Original investigation

Physical fitness components associated with performance in a multiple sprint test

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Abstract

Purpose: The 5 m repeat sprint test (5 m-RST) measures resistance to fatigue after repeated bouts of short duration, high intensity activity. This study determined the components of fitness associated with performance in 5 m-RST.

Methods: Speed (10 m and 40 m sprints), strength (bench press), agility, strength endurance (pull ups and push ups) and aerobic power (20 m shuttle run test) were measured in male provincial or national level rugby (n=110), hockey (n=59) and soccer (n=55) players.

Results: Subjects with either high (HI) or low (LO) resistance to fatigue in the 5 m – RST differed in body mass (76.9 ± 11.6 kg vs. 102.1 ± 18.9 kg, HI vs. LO respectively, $p < 0.001$), agility (14.55 ± 0.41 s vs. 15.56 ± 0.30 s, $p < 0.001$), bench press (86 ± 20 kg vs. 114 ± 33 kg, $p = 0.03$), pull ups (13 ± 4 vs. 8 ± 5, $p = 0.02$), push ups (56 ± 12 vs. 39 ± 13, $p = 0.002$) and 20 m shuttle run test (133 ± 11 vs. 87 ± 12 shuttles, $p < 0.001$). A combination of body mass, strength and aerobic capacity were the best predictors of 5 m-RST performance (5 m-RST = -1.274(mass) + 0.756(1RM bench press) + 2.053(number of 20 m-RST shuttles) + 549.409) ($R^2 = 0.66$).

Conclusions: Performance in the 5 m-RST is predicted best by a combination of factors including body mass, strength and aerobic ability, rather than by any single component of fitness.

Key Words: 5 m repeat sprint test, fatigue resistance, performance measures, effect of mass.

Introduction

The 5 m multiple shuttle repeat sprint test (5 m-RST) was adapted from the Welsh Rugby Union shuttle run test[1] by the Sport Science Institute of South Africa[2]. The test consists of six 30 second repeat sprint bouts, interspersed by 35 second rest periods. The 5 m-RST measures the ability to resist fatigue during repeated short bouts of sprinting and was designed to test match related fitness in a number of sports characterised by intermittent, short duration, high intensity bouts of activity, including rugby[3], field hockey[4], soccer[5], and Gaelic football and hurling[6]. The 5 m-RST is reliable in both female hockey (2,7[7]) and rugby players (interclass correlation coefficient; r = 0.98)[2] . Performance in the 5 m-RST was correlated with actual distance covered (r = 0.74) and mean running speed (r = 0.73) during a field hockey match, as determined by time-motion analysis[7]. Therefore, an analysis of factors which influence the performance in the 5m-RST has practical implications for players, coaches, trainers and sports scientists.

It is logical to assume that speed would influence performance in the 5 m-RST as speed is associated with the level of performance in a number of sports characterised by multiple sprints [8-13]. The 40 m sprint time of elite sportsmen participating in sports characterised by intermittent short duration, high intensity bouts of activity has been shown to be fairly homogenous ranging, on average, between 5 and 6 seconds. This has been shown in soccer[14], hockey[15], rugby union[16] and rugby league[17;18] indicating that speed only varies by about 20% among these elite sportsmen. The relatively low variation in speed (~20%) is in contrast to the wide variation (~45%) in 5 m-RST performance observed in the same group of participants. Our own observations are that the faster elite sportsmen do not necessarily perform better in the 5 m-RST. This suggests that factors other than speed must contribute to the ability to resist fatigue and maintain speed during short duration, high intensity work and that the ability to maintain speed after fatigue induced by repetitive bouts of short duration, high intensity exercise may be a more valuable fitness characteristic to participants in multiple sprint sports than absolute speed for a single sprint.

The identity of the factors associated with performance in the 5 m-RST are not well defined. Therefore, the aim of this study was to identify the physiological variables associated with 5 m-RST performance in a group of elite sportsmen from South African rugby union, soccer and hockey teams whose 40 m sprint time ranged between 5 and 6 seconds.

Methods

Subjects and Testing

Data were collected from male rugby (n=110), hockey (n=59) and soccer (n=55) players who had been tested in the High Performance Centre of the Sports Science Institute of South Africa from 1996 to 2005. The use of these data was approved by the ethical review board of the University of Cape Town. The rugby and hockey players had played either at provincial or national level, and the soccer players were 1st division club professionals. Approximately half of the sample had represented their country at national level. Subjects were included in the study on the basis of having completed both a 40 m sprint and 5 m-RST within a three day testing period, and being timed at between 5 and 6 seconds for the 40 m sprint. All testing was performed indoors on a rubberised flooring at the High Performance Centre. One of the authors (JD) supervised all testing.

