

Aerobic and anaerobic determinants of repeated sprint ability in team sports athletes

AUTHORS: Gharbi Z^{1,2}, Dardouri W³, Haj-Sassi R⁴, Chamari K⁵, Souissi N¹

¹ Tunisian Research Laboratory "Sport Performance Optimisation", National Center of Medicine and Science in Sports (CNMSS), Tunis, Tunisia

² High Institute of Sports and Physical Education, University of Gafsa, Gafsa, Tunisia

³ Department of physical Education, University of Hail-College of Education, Hail, Kingdom of Saudi Arabia

⁴ Research Unit, Sportive Performance and Physical Rehabilitation, High Institute of Sports and Physical Education of Kef, University of Jendouba, Kef, Tunisia

⁵ Athlete Health and Performance Research Centre, Aspetar, Qatar Orthopaedic and Sports Medicine Hospital, Doha, Qatar

ABSTRACT: The aim of this study was to examine in team sports athletes the relationship between repeated sprint ability (RSA) indices and both aerobic and anaerobic fitness components. Sixteen team-sport players were included (age, 23.4 ± 2.3 years; weight, 71.2 ± 8.3 kg; height, 178 ± 7 cm; body mass index, 22.4 ± 2 kg · m⁻²; estimated VO₂max, 54.16 ± 3.5 mL · kg⁻¹ · min⁻¹). Subjects were licensed in various team sports: soccer (n = 8), basketball (n = 5), and handball (n = 3). They performed 4 tests: the 20 m multi-stage shuttle run test (MSRT), the 30-s Wingate test (WingT), the Maximal Anaerobic Shuttle Running Test (MASRT), and the RSA test (10 repetitions of 30 m shuttle sprints (15 + 15 m with 180° change of direction) with 30 s passive recovery in between). Pearson's product moment of correlation among the different physical tests was performed. No significant correlations were found between any RSA test indices and WingT. However, negative correlations were found between MASRT and RSA total sprint time (TT) and fatigue index (FI) ($r = -0.53$, $p < 0.05$ and $r = -0.65$, $p < 0.01$, respectively). No significant relationship between VO₂max and RSA peak sprint time (PT) and total sprint time (TT) was found. Nevertheless, VO₂max was significantly correlated with the RSA FI ($r = -0.57$, $p < 0.05$). In conclusion, aerobic fitness is an important factor influencing the ability to resist fatigue during RSA exercise. Our results highlighted the usefulness of MASRT, in contrast to WingT, as a specific anaerobic testing procedure to identify the anaerobic energy system contribution during RSA.

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Corresponding author:

Zied Gharbi

High Institute of Sports and Physical Education of Gafsa, University of Gafsa, Gafsa, Tunisia.

Tel: +216 24 56 86 42. Fax: +216 76 211 616

E-mail: zied1976@yahoo.fr

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INTRODUCTION

The ability to repeat high-intensity, short duration efforts following short recovery periods has been termed 'repeated sprint ability' (RSA) [1]. RSA is an important element of the fitness requirements, especially in team sports [2-5]. To develop optimal RSA training programmes, it is important to know which fitness determinants (i.e. aerobic or anaerobic) are associated with performance, and to what extent. Previous research reported that the relationship between RSA performance indices and both aerobic and anaerobic parameters shows conflicting results [6, 7]. In several studies maximal oxygen uptake (VO₂max) appears to be related to the RSA performance [7-9]. Indeed a greater VO₂max may improve RSA performance by allowing the replenishment of phosphocreatine (PCr) stores during recovery between sprints, thus helping to maintain performance across multiple high intensity efforts [10]. However, in others studies, VO₂max appears to be moderately related to RSA [11-13]. This suggests that factors

other than VO₂max may be more important for repeated high-intensity activity, including a likely contribution from anaerobic fitness [14]. Indeed, previous studies demonstrated that after performing RSA tests, players achieved high concentrations of blood lactate values ranging from 10 to 15 mmol · l⁻¹, indicating involvement of anaerobic metabolism [15-17]. To address the relationship between ability to perform repeated sprints and anaerobic fitness, the majority of studies have mostly used the Wingate test as the gold standard measure of anaerobic capacity in athletes [18]. Nevertheless, many researchers have reported no or a low significant relationship between Wingate test performance indices and RSA [19, 20]. One of the reasons for this poor correlation probably results from questionable application of this test for intermittent-type sports [20, 21]. Therefore a study was needed to investigate the relationship between RSA performance and anaerobic fitness, utilizing a more specific test procedure in team-

