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Relationship between Explosive Performance Measurements of the Lower Limb and Repeated Shuttle-Sprint ability in Elite Adolescent Handball Players

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ABSTRACT

This study investigated the relationship between performance measures of the lower-limb and repeated shuttle-sprint ability (RSSA) in elite adolescent handball players. Twenty-two male handball players (age: 17.7 ± 0.3 years) participated in the study. Subjects underwent measurements of lower-limb maximal strength (1-RM half back squat), explosive power (force-velocity test), jumping ability (squat and counter-movement jumps), sprinting velocities over the first step (V_S) and the first 5 m (V_5) of a 15 m sprint, and Yo-Yo Intermittent Recovery Test, Level 1. The players were tested for RSSA using a protocol of 6 repetitions of maximal 2 x 15-m shuttle sprints with 180° turns (~6 s) departing every 20 s. RSSA results were evaluated in three ways: best time in a single trial ($RSSA_{best}$), decrement ($RSSA_{dec}$) and total time ($RSSA_{TT}$). The correlations of RSSA with the assorted fitness measures varied considerably. The $RSSA_{TT}$ and $RSSA_{dec}$ were positively associated with 1-RM half back squat (r = 0.78 and r = 0.68 respectively; p< 0.01). Significant correlations were also found between $RSSA_{TT}$ and

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$RSSA_{best}$ and absolute peak power of the lower limb (r = -0.81 and -0.66, respectively; p<0.01). There was a moderate correlation between first step sprinting velocities and $RSSA_{TT}$ (r= -0.71; p< 0.01). The RSSA test score has a moderate to large association with other explosive power measurements in elite adolescent handball players. RSSA may provide a useful composite index on responses to training or rehabilitation, and is very suitable for monitoring athletic performance of the lower-limbs of elite adolescent handball players.

Key words: Power, Repeated Shuttle-Sprint Ability, Strength, Vertical Jump, Youth Handball

INTRODUCTION

The ability of athletes to perform repeated sprints and changes in direction is regarded by coaches and researchers as a predictor of superior performance in many intermittent and team sports. In handball, players are required to repeat sequences of short explosive efforts, such as sprints (<15 m) with frequent changes in direction [1-3], with players' physique and physiological attributes contributing to game success [1, 2, 4]. Frequent high-speed, multidirectional movements, coupled with deceleration and continuous jumping during a game, demonstrate the importance of anaerobic fitness to competitive success [2, 3, 5]. In addition, top level performance in handball appears heavily dependent on a player's anaerobic power (leaping ability), while aerobic capacity does not play a major role [1-3]. Consequently, the assessment and development of traditional fitness parameters, such as explosive strength and anaerobic power, is a common handball practice, especially during the in-season competitive period [6, 7].

Based on game time-motion analysis, RSA has strong ecological validity and is believed to be an important fitness component of many team sports, including handball (28, 32). For this reason, several different tests are used by sport scientists and coaches to assess the physical performance of handball players [1, 6, 7]. These tests include the assessment of sprint and repeated shuttle-sprint ability (RSSA), and muscular power [1]. The ability to recover and reproduce performance in subsequent sprints, termed repeated-sprint ability, is believed to be a specific fitness requirement of handball and other team sport athletes [1, 8]. Therefore, the relevance of RSSA tests for handball is mainly based on their ecological validity as these tests require the repetition of handball-specific high-intensity activities (i.e., repeated sprints with or without directional changes) and similar metabolic requirements [8]. Therefore, in handball it seems logical to evaluate the athletes' ability to repeatedly perform intense exercise and with that his/her potential to recover from intensive efforts. The relevance of RSA tests for handball is mainly based on their perceived ecological validity and the belief that these tests mimic the demands of competitive play. Replicating game demands during repeated-sprint sequences appears crucial regarding testing and training specificity [5, 9]. In addition, handball-specific RSSA test protocols have been recently presented [1, 4, 10].

Because RSSA is considered a critical factor for performance in handball, strength and conditioning coaches are interested in how to develop this quality in their athletes. In order to do so, they need a strong understanding of the RSSA determinants and possible association with other specific explosive lower limb qualities. Unfortunately, while considerable attention has been devoted to the energetic requirements of RSSA, few studies have established the relationship between fitness parameters and RSSA [11, 12]. In addition, no study has evaluated these relationships in top-level handball players. It is likely that such information could be particularly important for coaches and fitness trainers working with elite handball players. Therefore, the aim of this study was to investigate the relationship between measures of explosive power of the lower limb and the handball specific RSSA test in a sample of elite-level adolescent handball players.