The mass of the subjects were measured to the closest 0.1 kg using a digital scale (Seca model, 708 Germany). Height was measured to the nearest centimetre using a stadiometer (Seca model, 708 Germany). Following a thorough warm up, players performed the following tests:

5 m Repeat Sprint Test (5 m – RST)

The 5 m-RST was performed as described by Boddington et al (2001)[2]. Each subject was allowed 10 minutes to complete his own specific warm-up and 2 (125 m) submaximal repeats of the modified 5 m-RST. Six beacons were placed 5 meters apart in a straight line to cover a total distance of 25 meters. Subjects were instructed to avoid pacing and perform with a maximal effort throughout the whole test. Each subject started the test in line with the first beacon, and upon an auditory signal sprinted 5 m to a second beacon, touched the ground adjacent to the beacon with their hand and returned back to the first beacon, touching down on the ground adjacent to the beacon with the hand again. The subject then sprinted 10 m to the third beacon, and back to the first beacon etc. until an exercise period of 30 seconds had elapsed. No instruction was given as to which hand should touch during each turn. The distance covered by each subject was approximated to the nearest 2.5 m during each 30-second shuttle. The subjects performed 6 repeat bouts of this protocol with a 35 second rest between bouts. The total distance covered in the 6 bouts was recorded.

Sprint Speed

Sprint speed was measured over 10 m and 40 m using an electronic sprint timer with photo-electric sensors. The photo-electric sensors were placed at the start line and 10 m and 40 m from the start line. The player was instructed to start from a crouched standing, with their front toe 30 cm behind the start line. He then sprinted maximally for 40 m through the sensors. The player completed two maximal effort runs separated by a 5-10 minute recovery period. Players wore running shoes without spikes. The fastest 10 m and 40 m times for each player were recorded.

1 RM Bench Press

Upper body strength was measured by a one repetition maximum (1RM) bench press and was recorded as the maximum weight (kg) that could be lifted in one repetition. The player lay supine on a bench with his feet flat on the floor and his hips and shoulders in contact with the bench. An Olympic bar was gripped 5 -10 cm wider than shoulder width, so that when the bar was placed on the chest, the elbow joints were flexed to approximately 90 degrees. The player started this test by lowering the bar in a controlled manner to the centre of the chest, touching the chest lightly and then extending upwards until the arms were in a fully locked position. A light warm-up set of 10 repetitions was performed using a 20 kg weight. This was followed by 6-8 repetitions at approximately 30-40% of the estimated 1RM, which was based on previous resistance training experience. A 2-minute stretching routine for the shoulders and chest was completed, followed by a further six repetitions on the bench press at a weight corresponding to 60% of the estimated 1RM. The player then rested for 3-4 minutes before attempting his 1RM. If the 1RM was successful, the player had a 5-minute rest before attempting a bench press using a resistance that had been increased by 2.5% to 5.0%. If the player could not lift the weight the previous successful weight lifted was recorded as his 1RM. A lift was disqualified if the player lifted the buttocks during the movement, bounced the bar off the chest, extended the arms unevenly, or if the bar was touched by the spotter. The 1RM bench press value was used to calculate the subjects upper body strength to weight ratio (kg/kg) using the allometric modelling ratio 1RM/mass$^{0.57}$ described by Dooman and Vanderburgh (2000)[19].

Illinois Agility Test

Agility was assessed using the Illinois agility testing protocol (Getchell, 1985)[20]. In brief the course is marked out in an area 9.15 m x 4.32 m with a cone in each corner to indicate the start, finish and turning points of the course. A further four cones are placed 3.05 m apart in the centre of the course. The player starts lying face down 30 cm behind the start line. On an auditory signal, the player runs systematically around the cones, weaving through the middle cones in a set pattern (~56 m). The starting light sensor was placed 30 cm above the ground. Another light sensor was placed at the finish line 1 m above the ground. The time was recorded as the time taken for the player to break the light sensors at the start and finish. The best time of two maximal attempts was recorded.

Strength Endurance

Strength endurance was measured as the maximum number of correctly executed push ups that each subject could complete within one minute and the maximum number of pull ups.

Push ups**:** The player began in a prone position with his hands on the floor, thumbs shoulder width apart and elbows fully extended. Keeping his back and body straight, the player descended to the tester's fist which was placed on the floor below the player's sternum, and then ascended until the elbows were fully extended. If the player did not adhere to these specifications the repetition was not counted. The test was scored as the number of push ups performed in one minute.