sport players. In this context, recently, Dardouri et al. [21] demonstrated the reliability and validity of a new maximal anaerobic shuttle running test (MASRT). We hypothesise that in team-sport players, MASRT as a specific anaerobic testing procedure would be more suitable to characterize RSA than the Wingate test. To improve RSA performance, knowledge about the contribution of aerobic fitness and anaerobic fitness to RSA performance has important implications for specific team-sport training prescriptions [22]. Thus the aim of this study was to examine the relationship between RSA indices and both estimated VO_2max and laboratory and field anaerobic fitness tests.

MATERIALS AND METHODS

Participants. Sixteen male team-sport players (age, 23.4 ± 2.3 years; weight, 71.2 ± 8.3 kg; height, 178 ± 7 cm; body mass index, 22.4 ± 2 $\text{kg} \cdot \text{m}^{-2}$; % fat mass, $11.8 \pm 2.7\%$; estimated VO_2max , 54.16 ± 3.5 $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) were selected among students of the Higher Institute of Sport and Physical Education, Kef, Tunisia. Subjects were licensed in various team sports: soccer ($n = 8$), basketball ($n = 5$), and handball ($n = 3$). They were selected according to their team sport experience (each subject had at least 5 years of training experience in his sport). All subjects trained regularly (6 ± 2 sessions per week) in addition to various physical activities including their university studies. All the participants provided written consent after being informed of the aims, benefits and risks involved with this investigation. The local University Ethics Committee approved the study protocol design, which respected the principles of the Declaration of Helsinki (1975 and further updates).

Experimental procedures

All tests were performed indoors at the university gymnasium on a synthetic hard floor. Before beginning the tests, participants were allowed 15 minutes to complete a standardized warm-up, including ~5 minutes of light jogging, coordination, agility drills, lateral displacements, and dynamic stretching. In order to prepare the participants for RSA testing, subjects performed 3 single 2×15 m shuttle sprints (30 m with 180° change of direction – [COD]) with 2 minutes of passive recovery in between. A 3 min pause was given before players undertook any test protocol. All assessment sessions were conducted in a randomized, counterbalanced order over a 3-week period. Only one test was carried out on any given day, and each session was separated by at least 48 hours. Consistent strong vocal encouragement was given throughout the assessments for all the participants and for all the tests. Subjects were instructed before assessment to produce maximal effort for the test. None of the participants were injured during the protocol. All participants were given a familiarization trial for all tests two weeks before data collection.

Three minutes after each assessment, blood lactate samples were taken from the participants' fingertip (Lactate Pro; Arkray, Tokyo, Japan). All sessions were performed at the same time of day from 10 am to noon to minimize the effects of diurnal variations on the measured variables. The participants were instructed to consume no

food for 3 hours and not to perform any hard physical activity 48 hours prior to each assessment session.

Repeated sprint ability test (RSA test)

The RSA test consisted of 10 repetitions of 30-m shuttle sprints ($15 + 15$ m) interspersed with 30 s of passive recovery. Each sprint shuttle was performed with one change of direction (180° turn) and was timed using a photocell system (Brower Timing System, Salt Lake City, 174 UT, USA; accuracy of 0.01 s). This distance and exercise mode were chosen as time-motion analysis indicated 30 m shuttle runs as the upper-range distance covered at a high intensity during a game by team sport players [2, 16]. Participants were encouraged to decelerate as soon as possible after crossing the finishing line and to reach the starting line walking back slowly and waiting still for the next sprint on the starting line set exactly 50 cm before the line covered by the first photocell beam. All the sprints were timed with the subjects starting 50 cm before the first photocell beam. The photocell beam was placed at a height of 1 m, and the subjects had to cross the 15 m line and place at least one foot behind this line before sprinting back to the 0 m beam gate. Each participant was running in a straight corridor of 1 m width. During the experiment, all participants complied with the latter rule and none fell.

