this in mind, more mature basketball players have a greater probability of being selected to compete in an international championship, at the youth level (3). Hence, the key analysis is to understand whether maturation affects important physical abilities such as repeated sprinting, linear sprinting, and aerobic performance. Another interesting finding from our study was that linear sprinting (i.e., 25 m) and repeated linear sprinting (i.e., RSG) were directly influenced by maturation, but not the ability to repeat short sprints with a COD. Similar results have been found in a group of football players showing substantial between-age differences in maximal sprinting are not evident when APHV was controlled for (25). Furthermore, the interaction between being relatively older and advanced in maturity status corresponds to a substantial advantage on RSA in youth soccer players (14). Accordingly, it is recommended to control for APHV before establishing conclusions when players of the same chronological age are compared related to sprinting and repeated-sprinting abilities. The primary reason is because linear sprinting ability is mainly affected by power, strength, neural coordination, and flexibility (4), which are considerably altered by the maturation status (23). However, in addition to physical factors such as strength and linear sprinting, technical factors primarily impact the ability to optimize COD performance (5). Basketball players continuously change direction, accelerate, decelerate, and repeat these movements. As playing experience increases, the technical ability to perform such movements should (in theory) be improved. Consequently, as the significant between-age differences were still maintained after controlling APHV in the ability to repeat short sprints with COD, such ability may depend on technical factors or playing experience rather than maturation. Therefore, while the ability to perform linear and repeated linear sprints may be adjusted through maturation progression, the inclusion of multi-directional skills during adolescence should be a key factor as they need to be trained independently of the maturation status.

There are a couple of limitations in the present study which should be acknowledged. First, the present study's findings can only be attributed to youth basketball players.

Whilst this was of course our aim, we also referred to soccer studies throughout the discussion. Thus, future investigations may wish to consider between-sport comparisons, to determine if repeated sprint performance is specific to the movement demands of any given sport that is assessed. Second, despite the power calculations required 27 subjects (35 participants in the current study), when the sample was split the number of subjects per group was lower than required. It resulted in wide confidence intervals when calculating ES data. As such, mean differences between groups were required to be quite large, in order to showcase statistical significance. As is often the case in sports science-based research, larger sample sizes should be aimed for, where possible so that there is a greater chance of results being extrapolated to wider sporting populations.

PRACTICAL APPLICATIONS

The current results can help practitioners to use both specific testing and training methods, throughout maturation. When aiming to assess RSA ability, we suggest the use of repeated specific sprint test for basketball players, as COD movements are highly prevalent in the game. Furthermore, given basketball players typically perform a COD action every 2 s and players are virtually guaranteed to never sprint 25-m (as the court is 28 m in length), this further supports the notion of testing basketball players in a shorter distance RSA protocol, with the inclusion of a COD. From a long-term perspective, training methods should focus on concurrently improving linear sprinting and aerobic performance, which in turn, will assist in optimizing repeated-sprint performance. Furthermore, as locomotive demands are position-dependent, RSA should also be position-specific. Finally, maturation status should also be considered during the talent ID process to avoid misinterpretation during the player’s profile assessment.

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Figure Legends.

Figure 1. Description of the running course during the repeated specific sprint test. Sprints 1, 3, and 5 are performed from black to white circles, while sprints 2, 4, and 6 are executed from white to black circles.

Figure 2. Correlation coefficients (90% confidence limits) describing the relationships between repeated sprint performance in general repeated-sprint test (RSG_m) and age, height, body mass, percentage of body fat (%Body fat), age at peak height velocity (APHV), 5-m, 10-m, 25-m, best sprint time in general repeated-sprint test (RSG_b), the percentage of decrement in general repeated-sprint test ($\%Dec_{RSG}$), best (RSS_b) and mean (RSS_m) sprint time in specific repeated-sprint test, the percentage of decrement in specific repeated-sprint test ($\%Dec_{RSS}$), and the final speed reache in 20-m shuttle run test ($V_{20\text{-m ST}}$) for all players pooled together (n = 35).