METHOD

DESIGN

This study was designed to examine the possible association between the RSSA test and performance tests of explosive power of the lower limbs (estimated by lower-limb force velocity tests, first step and 5-m sprint; squat and counter movement jump tests; and Yo-Yo intermittent recovery test, Level 1) in top level handball players. Pearson's product moment correlations and linear regression analysis were used to examine the relationships between RSSA performance and the various physical tests related to handball. We hypothesized that repeated shuttle-sprint ability would be significantly associated with explosive measurements of the lower limb, but not high-intensity, intermittent running ability (as estimated from the Yo-Yo intermittent recovery test).

SUBJECTS

All subjects were members of the development program of the same professional handball club, and involved in regular handball competition at the time of the study. Twenty-two national-elite top level male handball players from one team (age: 17.7 ± 0.3 years, body mass: 91.0 ± 5.0 kg, height: 1.89 ± 0.09 m, percentage body fat: 12.8 ± 1.1 %; handball experience: 8.3 ± 0.2 years) participated in the study. All procedures were approved by the Institutional Review Committee for the ethical use of human subjects, according to current national laws and regulations. All players were examined by the team physician, focusing on orthopaedic and other conditions that might preclude testing and found to be in good health. Subject and/or parental/guardian consent was provided before participation in the study after receiving both a verbal and a written explanation of the experimental design and its potential risks.

TESTING BATTERY

The RSSA protocol employed 2 x 15-m shuttle sprints with 180° turns (~6 s) departing every 20 s. An active walk recovery was used between sprints [6]. All players completed two familiarization trials in the two weeks prior to the main testing. The testing battery included explosive test measurements of the lower limbs, the RSSA test, 1-RM half back squats, first step and 5-m velocity over a 15-m sprint, squat (SJ) jump, counter movement jump (CMJ), a force-velocity test to evaluate the peak power (Wpeak) of the lower limbs and the Yo-Yo intermittent recovery test, level 1. The testing sessions were conducted at the same time of the day, and under the same experimental conditions, at least 3 days after the most recent competition. All participants were tested using identical protocols and the tests were completed in a fixed order. Verbal encouragement was given for all maximal effort tests.

TESTING SCHEDULE

Day 1

Repeated-shuttle sprint ability (RSSA) test

Before the test, players completed a warm-up consisting of 10 minutes of jogging supplemented with an additional 3-5 single 15-m shuttle sprints with 2 minutes of passive recovery. No static stretching was allowed before the RSSA protocol. An additional 3 min rest was given before players undertook the handball specific RSA test protocol [13]. The test consisted of 6 repetitions of maximal 2 x 15-m shuttle sprints with 180° turns (~6 s) departing every 20 s [6]. During the ~15-s recovery between sprints, subjects were required to perform an active recovery (brisk walk back to the starting line). Three seconds before starting each sprint, the subjects were asked to assume the start position and await the start signal. Two sets of timing gates (Microgate Srl; Italy) were used, working in opposite directions, to allow subjects to start the next run from the same end at which they had finished the preceding sprint. Each sprint was initiated from an individually chosen standing position, 50 cm behind the timing gate, which started a digital timer. Strong verbal encouragement was provided to each subject during all sprints, and subjects were instructed to produce maximal effort for each sprint and to avoid pacing themselves. Three scores were calculated for each RSSA test; best sprint time in a single trial ($RSSA_{best}$), total sprint time ($RSSA_{TT}$) and fatigue ($RSSA_{dec}$), calculated using the percentage decrement method: 100 – (Total time / ideal time × 100); where the ideal time = 6 × RSA best [12].