Pull ups**:** The player began hanging (arms fully extended) from the pull up bar using an underhand grip, with his hands 10-15 cm apart. The player then pulled his body up towards the pull up bar until his chin was above the bar. The player then lowered himself down to the start position in a controlled movement. The player was allowed to lift his knees during the upward movement to prevent arching of his back. If the player did not adhere to the specifications, the repetition was not counted. This is a maximal test and the test was scored as the number of complete pull ups performed with proper form until no further repetitions could be performed.

20 m Multiple Shuttle Run Test (20 m-SRT)

Aerobic endurance was assessed using the 20 m-SRT (Léger et al, 1987)[21]. The first two stages of the 20 m-SRT were used as familiarisation and for a light warm-up before starting the test. Each subject ran back and forth on a 20 m course, starting at a speed of 8.5 $km.h^{-1}$ (2.36 $m.s^{-1}$). The running speed was increased by 0.5 $km.h^{-1}$ (0.14 $m.s^{-1}$) every minute. The running pace was regulated by a pre-recorded audio tape, which signalled when the subject needed to be at one or the other end of the 20 m course. Subjects tried to complete as many stages of the shuttle run test as possible, and the test was terminated when they were unable to maintain the prescribed pace. The subjects were given a warning the first time they were behind the sound signal and the test was stopped on the third warning. Results of the 20 m-SRT are presented as the number of shuttles completed.

The 20 m-SRT and the 5 m-RST were not performed on the same day due to the strenuous nature of both tests.

Statistical Analysis

Data are expressed as mean ± standard deviation. A Pearson's product moment correlation was used to determine the relationship between the fitness variables and the distance covered in the 5 m-RST. A multiple regression analysis was performed to determine which combination of measured characteristics could predict 5 m-RST performance. The Mann-Whitey U test was performed to determine the differences between groups which displayed high (HI) and low (LO) resistance to fatigue. All statistical analyses were performed using Statistica v 7 software (StatSoft, Inc. (2004), www.statsoft.com). Statistical significance was accepted at $p < 0.05$.

Results

Descriptive data for all 224 hockey, rugby and soccer players are shown in Table 1. Figure 1a shows the relationship between performance in the 5 m-RST and 40 m speed as determined by the least squares method for the whole group (n = 224). Linear regression analysis indicated that approximately 11% of the variance in 5 m-RST performance was accounted for by variance in 40 m speed. In figure 1b, all subjects whose actual score for the 5 m-RST fell within the predicted score ± Standard Error of the Estimate (SEE) for the 5 m-RST as predicted by their 40 m speed were removed from the analysis (n = 176). The remaining subjects (n = 48) formed two groups; those subjects whose 5 m-RST scores were either higher than predicted score + SEE (HI) (n = 21), or lower than the predicted score –SEE (LO) (n = 27). The HI group were classified as a group of athletes who had a superior resistance to fatigue and the LO group was classified as a group with a relatively low resistance to fatigue, based on their 40 m speeds. It is evident from figure 1b that there are clusters of athletes from different sports within these two groups. The HI group consists of mostly hockey players, while the majority of the LO group are rugby players.

The HI and LO groups were then compared using the Mann-Whitney U-test to determine which physiological variables and performance measures were different between the two groups (Table 2). The HI and LO groups differed significantly in mass, height, agility, 1 RM bench press, pull ups, push ups and 20 m-SRT. Analysis of covariance established that even when differences in mass were accounted for, 5 m-RST performance was still different between the HI and LO groups, 784 ± 45 m vs. 658 ± 180 m, (mean ± SD, $p < 0.001$). Multiple regression analysis indicated that together mass, 1 RM bench press and number of 20 m-RST shuttles could account for approximately 66% of the variance in 5 m-RST performance, according to the regression formula: 5 m-RST performance = -1.274(mass) + 0.756(1RM bench press) + 2.053(number of 20 m-RST shuttles) + 549.409.