Figure 3. Correlation coefficients (90% confidence limits) describing the relationships between repeated sprint performance in specific repeated-sprint test (RSS_m) and age, height, body mass, percentage of body fat (%Body fat), age at peak height velocity (APHV), 5-m, 10-m, 25-m, best (RSG_b) and mean (RSG_m) sprint time in general repeated-sprint test, the percentage of decrement in general repeated-sprint test ($\%Dec_{RSG}$), best (RSS_b) sprint time in specific repeated-sprint test, the percentage of decrement in specific repeated-sprint test ($\%Dec_{RSS}$), and the final speed reached in 20-m shuttle run test ($V_{20\text{-m ST}}$) for all players pooled together (n = 35).

Figure 1.

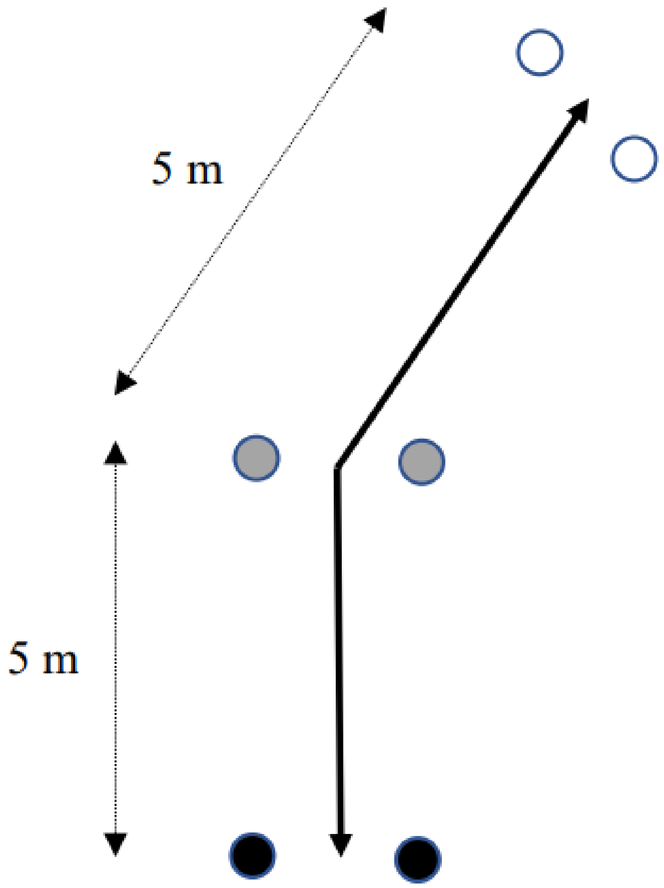
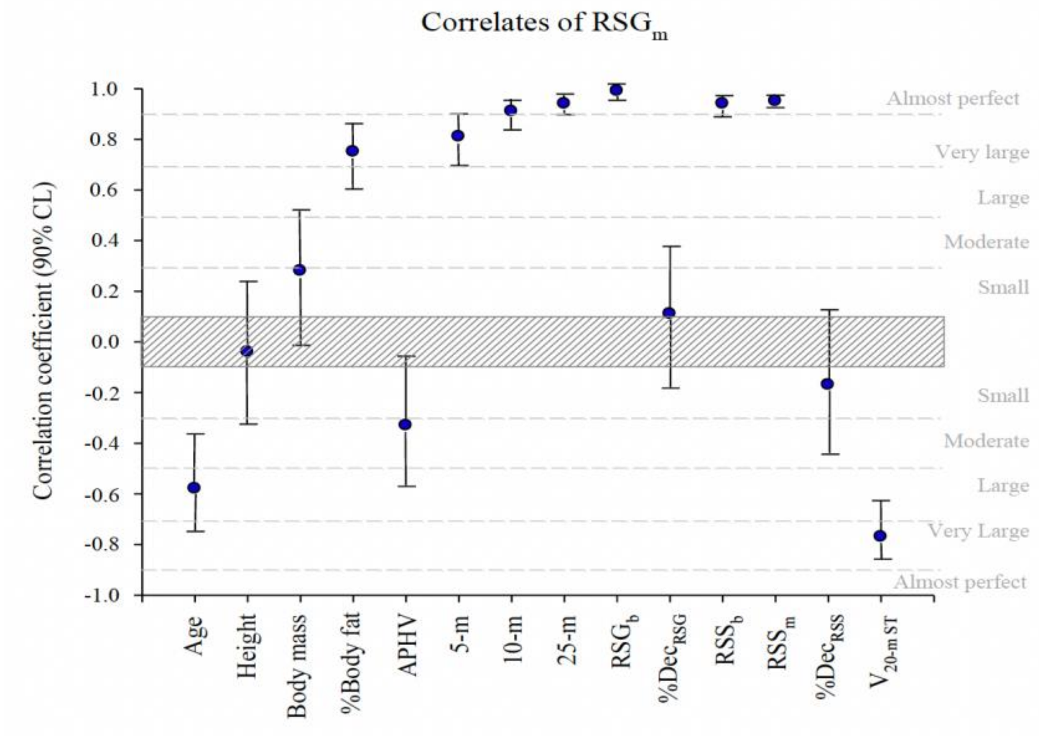
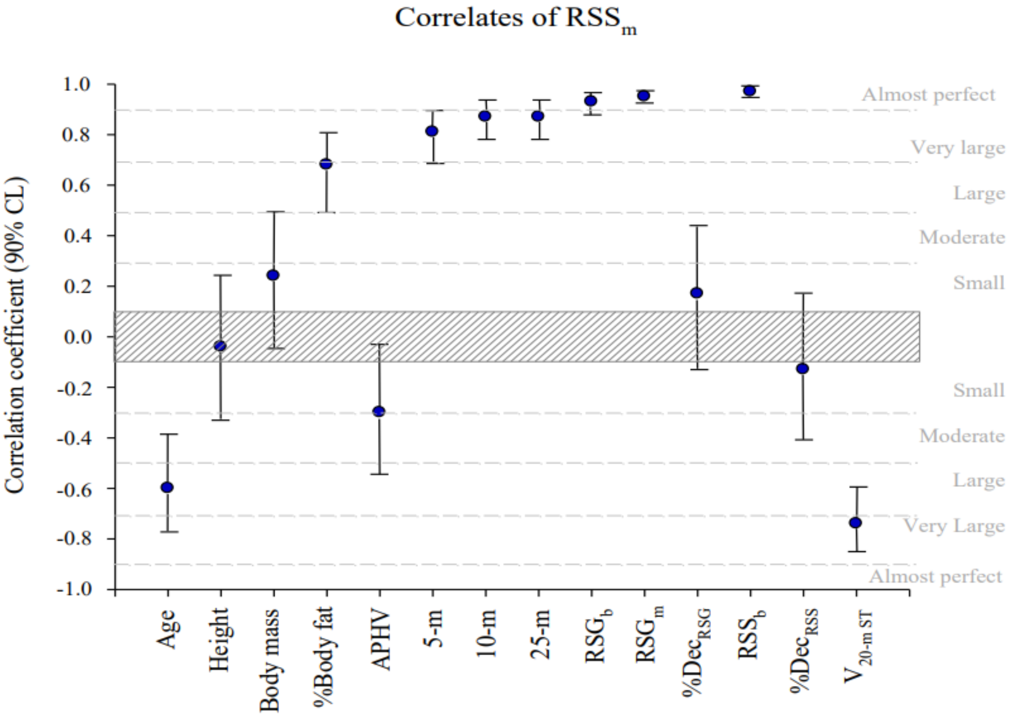