The following variables were derived from the RSA test: (a) peak time (PT): the best time of each RSA test; (b) total time (TT): the sum of all 10-sprint times; (c) the fatigue index (FI): calculated as recommended by Fitzsimons et al. [1] from sprint running performance using the following formula:

$$\text{FI} (\%) = \left\{ \frac{\text{TT}}{\text{PT} \times \text{number of sprints}} - 1 \right\} \times 100$$

The 20 m multi-stage shuttle run test (MSRT)

The MSRT was conducted as previously described by Léger et al. [23]. This test consisted of shuttle running between two lines, spaced 20 m apart. The initial velocity of the incremental test was set at $8 \text{ km} \cdot \text{h}^{-1}$ and was increased by $0.5 \text{ km} \cdot \text{h}^{-1}$ every minute. The participants adjusted their running velocity according to a combination of regular auditory pacing signals provided by a calibrated beeper (Best Electronic, France). The test was finished if (1) the participant felt he could no longer sustain the running pace, or (2) the participant failed to arrive within 2 m of the end line on two consecutive laps. The estimated maximal aerobic velocity (MAVest) was calculated as the speed of the last fully completed stage and was used to predict maximal oxygen uptake (VO_2max) using the equation of Léger et al. [23]. Heart rate was continuously recorded during the MSRT using a heart rate monitor (S810TM, Polar, Kempele, Finland).

The Maximal Anaerobic Shuttle Running Test (MASRT)

MASRT is a field test for assessing anaerobic capacity reproducing the basic effort/movement pattern of most intermittent sports [21]. MASRT was administered using the protocol outlined by Dardouri et al. [16]. The subjects had to shuttle run for 20 s between two parallel lines, spaced 20 m apart, with 100 s of passive recovery in be-

tween. The initial velocity of the first stage was set at 100% of the individual's MAVest. The velocity was increased by 0.28 m·s⁻¹ for each consecutive stage of 20 s shuttle runs until volitional exhaustion. The subjects had to shuttle run for 20 s from the start line to the parallel line in time with the audio beeps emitted from the computer that helped them to adjust their running speed during the 20 s of effort. The participant continued this pattern of shuttle running until volitional exhaustion or when he failed to reach the line in time with the audio signals on two successive occasions. MASRT results were expressed as the velocity of the last completed stage of a 20 s shuttle run (V_{MASRT}). The intraclass correlation coefficient (95% confidence interval) and the coefficient of variation for the V_{MASRT} were 0.84 (0.54-0.94) and 3.6%, respectively.

The Wingate test (WingT)

After familiarization, a 30-s Wingate test was performed on a mechanically braked cycle ergometer (Monark, 894E, Stockholm, Sweden). All subjects performed a standardized 5-min warm-up prior to experimental data collection. After 5 min of rest, the subjects were allowed 5 s of load-less pedalling to reach maximum cadence and were instructed to maintain maximal pedal speed throughout the 30-s period once the appropriate resistance was applied. The subjects were instructed to pedal as fast as possible with an individual braking load set at 75 g·kg⁻¹ of body mass [24]. The following variables were determined: peak power output (PPO), mean power output (MPO) and anaerobic fatigue index (FI). PPO was the highest power gener-

ated during any 5-s period of the test, whereas MPO was calculated as the average power during the entire 30-s period of the test. The FI was calculated as the percentage of power output drop throughout the test from the maximal power output. PPO and MPO were reported in absolute values (W) and relative to body mass (W·kg⁻¹).

Statistical analysis

Results are presented as means ± standard deviations (SD). Before any parametric statistical analysis was performed, the assumption of normality was tested with the Kolmogorov-Smirnov test on each variable. A Pearson product-moment correlation was used to determine the relationship between variables. Magnitude of correlation was qualitatively ranked according to Hopkins et al. [25] as follows: $r \leq 0.1$, trivial; $0.1 < r \leq 0.3$, small; $0.3 < r \leq 0.5$, moderate; $0.5 < r \leq 0.7$, large; $0.7 < r \leq 0.9$, very large; and $r > 0.9$, almost perfect. Confidence intervals (95% CI) were calculated for each correlation. Blood lactate concentrations ([La]) of the different physical tests were compared using a one-way ANOVA with repeated measures. An alpha value of $p < 0.05$ was assumed to check statistical significance, and all multiple comparisons were adjusted using the Bonferroni method. Statistical analyses were performed using SPSS 15.0 for Windows.

RESULTS

Descriptive statistics were calculated for each variable. Table 1 shows the mean and standard deviation of measured parameters.