Day 2

One Repetition Maximum (1RM) Back Half-Squat at 90 °

Each participant kept an upright position, looking forward and firmly grasping the bar with both hands. The bar was also supported on the shoulders. Then the subject bent his knees until he reached the limit of 90 degrees. After reaching this position, the subject raised himself to the upright position with the lower limbs completely extended. Because this technique was unfamiliar for the participants in this study, an instructor explained and demonstrated this lifting technique. All subjects performed 8 technical training sessions during the month preceding the 1-RM measurements. During the familiarization session, a pretest 1-RM was performed to determine the approximate 1-RM value. To measure the experimental 1-RM values, a barbell was loaded with free weights across the upper back of the participant and using an initial loading corresponding to 90% of the pretest 1-RM. Two consecutive loaded flexion–extensions were performed at 90 degrees of knee flexion (a back half squat). Each time the 2 repetitions were mastered, a load of 5 kg was added after allowing a recovery interval of at least 5 minutes. When the subject performed 2 successful repetitions with his pretest 1-RM value, a load of 1 kg was added after the recovery period. If the individual was unable to successfully complete the second repetition with the new loading, the corresponding load was considered as the individual's 1-RM. The average number of lifting actions before reaching 1-RM was 3 to 6.

Day 3

The force–velocity test

Force–velocity measurements for the lower limbs were performed on a standard Monark cycle ergometer (model 894 ^{E}, Monark Exercise AB, Vansbro, Sweden) as described elsewhere [14,15]. In brief, the instantaneous maximal pedaling velocity during a 7-second all-out sprint was used to calculate the maximal anaerobic power for each braking force, and the subject was judged to have reached peak power (Wpeak) if an additional load induced a decrease in power output. The parameters measured included Wpeak, maximal pedaling force for lower limbs ($F0_{LL}$) and maximal pedaling velocity for lower limbs ($V0_{LL}$). After a 5-minute recovery, the braking was increased in sequence to 2, 3, 4, 5, 6, 7, 8, and 9% of body mass.

Day 4

Squat Jump (SJ) and Countermovement Jump (CMJ)

Characteristics of the SJ and the CMJ were determined by a force platform (Quattro Jump, version 1.04; Kistler Instrumente AG, Winterthur, Switzerland). The calculation method and the apparatus have been previously described [16]. The displacement of the center of gravity during the flight (h) corresponds to the jumping height and is calculated using the recorded flight time (tf) as follows [16]:

$$h = \frac{g * t}{8}$$

where "g" is the acceleration of gravity (9.81 m/s^2). In short, this apparatus comprises a digital timer (accuracy 0.001 second) connected to a resistive platform. The timer is triggered by the feet of the individual at the moment of release from the platform and is stopped at touchdown. Thus, the flight time during the jump is recorded and allows the determination of the height reached during the jump. This method of calculation assumes that the positions of the jumpers on the apparatus were the same on take-off and on landing. Because the flight time is used to calculate the jump height, strict instructions were addressed to all subjects to keep their legs straight during the flight time of the jump. During the CMJ, the subject starts from an upright standing position on the contact mat, makes a downward movement until approximating a knee angle of 90 degrees, and subsequently begins to push off. During the SJ, the subject starts from a knee angle of 90 degrees and performs a vertical jump by pushing on his legs. During SJ, all subjects were instructed to avoid any downward movement before the pushing phase. For both jumps (SJ and CMJ), all subjects performed familiarization trials before doing 3 consecutive experimental trials for each jump. The highest value for each jump was retained.

Sprint Running Performance

After familiarization, subjects made a maximal 15-m sprint on an outdoor tartan surface. Body displacement was filmed by 1 camera (Sony Handycam, DCR-PC105^E, Tokyo, Japan; 25 frames per second) placed at a distance of 10 m perpendicular to the running lane. The camera filmed the individual over the first 5 m. Participants performed 2 trials, seperated by an interval of 5 minutes. Appropriate software (Regavi and Regressi; Micrelec, Coulommiers, France) converted measurements of hip displacement to the corresponding velocities: the first step after the start (V1S) and the first 5 m (V5m). The reliability of the camera and the data processing software has been confirmed previously [15, 17].

Day 5

Yo-Yo Intermittent Recovery Test Level 1 (IR1)

The IR1 was performed according to the procedures suggested by Bangsbo [18]. The test consists of repeated 2 x 20 m runs back and forth between the starting, turning, and finishing line at a progressively increased speed controlled by an audio metronome from a calibrated CD player. The participants had a 10-s active rest period (decelerating and walking back to the starting line) between each running bout. When a participant failed twice to reach the finishing line in time, or decided that he could no longer run at the imposed pace, the total distance covered was recorded.