Figure 2.



Correlates of RSG$_m$
Correlation coefficient (90% CL)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
Almost perfect
Very large
Large
Moderate
Small
Small
Moderate
Large
Very Large
Almost perfect
Age
Height
Body mass
%Body fat
APHV
5-m
10-m
25-m
RSG$_b$
%Dec$_{RSG}$
RSS$_b$
RSS$_m$
%Dec$_{RSS}$
V$_{20\text{-m ST}}$

Figure 3.



Correlates of RSSm
Correlation coefficient (90% CL)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
Almost perfect
Very large
Large
Moderate
Small
Small
Moderate
Large
Very Large
Almost perfect
Age
Height
Body mass
%Body fat
APHV
5-m
10-m
25-m
RSGb
RSGm
%DecRSG
RSSb
%DecRSS
V20-m ST

Table 1. Measures of reliability in the repeated-sprint specific test (n=15).

	Session 1	Session 2	TEM (90% CL)	CV (90% CL)	ICC (90% CL)	Difference (90% CL)	ES (90%CL) (rating)	SWC 0.2 (%) (rating of usefulness)	SWC 0.6 (%) (rating of usefulness)	SWC 1.2 (%) (rating of usefulness)
$RSSR_b$	1.87 ± 0.16	1.86 ± 0.15	0.02 (0.01, 0.03)	1.0 (0.7; 1.6)	0.99 (0.97, 1.00)	-0.01 (-0.02, 0.01)	-0.04 (-0.14, 0.05) Trivial	0.03 (1.6%) Ok	0.093 (4.98%) Good	0.186 (9.97%) Good
$RSSL_b$	1.89 ± 0.13	1.91 ± 0.13	0.02 (0.01, 0.03)	0.8 (0.6; 1.3)	0.99 (0.97, 1.00)	0.02 (0.01, 0.03)	0.14 (0.06, 0.23) Trivial	0.026 (1.37%) Ok	0.078 (4.1%) Good	0.156 (8.2%) Good
RSS_b	1.85 ± 0.14	1.86 ± 0.15	0.02 (0.02, 0.03)	1.1 (0.8; 1.9)	0.99 (0.95, 1.00)	0.01 (-0.01, 0.03)	0.05 (-0.06, 0.16) Trivial	0.029 (1.56%) Ok	0.087 (4.69%) Good	0.174 (9.38%) Good
$RSSR_m$	1.91 ± 0.15	1.90 ± 0.12	0.05 (0.04, 0.08)	2.6 (1.9; 4.4)	0.89 (0.69; 0.96)	-0.03 (-0.07, 0.01)	-0.09 (-0.18, 0.03) Trivial	0.027 (1.42%) Marginal	0.081 (4.25%) Good	0.162 (8.5%) Good
$RSSL_m$	1.93 ± 0.12	1.91 ± 0.14	0.03 (0.02, 0.05)	1.7 (1.2, 2.8)	0.96 (0.87, 0.99)	-0.03 (-0.05, 0.00)	-0.15 (-0.26,-0.01) Trivial	0.026 (1.35%) Ok	0.078 (4.1%) Good	0.156 (8.12%) Good
RSS_m	1.92 ± 0.13	1.90 ± 0.14	0.02 (0.01, 0.03)	1.1 (0.8, 1.8)	0.98 (0.94, 0.99)	-0.03 (-0.05, 0.02)	-0.14 (-0.24, -0.04) Trivial	0.027 (1.41%) Ok	0.081 (4.24%) Good	0.162 (8.48%) Good

TEM: typical error of measurement; CL: confidence limits; CV: coefficient of variation expressed as percentage of TEM; ICC: Intraclass correlation coefficient; Difference: difference in mean between the 2 trials; ES: effect size and ES rating (see methods); SWC: smallest worthwhile change (0.2 x standard deviation (SD) = $SWC_{0.2}$; 0.6 x SD = $SWC_{0.6}$; 1.2 x SD = $SWC_{1.2}$) and rating of usefulness; RSSRb: the best time of the right side in the repeated-sprint specific (RSS) test, RSSLb: the best time of the left side in the RSS test; RSSb: the best time in the RSS test; RSSRm: the mean time of the right side in the RSS test, RSSLm: the mean time of the left side in the RSS test; RSSm: the mean time in the RSS test.

Table 2. Physical characteristics for U-14, U-15, and U-16 basketball players (mean ± SD) and between-group differences in speed tests, repeated sprint general and specific tests, and 20-m shuttle run test.

