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Determinant Factors of Repeat Sprint Sequences in Young Soccer Players

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Key words
- repeated sprint ability
- muscle strength
- intermittent fitness testing
- vertical jump
- kicking
- metabolites

Abstract

The aim of this study was to investigate the relationships between repeated explosive effort sequences (20 + 20 m shuttle sprint with change of direction, kicking and jumping), metabolic response (lactate and ammonia), and fitness qualities (strength and endurance) in under-19 soccer players. 21 players completed: 1) sprint test: 30 m (T_{30}) and 40 m (20 + 20 m) shuttle sprints; 2) countermovement jumps (CMJ); 3) maximal kicking; and 4) 9 repeated-explosive effort sequences (RES); 4) a progressive isoinertial loading test in full squat to determine the load which subjects achieved ~1 m·s^{-1} (V_1-load); 6) Yo-Yo Intermittent Recovery Test Level 1 (YYIRT-1). Mean sprint time of the 9 repeated sprints ($RSA_{mean1–9}$) showed correlation with V_1-load (r = −0.52 [−0.79, −0.25]) metabolic response (lactate, r = 0.67 [0.47, 0.87] and ammonia, r = 0.53 [0.27, 0.79]). YYIRT-1 correlated with $RSA_{mean1-9}$ (r_w = −0.78 [−0.92, −0.64]) when the body weight was controlled. Furthermore, the 3 first sprints ($RSA_{mean1-3}$) correlated with RSA_{best} (r = 0.93 [0.88, 0.98]), V_1-load (r = −0.64 [−0.86, −0.42]), and T_{30} (r = 0.63 [0.41, 0.85]). These results suggest that the soccer player's lower body strength (V_1-load, jumping and sprinting) explains a large part of the performance in the first sequences, whereas the aerobic capacity, estimated through YYIRT-1, becomes more important to performance as the number of sprints is increases.

Introduction

The high-intensity performance of a soccer player is considered to be key factor in elite soccer [31]. For this reason, different researchers have aimed to clarify the importance of the main aspects from different repeated sprints protocols [4, 9, 12, 13]. With regard to aerobic influence, maximal oxygen uptake might not be the most important determinant of repeated sprint ability (RSA) [1, 2, 4, 5, 9, 13–15, 29, 30]. Therefore, it is suggested that other factors have influence on the ability to endure repeated sprints. One of them might be the soccer player's strength. However, while the relationship between strength variables and single sprint has been widely studied showing clear relationships between them [11, 22, 26, 39], the possible association between strength and RSA has received less attention. On the other hand, blood lactate concentration as consequence of glycolytic energetic contribution has been associated with the reduction in strength or power output [33] and RSA in soccer players [31]. The other metabolite recently used as indicator of neuromuscular fatigue in high-intensity exercises is blood ammonia [35], but its relationship with RSA performance has not been yet studied.

Despite the ability to repeat soccer-specific explosive sequences being considered an important fitness component for soccer players [7], few studies [7, 8] have analyzed the player's ability to maintain performance in repeated sprints interspersed with specific soccer skills, such as jumping or kicking. On the other hand, several works [2, 9, 12–15, 21, 24, 29, 36] have analyzed the influence of variables related to strength or endurance on RSA. A recent study [12] showed a moderate relationship between the Yo-Yo Intermittent Recovery Test Level-1 (YYIRT-1) and sprint decrement (r = −0.44, P = 0.04). Moreover, this study [12] showed 30 m sprint time to be significantly associated with mean sprint time in the RSA test (r = 0.61, P = 0.02). However, to our knowledge, no study to date has examined the influence of these fitness variables and blood metabolites during a sequence of explosive

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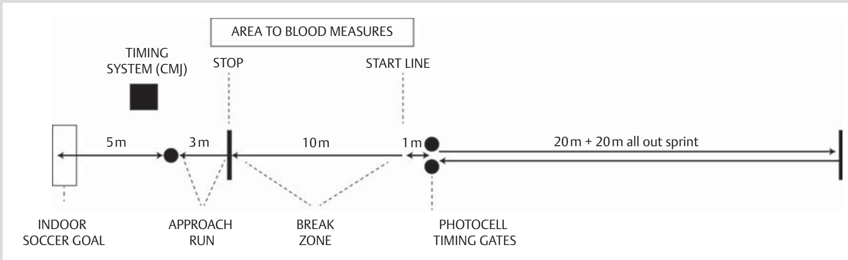

Fig. 1 Schematic of the repeated explosive effort sequences.

efforts (sprinting, jumping and kicking) with changes of direction.

Considering the aforementioned research related to RSA, the main purpose of this study was to investigate the relationship between repeated explosive effort sequences (RES) with specific skills (jumping and kicking) and metabolic response (lactate and ammonia) as well as fitness qualities (strength and endurance) in under-19 soccer players. We hypothesized that a soccer player's lower body strength would be relevant in the performance of the first sprints, jumps and kicks, whereas the intermittent endurance and the metabolic response would have more influence on the performance as the number of sequences increases.