Discussion

The first finding of this study is that 40 m sprint time only accounts for approximately 11% of the variation in 5 m-RST performance in elite participants in sports characterised by high intensity, short duration, intermittent exercise and whose 40 m sprint time lies between 5 and 6 seconds. This group was chosen as they are representative of the majority of elite multiple sprint sportsmen[14-18]. This suggests that other factors influence performance in the 5m-RST to a greater degree than absolute speed. Despite the low correlation between 40 m sprint time and 5 m-RST performance (r = 0.33) it should be noted that speed is still a primary requirement for performance in the 5 m-RST. The 5 m-RST assesses the maximum distance which can be covered in a given time and therefore, it is not possible to cover a greater distance in the 5 m-RST than each individual's maximum speed allows. In a group with a more diverse range of 40 m sprint times than the subjects in this study (5-6 s), the relationship of 40 m sprint time to 5 m-RST performance would presumably be improved.

The fact that 40 m sprint time is so poorly related to performance in the 5 m-RST may be due to a number of factors. Firstly, the 5 m-RST test protocol requires a number of relatively short efforts towards the beginning of each of the six stages. Cronin and Hansen (2005) suggest that 5 m speed is more a measure of first step quickness than of absolute speed, thus the early part of each test stage measures a subject's first step quickness and agility rather than speed[22]. Secondly, 40 m sprints begin from a standing start and with the subject fully rested, whereas during the 5 m-RST the subject must begin each sprint following a 180º-turn and with accumulating fatigue. Thirdly, the longest possible sprint in the 5 m-RST is 25 m in length.

The next finding of the study was that the HI group (superior resistance to fatigue) compared to the LO group (low resistance to fatigue) had differences in mass, height, agility, 1RM bench press, pull ups, push ups and 20 m-SRT shuttles completed.

It was expected that mass would be a major factor affecting fatigue resistance in the 5 m-RST. This is explained by the fact that a subject with a greater mass must perform a greater absolute amount of work compared to a lighter subject covering the same distance in the 5 m-RST. In addition a greater amount of force is required for a larger object to overcome inertia when accelerating and decelerating. Similarly, mass will affect performance in all weight bearing exercise including the agility, pull up, push up and 20 m-RST tests, and therefore mass represents a confounding variable within this study.

Data were not available concerning body fat % of the subjects tested in this study. This was unfortunate since it is anticipated that increased fat mass would have also reduced the resistance to fatigue. However the fact that all subjects tested were competing at the elite level within their sport suggests that the range of body fat % would have been reasonably narrow. The effect of body fat mass on resistance to fatigue is an interesting direction for further research.

Nonparametric statistics were used to assess differences between the HI and LO groups due to the differences in variance between outcome measures. It is not possible to assess covariance using nonparametric statistical procedures. Therefore we used a parametric analysis of covariance, even though we are aware that the data did not fulfil all of the assumptions for this analysis. Having considered this limiting factor, the analysis revealed that when differences in body mass were accounted for, the results for the 5 m-RST were still significantly different between the two groups.

Height was also different between HI and LO fatigue resistance groups, with the LO group being significantly taller than the HI group. The difference in fatigue resistance between taller and shorter subjects may be accounted for by associated differences in mass, for the reasons mentioned above. A second factor which may affect performance in 5 m-RST between taller and shorter subjects is the mechanism of turning during the test. Taller subjects must stoop relatively lower to touch the floor at each turn than their shorter counterparts; this requires a greater amount of physical work and time and thus contributes to decreased 5 m-RST performance.

Agility is a skill-dependant component of physical fitness that relates to the ability to rapidly change the position of the entire body in space with speed and accuracy. Agility was shown to be different between the HI and LO resistance to fatigue groups. It is logical to assume that agility is affected by both height and mass and thus these factors may account for a portion of the differences in performance. Height and mass however, are not the only factors which differentiate subject's performance in terms of agility. Agility requires well developed proprioceptive abilities and neuromuscular communication, and is intrinsic to each individual. Due to the nature of the 5 m-RST, which requires a number of 180º- turns, it is understandable that agility would be a discriminating factor in performance in this test.

Subjects with greater upper body strength were mostly in the LO resistance to fatigue group. Certainly mass is a confounding factor in this relationship because with increased muscular strength one would expect a concurrent increase in body mass. When the 1RM bench press value is corrected for body mass using the strength to weight ratio[19], it becomes apparent that there is no difference in relative strength between subjects with either high or low resistance to fatigue. Therefore it seems that increases in absolute strength and the associated increases in muscle mass, have a negative influence on fatigue resistance.

Performance in both the push up and pull up tests were different between the HI and LO groups, with the HI group scoring higher in both tests. Both of these tests measure local muscle endurance. This suggests that subjects with the highest fatigue resistance, as measured by the 5 m-RST, also have the highest local muscle endurance. A direction for future research would be to establish the accuracy with which either the push up or pull up tests could be used as a more practical test of fatigue resistance within multiple sprint sports.