STATISTICAL ANALYSIS

Descriptive statistics were calculated for each variable as mean ± standard deviation (SD).

Before using parametric tests, the assumption of normality was verified using the Shapiro-Wilk test. Pearson's product moment correlations and linear regression analysis were used to examine the relationships between RSSA performance and the various physical tests related to handball. The level of significance was set at 0.05. The reliability of data and 95% confidence intervals (95% CI) were calculated using the methods outlined by Fisher (20) and presented where appropriate (Table 1). The following criteria were adopted for interpreting the magnitude of correlation (*r*) between the measures: < 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 [19]. All analyses were performed using SPSS v 13 (SPSS, Inc., Chicago, IL, USA).

RESULTS

The data obtained for all performance parameters are presented in Table 2. The mean (±SD) for $RSSA_{TT}$, $RSSA_{best}$, $RSSA_{Mean}$ and $RSSA\ \%_{dec}$ were 37.25 ± 1.53 s, 6.1 ± 0.1 s, 6.2 ± 0.1 and 3.80 ± 0.67%, respectively. The 1-RM half back squat was closely related to both the $RSSA_{TT}$ and $RSSA_{Dec}$ (r= 0.78 and r = 0.68, p< 0.05) (Table 3; Figure 1). Strong correlations were also found between absolute PP_{LL} calculated from the force-velocity test, $RSSA_{TT}$ and $RSSA_{best}$ (r = -0.81 and r = -0.66, p<0.01; Table 3; Figure 2). Moderate correlations were also shown between velocity of the first step, $RSSA_{TT}$ and $RSSA_{dec}$ (r=-0.71, p< 0.01 and r =-0.70, p< 0.05; Table 3; Figure 3). The total distance covered for the Yo-Yo IR1 was significantly correlated with $RSSA_{TT}$ and $RSSA_{dec}$ (r = 0.57, p < 0.01and r = 0.63, p< 0.001). No significant associations were observed for the other RSSA test variables and countermovement jump performance and squat jump (all p > 0.05).

Table 1. Intraclass correlation coefficients for relative reliability and coefficient of variation of the measured parameters (n = 22)

	ICC	95%IC	CV (%)
Repeated-shuttle sprint ability test (RSSA)	0.95	0.98-0.94	3.3
1-RM strength half back squat (kg)	0.92	0.82-0.96	4.2
Force velocty test of lower limb			
Power (W)	0.98	0.86-0.95	3.6
Yo-Yo Intermittent Recovery Test (IR1)			
Distance covered (m)	0.96	0.91-0.98	3.3
Track running velocity ($m.s^{-1}$)			
First step (VS)	0.96	0.90-0.98	5.2
First 5 m (V5)	0.82	0.56-0.91	4.3
Jump tests			
Squat jump (cm)	0.96	0.90-0.98	4.5
Countermovement jump (cm)	0.97	0.95-0.99	2.8

ICC = intraclass correlation coefficient; CI = confidence interval; CV = coefficient of varation

Table 2. Results of the measured parameters, values are given as mean ± SD (n = 22)

	Mean	**± SD**
Repeated-shuttle sprint ability test (RSSA)		
Total Time (s)	37.25	1.53
Mean Time (s)	6.18	0.10
Best Time (s)	6.11	0.10
%dec	3.80	0.67
Yo-Yo Intermittent Recovery Test (IR1)		
Distance covered (m)	1745.45	404.08
Maximal strength of lower limb		
1-RM half back squat (kg)	202.68	17.76
Force–velocity test		
Power (W)	815.77	170.19
Power ($W.kg^{-1}$)	9.98	1.64
Jumps test values		
Squat jump (cm)	43.02	3.48
Countermovement jump (cm)	45.73	2.26
Track running velocity ($m.s^{-1}$)		
First step (VS)	3.61	0.38
First 5 m (V5)	6.17	0.52

Table 3. Correlation coefficients obtained between repeated shuttle-sprint ability (RSSA) test performances and the measured parameters (n = 22 for all relationships)