Material and Methods

Subjects

21 soccer players (mean ± SD: age 18.4 ± 0.8 years, height 1.78 ± 0.07 m, body mass 71.9 ± 6.8 kg) volunteered to participate in this study. Subjects played in the U-19 Spanish National League division and participated in 4 training sessions (90 min each) plus one official game per week. Of the 4 weekly training sessions, 2 were focused on developing the physical conditioning such as improving the aerobic performance of the players. To this end, players executed high-intensity interval running, physical-technical circuits and small-sided games. After being informed about the purpose, testing procedures and potential risks of the investigation, all subjects gave their voluntary written consent to participate. For those players who were minors, written consent was obtained from their parents. No physical limitations, health problems or musculoskeletal injuries that could affect testing or training were found following a medical examination. The present investigation met the ethical standards of this journal [19] and was approved by the Research Ethics Committee of Pablo de Olavide University.

Experimental design

All the tests were carried out at the end of the season (May) over a period of 3 consecutive weeks. Furthermore, each test was performed at least 48 h after the most recent game. All tests were conducted at the same time of day, from 5:00 p.m. to 9:00 p.m. Subjects completed all testing following preliminary familiarization and pre-testing. In the first session a battery of tests was performed in the following order: 1) 30 m and 40 m (20 + 20 m) all-out running sprints; 2) countermovement vertical jumps (CMJ); 3) maximal instep kicking; and 4) RES test. In the second testing session players completed a progressive isoinertial loading test in full squat. Finally, in the third session YYIRT-1 was performed. In the preceding 2-week period, 4 preliminary familiarization sessions were undertaken with the purpose of emphasizing proper execution technique in the different tests assessed. Sessions took place at a neuromuscular research laboratory under the direct supervision of the investigators, at the same time of day for each subject and under constant environmental conditions (20 °C, 60 % humidity). Before the tests were completed, subjects executed a standardized warm-up directed by both the primary researcher along and the coach. During the execution of these tests, the players were verbally encouraged to give their maximal effort. The tests executed for the measurement of performance are explained in detail below.

Measurement of sprint capacity

Two 30 m sprints, separated by a 3 min rest, were performed on an indoor running track. Photocell timing gates (Polifemo Radio Light, Microgate, Bolzano, Italy) were placed at 0 and 30 m (T_{30}). A standing start with the lead-off foot placed 1 m behind the first timing gate was used. Subjects were required to give an all-out maximal effort in each sprint, and the best of both trials was kept for analysis.

Measurements of ball velocity and jumping ability

The players performed 3 maximal instep kicks with their dominant leg with 3 m approach run, aiming at a circled target measuring 1 m in diameter and located in the middle of a goal (3 × 2 m) (**Fig. 1**). 3 kicks were performed with an interval of 1 min between each. From the 3 trials, the highest ball velocity observed was selected for further analysis ($KICK_{best}$). The speed of each kick was measured using radar device (Stalker Sport, Applied Concepts Inc, Texas, USA). The radar was placed at a short distance from the ball (5 m) behind the indoor soccer goal, and elevated 1 m off the ground. A ball of standard characteristics (FIFA) was used. Jump height was calculated to the nearest 0.1 cm from flight time measured with an infrared timing system (Optojump; Microgate, Bolzano, Italy). Subjects completed 3 maximal countermovement jumps with their hands on their hips (without arm swing), and the average of these jumps was recorded (CMJ_{best}). For complete recovery, 1 min rests were taken between jumps. After the 3 jumps, the players executed the RES test.

Repeated-explosive efforts sequence test (RES)