The 20 m-SRT was originally designed as a practical field test to estimate VO_2 max[21]. There has been a fair amount of controversy regarding the accuracy of this method to predict VO_2 max[23]. However, by comparing the number of shuttles completed in the test rather than estimating VO_2 max, one can gain a functional measure of aerobic power. Aerobic fitness has been linked to improved performance in repeat sprint activities by a number of previous studies[2;24-26]. In this study, aerobic power as measured by the 20 m-SRT, was different between HI and LO fatigue resistance groups. These results indicate that fatigue resistance is improved by aerobic fitness, implying that there is a significant interaction between the aerobic and anaerobic energy systems during multiple sprint exercise. The mechanisms by which repeat sprint performance is improved by aerobic fitness have been extensively reviewed by Glaister (2005) [27], and are beyond the scope of this study. Yet it should be noted that while the 20 m-SRT and 5 m-RST are designed to test the aerobic energy and anaerobic energy systems respectively, the degree of overlap between these two tests suggests these energy systems cannot be tested independent of each other.

An unexpected finding was the clustering of different sports into the HI and LO fatigue resistance groups. Figure 1b shows that the majority of the HI group were hockey players (n = 20 out of 21), while the majority of the LO group was composed of rugby players (n = 20 out of 27). The physical profiles of the hockey and rugby players within this group were different; the rugby players were on average heavier than the hockey players (99.4 kg vs. 74.5 kg, $p < 0.05$) and taller (185 cm vs. 178 cm, $p < 0.05$). While this factor may explain the clustering of different sports to some degree, it is possible that success at elite levels in these sports requires different physical characteristics and that these predispose hockey players to improved performance in the 5 m-RST.

The results of the multiple regression analysis indicate that mass, 1 RM bench press and number of 20 m-SRT shuttles are the most significant predictors of 5 m-RST performance. Variation in these factors accounts for 66% of the variation in 5 m-RST performance. This indicates that fatigue resistance is a complex characteristic which cannot be simply explained by a single factor such as speed.

Practical applications

These findings suggest that there are a number of training interventions which could be made to improve resistance to fatigue as measured during the 5 m-RST. For example, decreasing a player’s mass may improve performance in the 5 m-RST. While the loss of mass may not be desirable for players in contact sports such as rugby, where increased size is an advantage, players can aim to minimise their body fat %, thus decreasing their mass which does not directly contribute to muscle function. Gains in strength and muscular endurance, which do not result in an increase in body mass, may also contribute to improved fatigue resistance during intermittent, short duration, high intensity activities. Training which results in improvements in agility and or aerobic power may also improve performance in the 5 m-RST.

Conclusions

The findings of this study indicate that in a group of elite athletes who participate in sports characterised by intermittent, short duration, high intensity bouts of exercise, 40 m sprint time is a poor predictor of performance in the 5 m-RST. Factors determining success in the 5 m-RST are multifaceted and performance is best predicted by a combination of factors including body mass, strength and aerobic ability.

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Figure 1 – Repeat sprint distance covered versus 40m speed between 5 and 6 seconds, (a.) for all rugby (n=110), hockey (n=59) and soccer (n=55) players. $y = -67.2x + 965$ ($P<0.001$),

(b.) excluding those rugby, hockey and soccer players whose scores lie within the SEE. Dashed lines indicate predicted repeat sprint values (using 40m sprint speed) ± SEE.