The correlation coefficients between performance indices of the RSA test, WingT and MASRT are summarized in Table 2.

No significant correlations were found between all RSA indices and WingT. However, negative correlations were found between MASRT and total sprint time (TT) and fatigue index (FI) of the RSA test ($r = -0.53$, 95% CI: -1.02 to -0.05, $p < 0.05$ and $r = -0.65$, 95% CI: -1.08 to -0.21, $p < 0.01$, respectively). There was no significant relationship between estimated VO_2max and peak sprint time (PT) and TT of the RSA test. Figure 1 shows a moderate significant correlation only between VO_2max and RSA test FI ($r = -0.57$, 95% CI: -1.04 to -0.09, $p < 0.05$).

TABLE 1. Mean ± SD of MSRT, MASRT, WingT and RSA test performances (n=16).

MSRT	
VO_2max (mL·kg ⁻¹ ·min ⁻¹)	54.16 ± 3.5
MAV (m·s ⁻¹)	3.8 ± 0.2
Peak heart rate (bpm)	197 ± 8.7
MASRT	
V_{MASRT} (m·s ⁻¹)	5.3 ± 0.2
[La] (mmol·l ⁻¹)	13.1 ± 2.5
Wingate test	
PPO (W)	693.6 ± 89.0
PPO (W·kg ⁻¹)	9.8 ± 1.2
MPO (W)	536.9 ± 83.8
MPO (W·kg ⁻¹)	7.6 ± 0.9
FI (%)	41.9 ± 7.6
[La] (mmol·l ⁻¹)	12.7 ± 1.6
RSA test	
PT (s)	6.1 ± 0.2
TT (s)	63.2 ± 2.2
FI (%)	3.5 ± 1.1
[La] (mmol·l ⁻¹)	15.3 ± 2.1

Notes: MAV: Maximal aerobic velocity; V_{MASRT} : velocity of the last completed stage 20 s shuttle run in MASRT; PPO: peak power output; MPO: mean power output; FI: fatigue index; [La]: Blood lactate concentration at 3 minutes after each test

TABLE 2. Pearson product moment correlation between RSA test, WingT and the MASRT indices (n=16).

		WingT			V_{MASRT} (m·s ⁻¹)
		PPO (W·kg ⁻¹)	MPO (W·kg ⁻¹)	FI (%)	
RSA indices	PT (s)	-0.13	-0.35	0.19	-0.33
	TT (s)	-0.27	-0.50	0.24	-0.53*
	FI (%)	-0.47	-0.47	0.16	-0.65**

Notes: V_{MASRT} : velocity of the last completed stage 20 s shuttle run in MASRT; PPO: peak power output; MPO: mean power output; FI: fatigue index; *: significant correlation at $p < 0.05$; **: significant correlation at $p < 0.01$

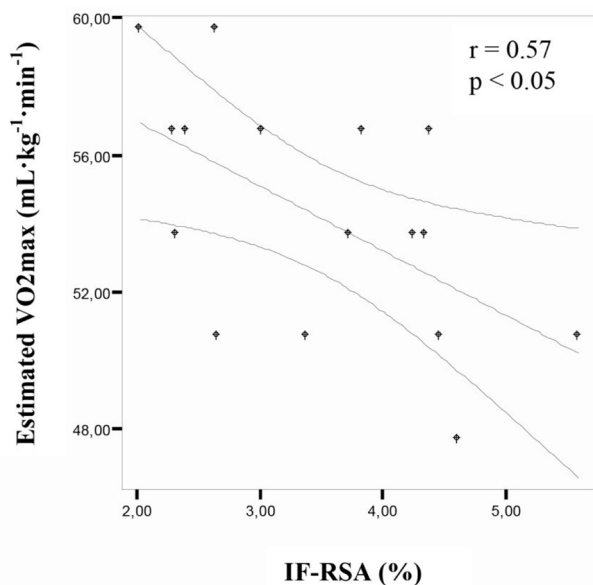


FIG. 1. Relationship between estimated VO_2max and FI recorded during RSA test. Dashed line represents 95% confidence interval.