	Total Time	**Mean Time**	**Best Time**	**%dec**
1-RM half back squat (kg)	0.78**	0.50*	0.14	0.68**
Power (W)	-0.81**	-0.02	-0.66**	-0.67**
Power (W.kg-1)	-0.70**	-0.14	-0.21	-0.40
Squat jump (cm)	-0.06	-0.21	-0.05	0.03
Counter movement jump (cm)	-0.23	0.17	0.00	-0.05
First step (VS)	-0.71**	-0.22	-0.40	-0.70*
First 5 m (V5)	-0.54**	0.29	-0.45*	-0.38
Distance covered of Yo-Yo test IR1	0.57**	0.74**	0.23	0.63**

*p< 0.05; **p <0.01

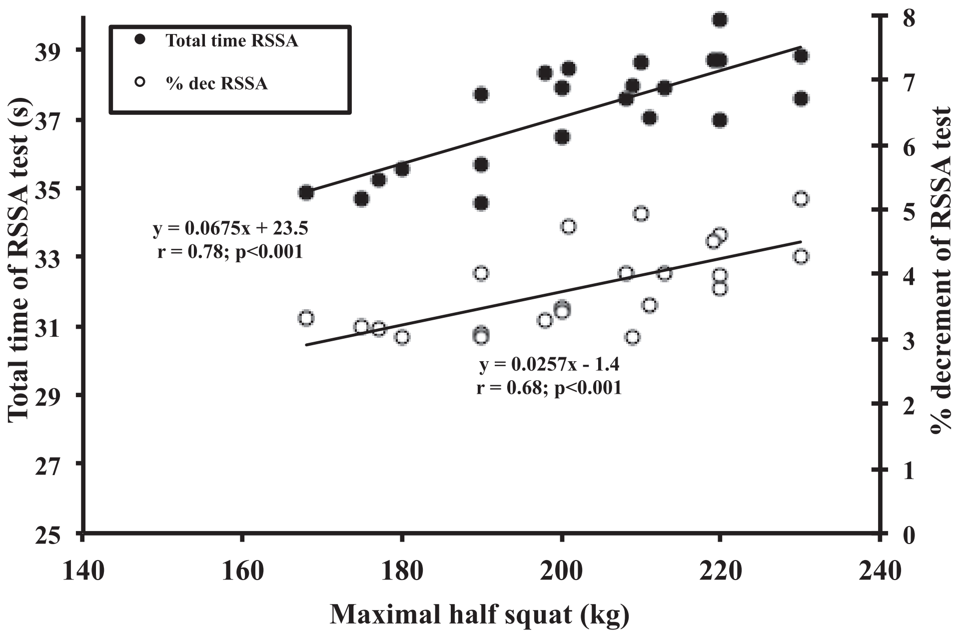

Figure 1. Relationship between the maximal strength of lower limb, total time and % decrement of RSSA ($RSSA_{dec}$) test performances

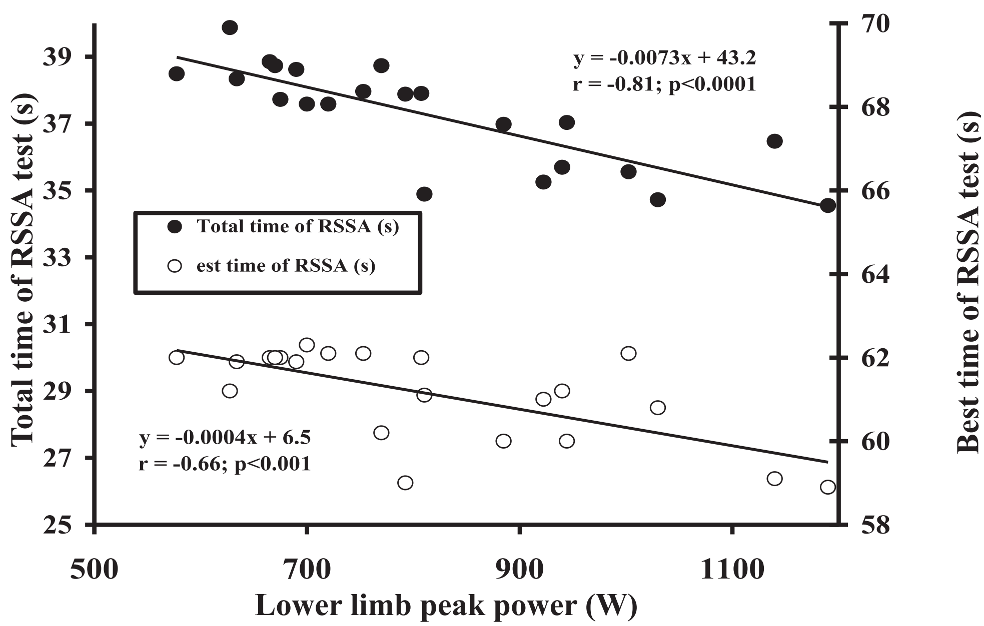

Figure 2. Relationship between absolute lower limb peak power, total time ($RSSA_{TT}$) and best time ($RSSA_{best}$) of the RSSA test