Before the RES, subjects executed a standardized warm-up consisting of a 5 min low-intensity run, 3 × 30 m progressive accelerations, and a maximal 30 m sprint, interspersed by 3 min of passive recovery. Thereafter, 30 m all-out running sprint, 2 maximal 40 m (2 × 20 m) shuttle sprints, maximal instep kicking and jump ability were evaluated. The best maximal single shuttle sprint time (20 + 20 m) was used as the players' reference performance (RSA_{best}). Repeated sprint tests began 3 min after the last jump. The RES consisted in a 40 m shuttle sprint (20 + 20 m with 180º turns) plus a maximal kick and 2 vertical jumps without recovery time between actions, repeated 9 times with 1 min of recovery between sequences. The maximal ball velocity of each instep kicking was registered. The mean of all kicks performed after each sprint ($KICK_{mean}$) was used for further analysis. After kicking the ball, the players performed 2 CMJ without arm swing separated by 5 s. The average height of these jumps was recorded for later analysis (CMJ_{mean}). Capillary blood samples were obtained immediately thereafter. Each 40 m sprint was initiated from a standardized position 1 m behind the starting line. Subjects assumed the ready position and awaited the start signal 5 s prior to the beginning of each sprint. The players sprinted to a line 20 m away and then returned to the starting line. Players were instructed to perform all sprints as fast as possible. The reliability of a sequence similar to that used in the present study has been demonstrated (CV = 1.0 %, 90 % confidence interval (0.7–1.6) for mean shuttle-sprints time with a CMJ performed between sprints, and CV = 2.9 %, 90 % confidence interval (2.1–4.7) for mean jump height) [8]. Time of each sprint was measured to the nearest 0.01 s with photocell timing gates (Polifemo Radio Light, Microgate, Bolzano, Italy). The mean time of the 9 sprints ($RSA_{mean1-9}$) expressed in seconds, and the 3 partial mean sprint times were calculated as follows: the mean of the first 3 sprint times ($RSA_{mean1-3}$), the mean of the fourth, fifth and sixth sprint ($RSA_{mean4-6}$), and finally the mean of the last 3 sprints ($RSA_{mean7-9}$) [3]. The percent sprint decrement (S_{dec}) was calculated as follows: $(RSA_{mean}/RSA_{best} \times 100) - 100$ [37]. The percent decrement of jump height ($Sdec_{CMJ}$) and kicking ($Sdec_{KICK}$) was calculated as follows: $(1 - CMJ_{mean}/CMJ_{best}) \times 100$, and $(1 - KICK_{mean}/KICK_{best}) \times 100$ [36].

Blood lactate and ammonia measurement

Capillary blood samples for the determination of lactate and ammonia concentrations were obtained from the fingertip before exercise and 40 s after the third, sixth and ninth sprint sequence. The Lactate Pro LT-1710 (Arkray, Kyoto, Japan) portable lactate analyzer was used for lactate measurements. The suitability and reproducibility of this analyzer has been previously established throughout the physiological range of 1.0–18.0 $mmol.l^{-1}$ [28]. Ammonia was measured using PocketChem BA PA-4130 (Menarini Diagnostics, Florence, Italy). Both devices were calibrated before each exercise session according to the manufacturer's specifications.

Yo-Yo intermittent recovery test level 1

This test comprised 2 × 20 m shuttle runs at increasing speeds, separated by 10 s of active recovery. The subjects were required to run on an indoor court, guided by a beep signal. The test was terminated when the subjects were no longer able to reach the finish line on the beep signal on 2 consecutive occasions. The total distance covered (m) was recorded as the final result of the test.

Isoinertial progressive loading test

The assessment consisted of an isoinertial test with increasing loads using the full squat exercise performed in a Smith machine (Multipower Fitness Line, Peroga, Murcia, Spain). Players performed a full squat descending at a controlled mean velocity to ascend at maximal velocity to the initial upright position. Initial load was set at 20 kg and was progressively increased in 10 kg increments. Subjects performed 3 repetitions with each load. Only the best repetition at each load according to the criteria of fastest mean propulsive velocity [34] was considered for subsequent analysis. 4 min of recovery were taken between sets. The test ended when the average velocity of lifting was less than $1\,m \cdot s^{-1}$. The load which players were able to achieve a ~$1.00\,m \cdot s^{-1}$ relative to body mass (V_1-load) was used to assess the strength performance. This load was chosen because the maximal power in squat exercise in semi-professional soccer players was attained with a load of ~60 % 1RM, which was lifted at ~$1\,m \cdot s^{-1}$ [32]. Warm-up consisted of 5 min of joint mobilization exercises, followed by 2 sets of 8 and 6 repetitions (3 min rests) with loads of 20 and 30 kg, respectively. The relevant kinematic parameters of every repetition were recorded using a dynamic measurement system (T-Force System, Ergotech, Murcia, Spain). Instantaneous velocity was sampled at a frequency of 1 000 Hz. The reliability of this system has been recently reported elsewhere [35].

Statistical analysis

Descriptive statistics are expressed as mean ± SD. The distribution of each variable was examined with the Shapiro-Wilk normality test. Homogeneity of variance was verified by a Levene test. Linear regressions with Pearson's coefficients (r) and 90 % confidence intervals (90 %CI) were used to calculate the respective relationships between performance parameters analyzed. To isolate the possible effect of body weight on physical performance, these relationships also were adjusted with partial correlations (r_w). Intraclass correlation coefficients (ICC) were calculated with the one-way random effects model. The standard error of measurement was calculated as the root mean square of total mean square intra-subject. This standard error was used for the calculation of coefficient of variation. The reliability was assessed in repeated measurements in the same testing session, with an interval of 3 min between sprints and 1 min for jumps and kicks. Within-subject variation for the tests was determined by calculating the coefficient of variation (CV). The probability level of statistical significance was set at $P \le 0.05$. The statistical analysis was performed using the SPSS 17.0 (SPSS, Chicago, IL).