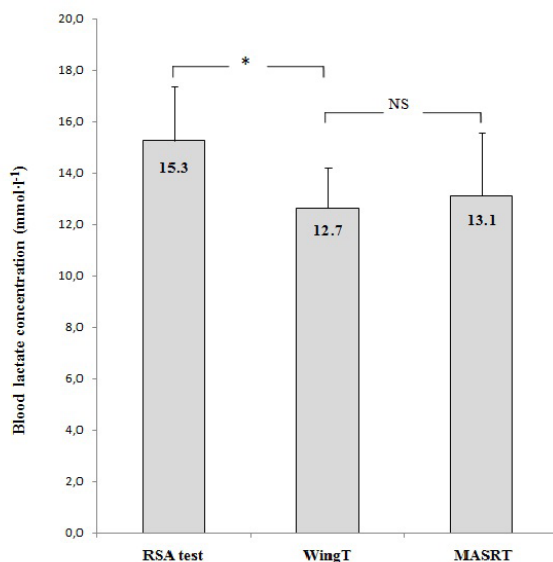


FIG. 2. Blood [La] levels after RSA test, WingT and MASRT. Note: *: significant difference in blood [La]. NS: no significant difference.

Figure 2 shows [La] levels after the RSA test, WingT and MASRT. [La] level after performing the RSA test ($15.3 \pm 2.1 \text{ mmol} \cdot \text{l}^{-1}$) was significantly higher than that after performing WingT and MASRT (12.7 ± 1.6 , $13.1 \pm 2.5 \text{ mmol} \cdot \text{l}^{-1}$, respectively).

DISCUSSION

The aim of this study was to examine the determinants of RSA with respect to aerobic and anaerobic fitness in team sports players using field test procedures adapted to these athletes. The results highlighted the usefulness of MASRT, in contrast to WingT, as a specific anaerobic testing procedure to identify the anaerobic energy system

contribution during the RSA test. On the other hand, our study examined the relationship between RSA indices and aerobic fitness in team sports athletes. We found that estimated VO_2max was significantly correlated only with RSA test FI (figure 1). This finding corroborates studies on RSA highlighting the key role played by VO_2max as an important factor influencing recovery during RSA [7-9,26, 27]. The ability of an enhanced VO_2max to improve recovery between repeated sprint is likely related to the ability to tolerate, remove, and buffer hydrogen ions (H^+) from the working muscles [28] while efficiently restoring PCr and ATP stores from inorganic phosphates at post-exercise [10]. Previous research has shown that the extent of PCr degradation and H^+ accumulation, which increases with repeated bouts of maximal exercise [29], is associated with muscular fatigue in soccer players. Various mechanisms could be proposed; for example, an individual with a higher VO_2max may exhibit an increase mitochondrial number, size, and surface area. This suggests that increasing VO_2max via appropriate training [30] may allow for a greater aerobic contribution during the latter sprints as well as during the recovery phase between sprints, potentially minimizing fatigue and improving performance. This may explain why participants with a greater VO_2max display better RSA performances [9, 31]. However, other studies have reported no significant correlations between VO_2max and RSA performance indices [13, 16, 32]. Indeed, Castagna et al. [16] failed to find significant correlations between basketball players' VO_2max and both FI and TT ($r = -0.28$ and $r = 0.37$, respectively). Likewise, Bishop et al. [13] reported a non-significant correlation between VO_2max and FI of the RSA test in a group of female field hockey players. The difference reported by these studies could be due to the different RSA protocols used. In addition, the lack of correlation between VO_2max and RSA indices could be due to the fact that maximal aerobic power (i.e. VO_2max) is thought to be determined essentially by central factors, while RSA performance is more associated with peripheral factors [33]. Furthermore, VO_2max is not the only indicator of aerobic fitness. Indeed, aerobic capacity, as represented by anaerobic threshold or the velocity at the onset of blood lactate accumulation (OBLA), could have a greater association with RSA than VO_2max [33]. Indeed, da Silva et al. [33] showed that RSA indices are more strongly correlated with the OBLA than the more commonly used VO_2max measurement.