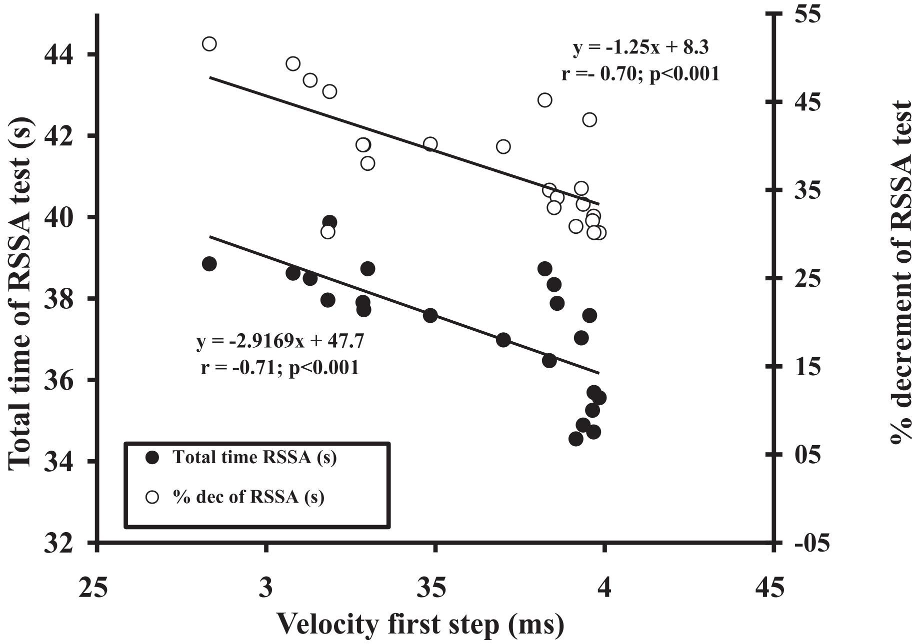

Figure 3. Relationship between sprinting ability over the first step, total time (RSS_{ATT}) and % decrement of RSSA test performances ($RSSA_{dec}$)

DISCUSSION

In accordance with our hypothesis, the main finding from this study is that the performance indices of the RSSA test were significantly associated with several explosive athletic qualities related to handball. A very large correlation was reported between lower body anaerobic power, as measured by the force-velocity test, and performance time in the RSSA test. This is the first investigation to demonstrate a relationship between explosive lower limb muscles measurements and repeated shuttle-sprint ability in handball players.

In recent years, many researchers have tried to establish relationships between muscle strength and performance in competitive events (e.g. sprinting performance) [20-22]. Blazevich and Jenkins [21] determined the associations between hip extensor/hip flexor strength, squat strength and sprint running velocity and found that hip flexor strength variables best predicted running performance. Dowson et al. [22] examined the relationship between muscle strength across three lower limb joints and sprinting performance in elite athletes and found that the strongest predictor of sprint performance was concentric knee extension at 240 deg /sec (r = – 0.688; P< 0.01).

The ability to accelerate over a shorter distance is likely a critical factor in some game situations. In team sports such as handball, players have to repeat sequences of short explosive efforts, such as sprints (<15 m) with frequent changes in direction followed by maximal explosive movements. In addition, RSSA has been shown to be associated with maximal performance power and has also been considered a relevant performance index in team sports and is thus considered as a discriminating variable of different competitive standards. The 1-RM half back squat was positively associated with several RSSA variables as RSSA $_{TT}$ RSSA $_{best}$, and RSSA$_{dec}$ (Table 2). At first examination, the findings showed that a player with greater strength can accelerate and move more rapidly and this seems logical. It is important to note that the large correlation between RSSA$_{TT}$ and 1-RM squat actually show that the strongest subjects performed the worst (slowest or experienced the most fatigue) on the RSSA test.