Results

▼

Means values and SD of the different variables assessed are reported in ◉ **Table 1**. Test-retest reliability for T_{30}, CMJ_{best} and $KICK_{best}$ as measured by the CV were 1.1, 2.2 and 4.1 %, respectively, and the ICC (95 %CI) were 0.90 [0.77–0.96], 0.99 [0.98–0.99] and 0.83 [0.65–0.92].

$RSA_{mean1-9}$ correlated significantly with $Sdec_{RSA1-9}$ (r = 0.55 [0.29, 0.81], P = 0.03). Moreover, $RSA_{mean1-9}$ showed significant correlation with V_1-load (r = −0.52 [−0.79, −0.25], P = 0.04), and with blood metabolites (lactate after the ninth sprint: r = 0.67 [0.47, 0.87], P = 0.003); and ammonia after the third: r = 0.56 [0.28, 0.84], P = 0.02; sixth: r = 0.72 [0.52, 0.92], P = 0.002; and ninth sprint: r = 0.55 [0.26, 0.84], P = 0.03) (◉ **Fig. 2**).

RSA_{best} was associated with $RSA_{mean1-3}$ (r = 0.93 [0.88, 0.98], P = 0.000) (◉ **Fig. 3**) and inversely with different measures of decrement RSA-performance ($Sdec_{RSA1-3}$: −0.41 [−0.72, −0.10], P = 0.11; $Sdec_{RSA4-6}$: −0.61 [−0.84, −0.38], P = 0.01; $Sdec_{RSA7-9}$: −0.50 [−0.78, −0.22], P = 0.06). RSA_{best} showed correlation with jump height and sprint capacity (CMJ_{best}: r = −0.74 [−0.91, −0.57], P = 0.001; CMJ_{mean}: r = −0.48 [−0.76, −0.20], P = 0.05, T_{30}: r = 0.79 [0.65, 0.93], P = 0.000) and V_1-load (r = −0.76 [−0.92, −0.61], P = 0.007). $Sdec_{KICK}$ correlated with $Sdec_{RSA1-9}$ (r = 0.86 [0.76, 0.96], P = 0.000).

Table 1 Values in selected neuromuscular performance variables.

RSA_{best} (s)	$RSA_{mean1\text{-}9}$ (s)	$RSA_{mean1\text{-}3}$ (s)	$RSA_{mean4\text{-}6}$ (s)	$RSA_{mean7\text{-}9}$ (s)	$T_{30\,m}$ (s)	YYIRT-1 (m)
7.10 ± 0.20	7.54 ± 0.20	7.26 ± 0.20	7.61 ± 0.28	7.83 ± 0.40	4.21 ± 0.11	1760 ± 329
$Sdec_{RSA1\text{-}9}$ (%)	**$Sdec_{RSA1\text{-}3}$ (%)**	**$Sdec_{RSA4\text{-}6}$ (%)**	**$Sdec_{RSA7\text{-}9}$ (%)**	**CMJ_{best} (cm)**	**CMJ_{mean} (cm)**	**$Sdec_{CMJ}$ (%)**
5.8 ± 3.1	1.8 ± 1.1	7.3 ± 5.4	9.5 ± 6.7	35.3 ± 4.1	28.2 ± 3.1	17.6 ± 6.0
$KICK_{best}$ ($km \cdot h^{-1}$)	**$KICK_{mean}$ ($km \cdot h^{-1}$)**	**$Sdec_{KICK}$ (%)**	**V_1-load (kg)**	**Lactate3 ($mmol \cdot L^{-1}$)**	**Lactate6 ($mmol \cdot L^{-1}$)**	**Lactate9 ($mmol \cdot L^{-1}$)**
97.5 ± 5.6	89.6 ± 5.2	7.9 ± 4.7	60.3 ± 9.8	11.6 ± 4.2	13.7 ± 3.3	15.1 ± 2.6
Ammonia3 ($\mu mol \cdot L^{-1}$)	**Ammonia6 ($\mu mol \cdot L^{-1}$)**	**Ammonia9 ($\mu mol \cdot L^{-1}$)**				
151.0 ± 58.7	171.4 ± 46.3	186.5 ± 43.2				

Data are mean ± SD

$RSA_{mean1\text{-}9}$, $RSA_{mean1\text{-}3}$, $RSA_{mean4\text{-}6}$, $RSA_{mean7\text{-}9}$: mean sprint time of the 9 sprints; mean of the first 3 sprints; mean of the fourth, fifth and sixth sprint; and mean of the seventh, eighth and ninth sprint

RSA_{best}: the best time of the 9 sprints

$Sdec_{RSA1\text{-}9}$, $Sdec_{RSA1\text{-}3}$, $Sdec_{RSA4\text{-}6}$, $Sdec_{RSA7\text{-}9}$: percent sprint decrement for the 9 sprints; for the first 3 sprints; for the fourth, fifth and sixth sprint; and for the seventh, eighth and ninth sprint