Our data show no significant difference in peak blood lactate concentration between MASRT and WingT, whereas subjects recorded a $2.6 \text{ mmol} \cdot \text{l}^{-1}$ higher significant peak blood lactate concentration during the RSA test than MASRT (figure 2). Possible explanations for the higher peak blood lactate concentration in the RSA test could be the shorter recovery duration during the RSA test than in MASRT (30 s vs 100 s), probably inducing a partial restoration of creatine phosphate stores, which led to a greater increase in glycolytic anaerobic pathway activity observed as higher lactate values found after the RSA test than after MASRT and WingT. The lactate concentration measured after the RSA test was $15.3 \pm 2.1 \text{ mmol} \cdot \text{l}^{-1}$. This result is in agreement with Castagna et al. [16], who reported

[La] of $14.2 \pm 3.5 \text{ mmol} \cdot \text{l}^{-1}$ with elite junior basketball players and an RSA protocol similar to the present study. This high lactate concentration suggests important solicitation of anaerobic glycolysis during the RSA test, and was confirmed by the significant relationship reported in the present study between RSA indices and MASRT (used here as an anaerobic power assessment procedure). However, there were no significant correlations between all RSA indices and WingT performance indices. In line with our findings, Meckel et al. [20] demonstrated, with 33 elite adolescent soccer players, non-significant to low correlations between anaerobic indices of the WingT and performance indices of the 2 RSA tests ($12 \times 20 \text{ m}$, departing every 30 s, and $6 \times 40 \text{ m}$, departing every 30 s). Moreover, when studying the relationship between RSA ($8 \times 40 \text{ m}$, with 30 s of rest in between) and the WingT in team sport players, Aziz and Chuan [19] found no significant correlations between WingT MPO and RSA total sprinting time. They reported only modest correlations between relative MPO and the RSA total sprinting time ($r = 0.46$) and between the 2 tests' FI values ($r = 0.46$). The authors concluded that there is limited support for the use of the WingT for determining anaerobic capabilities in athletes who are involved in team sports. Some possible reasons for this result may come from the differences between the two tests [19, 20]: (a) the differences in the duration and type of exercise pattern – the WingT is a 30-s continuous, single, all-out effort, while the effort in RSA is intermittent; (b) the difference in the mode of exercise, the RSA test being a running test in which subjects support their own body mass and activate large muscle groups, whereas the WingT is a cycling test, where the body mass is supported. In addition, the participation of aerobic metabolism has been shown to be relatively important during the WingT (28% for sprinters and as high as 45% for middle distance runners) [34].

To the best of our knowledge, this is the first study to address the relationship between the RSA test and MASRT as a specific valid field test for measuring anaerobic capacity. Relationships between RSA indices and MASRT in the present study demonstrated significant correlations (see Table 2). These results may be somewhat unsurprising, because both types of tests, the RSA test and MASRT, are intermittent running exercises involving the same effort-rest ratio of 1:5 with 180° change of direction. Moreover, one possible reason for the negative significant correlation between V_{MASRT} and FI of the RSA test may derive from the contribution of aerobic metabolism during

the MASRT test, which is supported by the significant correlation found in our study between V_{MASRT} and $\text{VO}_{2\text{max}}$ ($r = 0.63$, $p < 0.01$). Indeed, Zagatto et al. [35] found that, during the maximal anaerobic running test, energy system contributions were 65.4% to the aerobic system and 34.6% to the anaerobic system, while during effort periods only (20 s running) the anaerobic contribution corresponded to $73.5 \pm 1.0\%$. MASRT has a 100 s rest period after each effort, which leads to further aerobic contribution to increase lactic acid removal and creatine phosphate restoration for recovery, thus helping to maintain performance across multiple high-intensity efforts.

CONCLUSIONS

In conclusion, our results confirm the association of good aerobic fitness with the ability to resist fatigue during RSA exercise. This suggests that aerobic exercise must be included in the annual training cycle of team sport players to increase the ability to resist to fatigue during repeated sprint exercise. Our results also show that MASRT, as a specific anaerobic protocol for team sports athletes, is more suitable than WingT to establish the relationship between anaerobic fitness and RSA. The significant correlations found between MASRT and RSA test indices in this study confirm that anaerobic running fitness could be a determinant factor of RSA. Thus, to enhance the RSA of team sport players, it is important to include both aerobic and anaerobic running exercises in the annual training cycle. However, because of the moderate correlation between RSA and both aerobic and anaerobic fitness found in this study, we suggest that additional factors (e.g., coordination, balance, muscle strength and power, anthropometric variables) are likely to be determining for the performance in RSA with 180° changes of directions. Future studies are required to determine which of them is a better predictor of shuttle-RSA performance in team sport players.

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