Nevertheless, an increase in leg muscle mass increases body mass and thus inertia, potentially restricting acceleration and the speed attained [17]. We can conclude that leg muscle strength is important for both acceleration and velocity over short distances [17]. These two characteristics must be well developed in adolescent handball players to allow the quick changes of direction over shorter sprint distances required in successful players. Sprinting, acceleration, and rapid changes in direction are inherent to both practice and competition in handball [4, 17]. Such efforts depend not only on peak power and agility, but also on maximal strength [7]. There is a velocity-specific effect, and for optimal performance, handball training should simulate the sport movements as closely as possible.

In terms of the force/velocity test, our top level handball players obtained an average of 815.77 ± 170.19 W which is equal to or larger than that observed by other authors for elite male handball players [17] who reported the mean of maximal power to be 681 ± 122 W, but less than national juniors players 898 ± 120 W [17]. This difference could be due to the competitive level and age of the players. In contrast, the maximal average power of sub-elite French soccer players was reported to be 1021 W [24], and it is possible that these greater values may be explained by the higher level and years of training experience. However, competitive performance in handball depends not only on power of the lower-limb, but also on the ability to exert power in the upper-limb. Given the purpose of the study was to assess the relationship between measures of lower-limb power and RSSA, upper-limb power was not a specific focus of the present investigation. Clearly, assessing the upper-limb power qualities of handball players and whether they discriminate elite from sub-elite competitors is a direction for future research.

It may also be argued that the large relationship between the RSSA$_{TT}$, RSSA$_{best}$, RSSA $_{dec}$ and peak power could possibly be due to the difference in their mode of exercise (i.e., cycle vs. running). Furthermore, handball players are more familiar with running exercises than with cycling, the lower limb cranking are essentially cyclic movements, whereas sprinting reflects the power output obtained from a single whole-body movement [25, 26]. This could reflect a difference in the respective contributions of the limbs to these types of events, with the lower limbs making a more decisive contribution to repeated sprint performance.

The correlations between some indices of the RSSA test and peak power indicate that values obtained from the 7 s maximum cycle ergometry test are related to sprinting ability. Maximal intensity sprinting necessitates extremely high levels of neuronal activation. Potential mechanisms for improvements in sprint performance include changes in temporal sequencing of muscle activation for more efficient movement, preferential recruitment of the fastest motor units and increased nerve conduction velocity [26]. The results demonstrate that subjects with higher power are superior sprinters [26]. This observation may be related to the fact that the test protocol approximates more closely to muscle contraction dynamics and contraction times associated with the sprinting tests. The results from this study are in agreement with previous work [26, 27] which suggests that active muscle tissue should be used when determining resistive forces used during high-intensity cycle ergometry.

Acceleration and rapid changes in direction are inherent to both practice and competition in handball. The repeated contractions at a high velocity and rapid stretching of the lower limb musculature in the first 5 m suggests that relative explosive ability of the hip and knee extensors is critical to total time and best time in the RSSA test. However, the reduced performance in RSSA velocity might be related to explosive efforts and the important power produced during the first few steps [15, 17, 23]. The ability to accelerate over a single step is likely to be a critical factor in some game situations. One study [15] found a strong correlation between the propulsive force and running velocity during the first contact after the blocks in experienced male sprinters, further emphasizing the characteristics of the propulsive phase and the importance of force during the acceleration phase of sprinting.

The present results provide further evidence that the relative explosive leg power in the SJ is an important aspect of RSSA ability. The majority of research studies that have examined the relationships between jump performance and sprint ability at different distances have often used vertical or horizontal jump displacements as an indirect power measure with high correlations [28]. The few studies that have used more sensitive measures, such as height and power developed during the jump task, have all reported stronger correlations with sprint performance at shorter distances [23, 27, 28]. Other studies have reported significant correlations between vertical jumps and sprint speed [7, 8]. Surprisingly, the result of the present investigation shows that the ability to jump vertically (SJ and CMJ) is quite independent to the ability to perform a RSSA test. We expected that these two qualities would be related because of their similarity in muscle contraction (stretch shortening cycle) and to the many results reported in the scientific literature showing the relationships between sprint and jumping performance. The absence of any relationships between jumping and RSSA illustrate that they should be considered separately when evaluating an athlete.