V_1-load: The load which participants were able to elicit a ~1.00 $m \cdot s^{-1}$ relative to body mass

YYIRT-1: Yo-Yo Intermittent Recovery Test Level 1, $T_{30\,m}$: 30 m sprint time

CMJ_{best}: countermovement jump height without fatigue, CMJ_{mean}: mean jump height of the 9 repeat sprint sequences, $Sdec_{CMJ}$: percent jump height decrement for the 9 repeat sprint sequences

$KICK_{best}$: maximal kick velocity without fatigue, $KICK_{mean}$: mean kick velocity of the 9 repeat sprint sequences, $Sdec_{KICK}$: percent kick velocity decrement for the 9 repeat sprint sequences

Lactate3: blood lactate after the third sprint, Lactate6: blood lactate after the sixth sprint, Lactate9: blood lactate after the ninth sprint

Ammonia3: blood ammonia after the third sprint, Ammonia6: blood ammonia after the sixth sprint, Ammonia9: blood ammonia after the ninth sprint

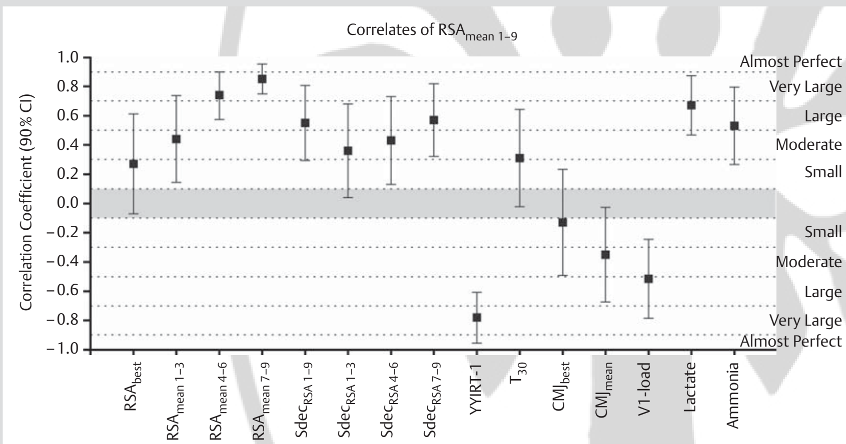

Fig. 2 Correlation coefficients (90 % confidence intervals) describing the relationships between mean performance of the 9 repeated sprints ($RSA_{mean1\text{-}9}$) and best repeated sprint time (RSA_{best}), mean of the first 3 sprint times ($RSA_{mean1\text{-}3}$), mean of the fourth, fifth and sixth sprint ($RSA_{mean4\text{-}6}$), mean of the last 3 sprints ($RSA_{mean7\text{-}9}$), percent sprint decrement of the first 3 sprint times ($Sdec_{RSA1\text{-}3}$), mean of the fourth, fifth and sixth sprint ($Sdec_{RSA4\text{-}6}$), mean of the last 3 sprints ($Sdec_{RSA7\text{-}9}$), Yo-Yo Intermittent Recovery test level 1 (YYIRT-1), sprint capacity (T_{30}), best (CMJ_{best}) and mean (CMJ_{mean}) jump height, load which players were able to achieve a ~1.00 $m \cdot s^{-1}$ relative to body mass ($V_{1\text{-}load}$), and blood metabolites (lactate and ammonia).

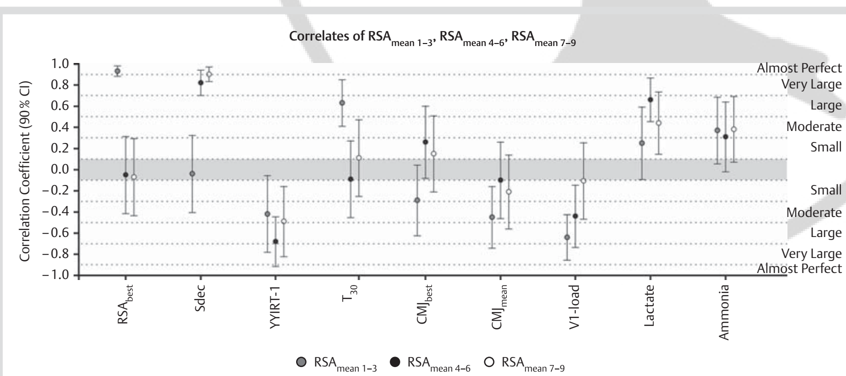

Fig. 3 Correlation coefficients (90 % confidence intervals) describing the relationships between the mean of the first 3 ($RSA_{mean1\text{-}3}$), fourth, fifth and sixth ($RSA_{mean4\text{-}6}$), and the last 3 repeated-sprints ($RSA_{mean7\text{-}9}$), and best sprint time (RSA_{best}), percent sprint decrement of the 9 sprints (Sdec), Intermittent Recovery test level 1 (YYIRT-1), sprint capacity (T_{30}), best (CMJ_{best}) and mean (CMJ_{mean}) jump height, load which players were able to achieve a ~1.00 $m \cdot s^{-1}$ relative to body mass ($V_{1\text{-}load}$), and blood metabolites (lactate and ammonia).