Variable	Age groups			Between-age differences		
	U-14 (n = 15)	U-15 (n = 11)	U-16 (n = 9)	U-14 vs. U-15	U-16 vs. U-14	U-16 vs. U-15
Age (years)	12.9 ± 0.4	14.4 ± 0.3	15.6 ± 0.7	4.06 (3.43; 4.69)*	4.82 (4.10; 5.54)*	2.28 (1.50; 3.06)*
Height (m)	1.76 ± 0.08	1.80 ± 0.1	1.87 ± 0.1	0.42 (-0.25; 1.08)	1.14 (0.43; 1.85)*	0.66 (-0.09; 1.40)
Body mass (kg)	60.7 ± 9.2	62.0 ± 9.7	73.9 ± 14.7	0.11 (-0.56; 0.78)	1.08 (0.35; 1.81)*	0.92 (0.16; 1.67)
Arm span (cm)	179.6 ± 8.1	182 ± 9.9	192.4 ± 11.2	0.24 (-0.43; 0.91)	1.22 (0.49; 1.95)*	0.92 (0.17; 1.67)
Leg length (cm)	85.1 ± 5.4	87.3 ± 5.7	93.1 ± 7.5	0.37 (-0.29; 1.03)	1.13 (0.40; 1.86)*	0.80 (0.04; 1.55)
Percent body fat (%)	13.9 ± 6.1	11.6 ± 2.8	13.2 ± 6.2	-0.46 (-1.11; 0.18)	-0.13 (-0.85; 0.58)	0.27 (-0.50; 1.03)
Years to/from APHV	0.2 ± 0.7	1.3 ± 0.7	2.2 ± 0.8	1.33 (0.54; 2.12)*	1.74 (0.95; 2.54)*	1.02 (0.25; 1.78)*
5-m sprint (s)	1.15 ± 0.09	1.11 ± 0.05	1.06 ± 0.08	0.64 (0.01; 1.28)	1.14 (0.43; 1.85)*#	0.72 (-0.06; 1.49)
10-m sprint (s)	1.96 ± 0.13	1.88 ± 0.07	1.78 ± 0.12	0.72 (0.09; 1.35)	1.34 (0.63; 2.04)*#	0.9 (0.13; 1.68)
25-m sprint (s)	4.13 ± 0.27	3.91 ± 0.11	3.76 ± 0.24	1.02 (0.39; 1.64)	1.44 (0.74; 2.15)*	0.8 (0.02; 1.59)
RSG_b (s)	4.19 ± 0.29	3.95 ± 0.14	3.78 ± 0.32	0.99 (0.36; 1.62)	1.33 (0.6; 2.06)*	0.71 (-0.07; 1.5)
RSG_m (s)	4.3 ± 0.3	4.08 ± 0.16	3.91 ± 0.35	0.89 (0.26; 1.53)	1.21 (0.48; 1.94)*	0.65 (-0.14; 1.43)
$\%Dec_{RSG}$ (%)	2.75 ± 1.15	3.19 ± 1.45	3.38 ± 1.06	-0.24 (-0.91; 0.43)	-0.62 (-1.3; 0.06)	-0.27 (-1; 0.46)
RSS_b (s)	2.07 ± 0.12	1.92 ± 0.1	1.83 ± 0.14	1.31 (0.65; 1.97)*#	1.77 (1.03; 2.51)*#	0.7 (-0.07; 1.46)
RSS_m (s)	2.12 ± 0.13	1.99 ± 0.1	1.92 ± 0.14	1.15 (0.5; 1.8)*#	1.5 (0.77; 2.23)*#	0.59 (-0.18; 1.36)
$\%Dec_{RSS}$ (%)	2.67 ± 1.05	3.54 ± 1.44	4.51 ± 2.88	-0.6 (-1.27; 0.07)	-0.63 (-1.39; 0.14)	-0.19 (-0.96; 0.58)
$V_{20\text{-m ST}}$ (km/h)	12.63 ± 0.84	12.98 ± 0.62	13.25 ± 0.88	0.46 (-0.18; 1.1)	0.67 (-0.04; 1.38)	0.32 (-0.45; 1.09)

Note: APHV: age at peak height velocity; RSG_b: best sprint time in the repeated sprint general test; RSG_m: mean sprint time in the repeated sprint general test; $\%Dec_{RSG}$: percentage of decrement in the repeated sprint general test; RSS_b: best sprint time in the repeated sprint specific test; RSS_m: mean sprint time in the repeated sprint specific test; $\%Dec_{RSS}$: percentage of decrement in the repeated sprint specific test, $V_{20\text{-m ST}}$: final speed reached at 20-m shuttle run test; ES: effect size; CL: confidence limit. *: $p<0.05$; #: $p<0.05$ when APHV is controlled.

Table 3. Predictors of repeated sprint performance.

		Variables	Standardized coefficient	Partial r	*p*	R^2	r	Rating
RSGm	**model 1**	*Intercept*				0.89	0.94 (0.90; 0.97)	Almost perfect
		25-m	0.94	0.94	<0.001			
	model 2	*Intercept*				0.92	0.96 (0.94; 0.98)	Almost perfect
		25-m	0.78	0.91	<0.001			
		%BF	0.25	0.57	0.001			
	model 3	*Intercept*				0.94	0.97 (0.95; 0.99)	Almost perfect
		25-m	0.71	0.89	<0.001			
		%BF	0.18	0.43	0.014			
		20-m ST	-0.17	-0.40	0.024			
RSSm	**model 1**	*Intercept*				0.79	0.89 (0.81; 0.94)	Very large
		25-m	0.89	0.89	<0.001			
	model 2	*Intercept*				0.84	0.91 (0.86; 0.96)	Almost perfect
		25-m	0.67	0.77	<0.001			
		20-m ST	-0.31	-0.49	0.003			