The intermittent running exercises of short duration, at high relative velocities (i.e., percentage of maximal aerobic speed like IR1), are original and can be linked to handball players' spontaneous activity [5, 12, 29]. In our study, a large significant relationship was found between the performances of IR1 and some performance indices of the RSSA protocol. Similar results were also reported by Chaouachi et al. [29], who found that players who performed better on the IR1 demonstrated significantly better performances on a RSSA test (7 x 30 m) in soccer players. However, Krustrup et al. [30] found no significant relationship between the Yo-Yo Intermittent Recovery Test Level 2 and repeated sprint performance over 5 x 30 m with a 25-s active recovery ($r = 0.26$, $p < 0.05$) in highly-trained soccer players. The study of Mendez-Villanueva et al. [31] found positive correlations between maximal speed on a RSA test and aerobic speed in young athletes ($r = 0.73$ to 0.52; $p < 0.01$). Recently, Spencer et al. [23] found a small-to-moderate correlation between IR1 and repeat sprint total time in athletes of varying ages. These results are consistent with data using a similar test of repeated-sprint ability in highly trained young Australian Rules football players [23]. Therefore, this suggests that fitness qualities of aerobic conditioning and repeated-sprint ability are quite different in this population of young handballers. However, it must be noted that other studies have reported larger correlations between tests of aerobic conditioning and repeated-sprint ability [5, 6, 10] and that this relationship, in addition to the energy system contribution to repeated-sprint ability, depends largely on the individual variables of the protocol such as sprint number, sprint duration, recovery duration, and recovery intensity.

It is possible that the small-to-moderate association between the aerobic fitness test and RSSA, may be due to partial depletion of creatine phosphate (CP) stores during the RSSA test. Indeed, during RSA tests involving longer duration efforts of high intensity exercise, with longer periods of recovery, modest associations have been found between tests of aerobic fitness and total sprinting time and the magnitude of fatigue [8, 22]. While speculative, a RSSA test involving longer efforts, and/or longer recovery durations may have resulted in a larger depletion of CP stores, possibly increasing activation of the aerobic system to resynthesise these stores.

LIMITATIONS

The strength of our study would be improved if data were available on the ability of the RSSA test (and other measures) to discriminate between handball players of different levels. As such, our claim that the RSSA test could be used to discriminate across playing standards and monitor fitness levels remains unsubstantiated. In addition, because our sample size was relatively small, it was not practical to classify players into specific positions (e.g., pivot, back, wing) and determine the relationship between lower-limb performance measures and RSSA on a position-by-position basis. However, since our aim was to assess the relationship between the repeated shuttle-sprint ability and fundamental explosive performance of the lower-limb in handball, these limitations do not affect the interpretation of our results.

PRACTICAL APPLICATIONS

Our findings are of great practical interest to strength and conditioning coaches. The RSSA test may be considered a field test relevant to handball players and consequently could be used in training prescription. However, the results of the present study also demonstrate that high-intensity intermittent running ability is associated with RSSA. The RSSA test employed in this study was also associated with explosive power of the lower limbs and maximum acceleration qualities. Thus, this suggests that when striving to develop RSSA, it is important for team-sport athletes and particularly handball players to follow specific training protocols to improve these physical qualities.

Strength and conditioning coaches who work regularly with players during the season should be given relevant information about interrelatedness of specific fitness parameters, in order to optimize the conditioning program. This study provides the first evidence in elucidating the relationship between explosive lower limb strength qualities and RSSA in elite adolescent handball players. Our data obtained in top level handball players suggest that the RSSA test could be an important assessment tool that takes into account several selected physiological variables simultaneously. The relationships obtained within a given individual are likely to be very consistent, and may well provide a useful basis for field assessments of the response to training or rehabilitation of players. Future studies should examine the consistency of relationships in a given player over time, and analysis should be extended to both women and a wider age range of male players.

CONCLUSION

The present study suggests that, the relationships obtained within a given individual are likely to be very consistent, and may well provide a useful basis for field assessments of the response to training or rehabilitation of players. Future studies should examine the consistency of relationships in a given player over time, and analysis should be extended to both women and a wider age range of male players.

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