It was found a correlation between YYIRT-1 and final blood ammonia ($r = -0.63$ [−0.85, −0.41], $P = 0.02$). V_1-load showed significant relationships with CMJ_{best} ($r = 0.54$ [0.28, 0.80], $P = 0.02$), T_{30} ($r = -0.51$ [−0.78, −0.24], $P = 0.02$), and $RSA_{mean1\text{-}3}$ ($r = -0.64$ [−0.86, −0.42], $P = 0.004$). Finally, CMJ_{mean} correlated significantly with blood metabolites (lactate after the ninth sprint: $r = -0.54$ [−0.80, −0.28], $P = 0.03$; and ammonia after the third: $r = -0.53$ [−0.83, −0.23], $P = 0.04$; sixth: $r = -0.51$ [−0.81, −0.21], $P = 0.05$; and ninth sprint: $r = -0.63$ [−0.88, −0.38], $P = 0.01$). Partial correlations are shown in **Table 2**.

Table 2 Matrix of partial correlations between repeated-sprint performance, technical skills, fitness and metabolic variables.

	RSA_{best}	$Sdec_{RSA1-9}$	CMJ_{best}	CMJ_{mean}	$KICK_{best}$	$KICK_{mean}$	YYIRT-1	V_1-load	Lactate9	Ammonia9
$RSA_{mean1-9}$	0.39 [0.04, 0.74]	0.46 [0.14, 0.78]	−0.32 [−0.69, 0.05]	−0.41 [−0.75, −0.07]	0.39 [0.04, 0.74]	0.08 [−0.33, 0.49]	−0.78 [−0.94, −0.62]**	−0.54 [−0.83, −0.25]	0.30 [−0.07, 0.67]	0.71 [0.51, 0.91]*
RSA_{best}		−0.61 [−0.87, −0.35]*	−0.46 [−0.78, −0.14]	−0.33 [−0.70, 0.04]	0.31 [−0.06, 0.78]	0.58 [0.31, 0.85]	−0.50 [−0.81, −0.19]	−0.55 [−0.84, −0.26]	0.50 [0.19, 0.81]	0.25 [−0.14, 0.64]
$Sdec_{RSA1-9}$			0.17 [−0.23, 0.57]	−0.01 [−0.42, 0.40]	−0.07 [−0.48, 0.34]	−0.58 [−0.85, −0.31]	−0.21 [−0.60, 0.18]	0.12 [−0.29, 0.53]	−0.22 [−0.61, 0.17]	0.35 [−0.01, 0.71]
CMJ_{best}				0.90 [0.82, 0.98]***	−0.29 [−0.67, 0.09]	−0.25 [−0.64, 0.14]	0.65 [0.41, 0.89]*	0.08 [−0.33, 0.49]	−0.49 [−0.80, −0.18]	−0.68 [−0.90, −0.46]**
CMJ_{mean}					−0.10 [−0.51, 0.31]	−0.03 [−0.44, 0.38]	0.69 [0.47, 0.91]*	−0.09 [−0.50, 0.32]	−0.70 [−0.91, −0.49]*	−0.81 [−0.95, −0.67]**
$KICK_{best}$						0.82 [0.69, 0.95]**	−0.32 [−0.69, 0.05]	−0.57 [−0.85, −0.29]	0.04 [−0.37, 0.45]	0.32 [−0.05, 0.69]
$KICK_{mean}$							−0.07 [−0.48, 0.34]	−0.48 [−0.80, −0.16]	0.19 [−0.21, 0.59]	0.04 [−0.37, 0.45]
YYIRT-1								0.27 [−0.11, 0.65]	−0.58 [−0.85, −0.31]	−0.75 [−0.93, −0.57]**
V_1-load									0.19 [−0.21, 0.59]	−0.21 [−0.60, 0.18]
Lactate9										0.56 [0.28, 0.84]

$RSA_{mean1-9}$: mean sprint time of the 9 sprints; RSA_{best}: the best time of the 9 sprints; $Sdec_{RSA1-9}$: percent sprint decrement for the 9 sprints; CMJ_{best}: countermovement jump height without fatigue; CMJ_{mean}: mean jump height of the 9 repeat sprint sequences; $KICK_{best}$: maximal kick velocity without fatigue; $KICK_{mean}$: mean kick velocity of the 9 repeat sprint sequences; YYIRT-1: Yo-Yo Intermittent Recovery Test Level 1; V_1-load: The load which participants were able to elicit a ~1.00 $m \cdot s^{-1}$ relative to body mass; Lactate9: blood lactate after the ninth sprint; Ammonia9: blood ammonia after the ninth sprint. *Denotes significance at P≤0.05. **Denotes significance at P≤0.01. ***Denotes significance at P≤0.001

Discussion

To the best of our knowledge, this is the first study with soccer players that has described the relationships between repeated explosive effort sequences (RES) interspersed with soccer-specific skills such as jumping and kicking, and indicators of strength and endurance fitness, as well as the acute metabolic response during that repeated sequence. In the present study it was observed that performance in the first sequences (1–3) is explained mainly by the soccer player's strength and sprint capacity, but is more related to endurance as the number of sequences increase (starting with number 4).