Note: Coefficient of determination (R^2, stepwise regression model) and associated correlation coefficient (r) illustrating the relationships between repeated sprint performance in general (RSG_m) or specific (RSS_m) and 25-m linear sprint test, percentage of body fat (%BF) and the final speed reached in 20-m shuttle run test ($V_{20\text{-m ST}}$) for all players pooled together (n = 35). The rest of variables were excluded from the models.

Table 4. Relationship between repeated sprint general (RSG_m) and specific (RSS_m) performance and the selected variables within each age group.

		Body mass	%Body fat	5-m	10-m	25-m	RSGb	RSGm	%DecRSG	RSSb	RSSm	%DecRSS	20-m ST
U-14 (n= 15)	RSGm	0.40 (-0.05; 0.71)	0.77 (0.49; 0.91)	0.65 (0.28; 0.34)	0.83 (0.61; 0.93)	0.93 (0.82; 0.97)	0.99 (0.97; 0.99)	-----	0.09 (-0.37; 0.51)	0.99 (0.97; 0.99)	0.96 (0.89; 0.98)	0.09 (-0.37; 0.51)	-0.72 (-0.88; -0.41)
	RSSm	0.61 (0.23; 0.83)	0.85 (0.65; 0.94)	0.72 (0.41; 0.88)	0.82 (0.59; 0.93)	0.85 (0.64; 0.94)	0.92 (0.80; 0.97)	0.96 (0.89; 0.98)	0.24 (-0.23; 0.61)	0.99 (0.97; 1)	-----	0.56 (0.16; 0.8)	-0.78 (-0.91; -0.51)
U-15 (n=11)	RSGm	0.66 (0.21; 0.88)	0.77 (0.42; 0.92)	0.92 (0.77; 0.98)	0.89 (0.69; 0.97)	0.81 (0.49; 0.93)	0.94 (0.81; 0.98)	-----	0.47 (-0.08; 0.80)	0.94 (0.81; 0.98)	0.87 (0.63; 0.96)	0.46 (-0.08; 0.8)	-0.47 (-0.80; 0.07)
	RSSm	0.42 (-0.14; 0.77)	0.8 (0.47; 0.93)	0.87 (0.65; 0.96)	0.92 (0.78; 0.98)	0.76 (0.4; 0.92)	0.74 (0.36; 0.91)	0.87 (0.63; 0.96)	0.58 (0.09; 0.85)	0.97 (0.9; 0.99)	-----	-0.21 (-0.66; -0.35)	-0.55 (-0.84; -0.04)
U-16 (n= 9)	RSGm	0.90 (0.66; 0.97)	0.96 (0.86; 0.99)	0.88 (0.63; 0.97)	0.96 (0.84; 0.99)	0.97 (0.9; 0.99)	0.99 (0.98; 1.00)	-----	0.49 (-0.13; 0.84)	0.99 (0.9; 0.99)	0.97 (0.89; 0.99)	0.49 (-0.13; 0.84)	-0.91 (-0.98; -0.69)
	RSSm	0.87 (0.58; 0.96)	0.82 (0.46; 0.95)	0.91 (0.7; 0.98)	0.89 (0.64; 097)	0.88 (0.6; 0.97)	0.98 (0.92; 0.99)	0.97 (0.89; 0.99)	0.37 (-0.28; 0.78)	0.93 (0.77; 0.98)	-----	0.1 (-0.52; 0.64)	-0.88 (-0.97; -0.62)

Note: Correlations coefficients (90% confidence limits) describing the relationships between repeated sprint general (RSG_m) and specific (RSS_m) performance and body mass, percentage of body fat (%BF), 5-m,10-m, and 25-m sprint tests, best (RSG_b) and mean (RSG_m) sprint time, and percentage of decrement ($\%Dec_{RSG}$) in general repeated sprint test, best (RSS_b) and mean (RSS_m) sprint time, and percentage of decrement ($\%Dec_{RSS}$) in specific repeated sprint test and the final speed reached in 20-m shuttle run test ($V_{20\text{-}m\ ST}$) in U-14, U-15 and U-16 basketball players.