Thus, an important and unique finding of this study is that there exists an almost perfect correlation (r=0.93 [0.88, 0.98], P=0.000) between RSA_{best} and $RSA_{mean1-3}$, whereas this relationship decreases in $RSA_{mean4-6}$ (r=−0.05 [−0.42, 0.62]) and $RSA_{mean7-9}$ (r=−0.07 [−0.44, 0.30]). These results might be due to performance in the first sprints possibly being explained by proper sprint capacity, since there is not an excessive impairment of performance ($Sdec_{RSA1-3}$=1.8%). However, the decrease in performance is considerable starting with the fourth sprint (▶ **Table 1**), according with other authors [13,16]. Therefore, performance might depend on other factors, such as aerobic contribution [16]. It is probable that this absence of a relationship between RSA_{best} and $RSA_{mean4-6}$ and $RSA_{mean7-9}$ as well as between RSA_{best} and $RSA_{mean1-9}$ is responsible. In this regard, there is considerable controversy in the literature. We have found a study in which the relationship between RSA_{best} and RSA_{mean} was not observed [15]. On the other hand, there are studies [12,13,28] that have found relationships between RSA_{best} and RSA_{mean}. In these studies, however, the sprint total distances (180–240 vs. 360 m) as well as the number of sprints (6–7 vs. 9) were lower than those used in our study. Thus, this absence of a relationship could be linked to the greater number of sprints and the longer sprint distance that may have increased the contribution of oxidative phosphorylation to the total energy expenditure [15,16,18] and therefore decreased the importance of the fastest sprint in the $RSA_{mean1-9}$.

According to previous studies [4,9,27], RSA_{best} and performance impairment were related. A plausible explanation might be that faster subjects tend to have higher percentage of fast twitch fibers [10]. Moreover, it has been reported that PCr resynthesis is slower in the fast fibers [38]. The finding that faster subjects had greater performance impairment may be related to the hypotheses presented above. On the other hand, we have observed a relationship between $RSA_{mean1-9}$ and $Sdec_{RSA1-9}$ (r=0.55 [0.29, 0.81], P=0.03) in line with previous studies [15,29]. Furthermore, the exhaustive analysis of the repeated-sequences test performed every 3 sprints, showed that the relationships between $RSA_{mean1-9}$ and $Sdec_{RSA1-3}$ (r=0.36, [0.04, 0.68], P=0.16), $Sdec_{RSA4-6}$ (r=0.43, [0.13, 0.73], P=0.09) and $Sdec_{RSA7-9\ 9}$ (r=0.57, [0.32, 0.82], P=0.03) increased with the number of sprints. These results support our hypothesis because RES performance is more related to endurance performance as the number of sprints increase.

Consistent with previous studies [26,39], we have found a relationship between a soccer player's strength and both sprint and jump performance. The finding that sets our investigation apart is that V_1-load was associated with RSA_{best} (r=−0.76 [−0.92, −0.61], P=0.007), $RSA_{mean1-3}$ (r=−0.64 [−0.86, −0.42], P=0.004), and $RSA_{mean1-9}$ (r=−0.52 [−0.79, −0.25], P=0.04). However, this relationship tends to decrease in the partial

$RSA_{mean4-6}$ (r = −0.44 [−0.74, 0.14], P = 0.10) and $RSA_{mean7-9}$ (r = −0.11 [−0.47, 0.26], P = 0.68). The relationship between V_1-load and RSA was also observed by López-Segovia et al., [25] who reported that the load that maximized the mechanical power output (~V_1-load) was associated with the soccer player's ability to maintain performance in a repeated sprint protocol of 40 m straight-line with 2 min of rest. Along this line of research, previous studies focusing on resistance training found an increase in mean performance during a repeated-sprint test [17, 20]. However, while we have found a correlation with all the sprints, an analysis every 3 sprints shows that this correlation decreases as sprints are repeated in the same way as with the association observed between RSA_{best} and RSA_{mean}. Therefore, the results of our study suggest that lower body strength, represented by sprint capacity and the magnitude of V_1-load, explains a portion of the performance in RSA_{best} and $RSA_{mean1-3}$, but not in $RSA_{mean4-6}$ and $RSA_{mean7-9}$. These relationships confirm the initial hypothesis, what means that the influence of strength decreases as the number of sprints increases.

Regarding blood metabolites, relationships were found between repeated explosive efforts ability ($RSA_{mean1-9}$ and CMJ_{mean}) and blood metabolites (lactate and ammonia). These relationships indicate that players who achieved better performance in efforts of this kind suffered less metabolic stress than players who achieved worse performance. Rampinini, et al., (2009) also reported that soccer players who achieved better RSA_{mean} produced lower blood lactate concentration (r = 0.66). Although the differences between the protocols used (10 × 10 s of running at 18 km·h^{-1} with 20 s of walking recovery at 5 km·h^{-1} between each bout) make direct comparative between both studies difficult, the results observed show a relationship between blood lactate and RSA performance. With regard to blood ammonia, we have not found any study that examines the acute response of this metabolite to RSA. The observed relationship in our study between increased blood ammonia concentration and lower RES performance suggests that the decreased availability of ATP or PCr levels would limit the maintenance of performance in RES, since increased blood ammonia concentration is interpreted as indicative of net degradation of adenine nucleotides in the muscle [6].

YYIRT-1 showed correlations with $RSA_{mean1-9}$ and CMJ_{mean} when the body weight was controlled (**Table 2**). This variable has proven to be important in sequences of this type being able to differentiate RSA performance [12], and has attained strong correlations with indices of RSA before and after training [36]. Additionally, the aerobic energetic contribution would be higher when the sprints are high in number, long, and alternated with brief active recovery periods [16]. Consequently, in prolonged effort (9 sprints of average duration 7.54 s) with an active recovery that included technique skills (jumping and kicking), the aerobic contribution might facilitate a decrease in the activation of the purine cycle with lower blood ammonia concentration, as shown by the negative correlation between this metabolite and YYIRT-1 (r_w = −0.75 [−0.91, −0.59], P = 0.02). The relationships found among blood ammonia, YYIRT-1 and the RES ability suggest that a higher aerobic performance may contribute to the restoration of PCr and ATP levels [38] and, thereby, improved performance in these actions. Despite the relationship found between sprint performance and jumping height [26, 39], the relationship between repeated sprint and repeated technical actions remains unclear. A previous study [7] examined the influence of adding a jump during repeated-sprint running sequences. While the study found a relationship between RSA_{best} and CMJ_{best} similar to ours (r = −0.53 vs. −0.48), its author reported a correlation between RSA_{mean} and CMJ_{mean} that we did not find (r = −0.58 vs. −0.35, P = 0.17). This discrepancy might be explained by the fatigue caused in our study being higher likely for 2 reasons: 1) in our study we performed jumping but also kicking; 2) in our case the distance of every sprint was longer (40 vs. 25 m). This higher fatigue was expressed by higher values of jump height loss (17.6 vs. 11.8 %), blood lactate concentration (15.0 vs. 10.4 mmol·L^{-1}) and sprint performance decrement (5.8 vs. 3.4 %).

The kicking velocity did not show a relationship with any of the variables assessed. This finding could be explained by the fact that kicking is an action very different from sprinting or jumping. However, it seems that fatigue influences kicking velocity in similar way to affect actions such as sprinting or jumping, as shown in the correlations between $Sdec_{KICK}$ and $Sdec_{RSA1-9}$, (r = 0.86 [0.76, 0.96], P = 0.000), and $Sdec_{CMJ}$ (r = 0.50 [0.22, 0.78], P = 0.05). We have not found any study analyzing the acute effect produced by an RSA test on kicking velocity. However, a previous study [23] examined the effect on this variable to perform an intermittent exercise that was considered to simulate soccer field conditions. However, this study did not analyze the possible relationship between ball-kicking velocity with other variables.

In conclusion, the results of the present study suggest that a soccer player's strength, represented by sprint capacity and magnitude of V_1-load, explain a large part of the performance in the first sequences, whereas this influence is decreases as the number of sprints increases. Conversely, the aerobic capacity gains importance for performance as the number of sprints increases. Higher blood lactate and ammonia concentrations are indicators of lower mean performance in repeated maximal actions (sprinting and jumping). As a limitation of this study, we cannot perform a direct assessment between maximal oxygen uptake and the muscle fiber type as a percentage. This fact could limit a deeper interpretation of the results. Therefore, the possible mechanisms that result in performance should be interpreted cautiously. The results of the present study can contribute to raising awareness about repeating soccer-specific actions such as sprinting, jumping and kicking. A practical application of this study is that repeated sprint and specific skills sequences should be used to assess and develop the ability of team-sport players to repeat specific maximal actions, such as sprinting, jumping and kicking. As a future line of research, it would be interesting to assess the evolution of the different variables analyzed and their relationships over the course of a season or the maturation of the soccer players in general.

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