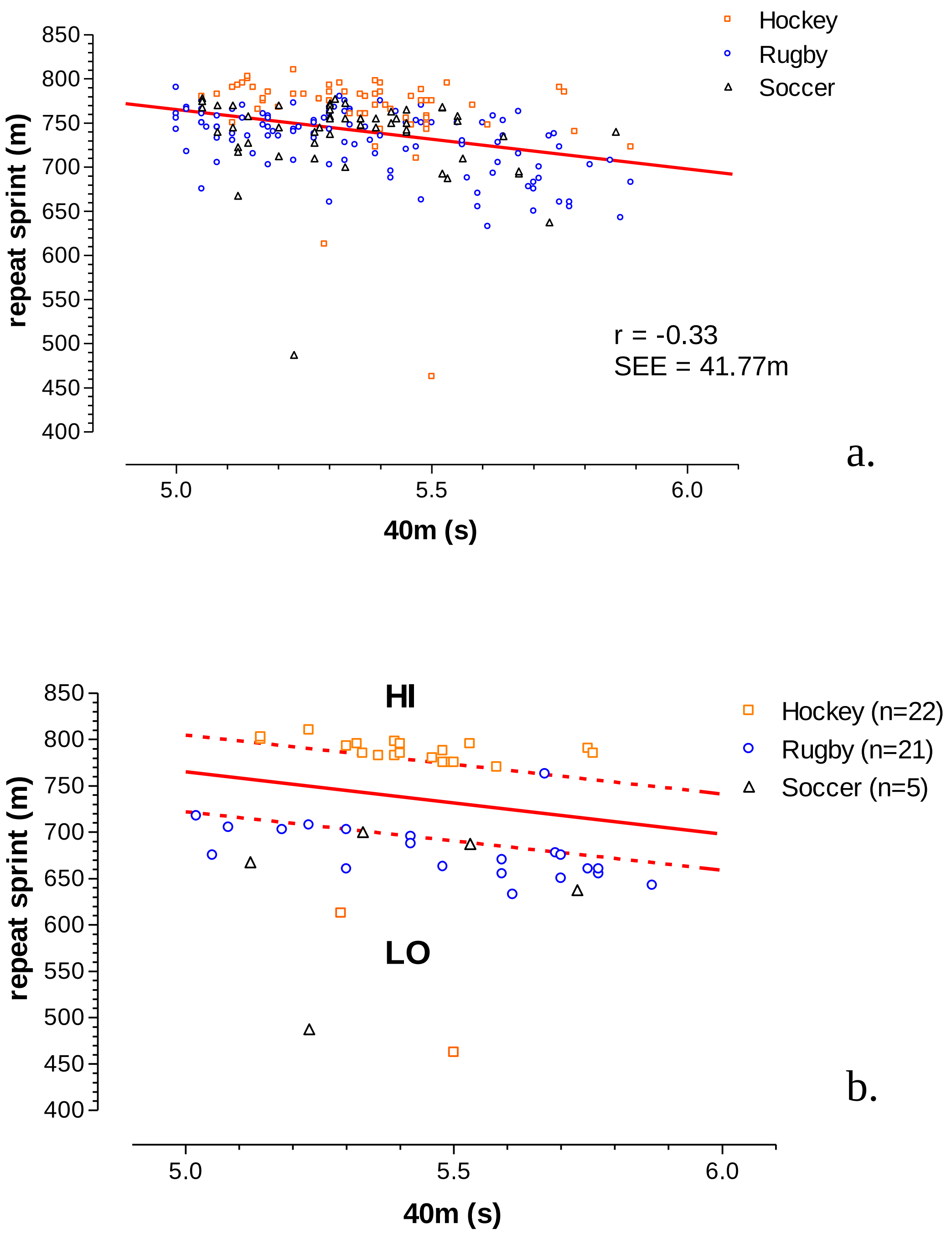

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Table 1 – Results of outcome measures for entire group. Data are presented as means ± SD, n is in brackets.

Mass (kg)	88.0	±	17.6	(196)
Height (cm)	181	±	9	(171)
10 m Time (s)	1.79	±	0.10	(221)
40 m Time (s)	5.36	±	0.22	(224)
5 m-RST (m)	741	±	44	(224)
Agility (s)	15.03	±	0.66	(64)
1 RM Bench Press (kg)	103.5	±	31.7	(181)
kg/kg	8.05	±	1.87	(169)
Pull Ups	12	±	5	(135)
Push Ups	48	±	15	(130)
20 m-SRT (shuttles)	110	±	17	(82)

5 m-RST : 5m repeat sprint test, *Agility* : Illinois agility test, *kg/kg* : strength to weight ratio calculated according to the formula: 1RM / body weight (kg)$^{0.57}$ [19], *Pull ups* : maximum number of pull ups which can be completed, *Push Ups* : maximum number of push ups completed in 1 minute, *20 m-SRT* : 20 m shuttle run test.

Table 2 – Differences between groups displaying high and low resistance to fatigue based on the results of the 5m-RST. Data are presented as means ± SD, n is in brackets.

	High				***Low***				***p***
Mass (kg)*	76.9	±	11.6	(13)	102.1	±	18.9	(26)	<0.001
Height (cm)*	180	±	6	(13)	185	±	7	(24)	0.02
10 m Time (s)	1.79	±	0.08	(18)	1.79	±	0.14	(27)	0.84
40 m Time (s)	5.43	±	0.17	(21)	5.45	±	0.25	(27)	0.71
5 m-RST (m)*	787	±	12	(21)	657	±	59	(27)	<0.001
Agility (s)*	14.55	±	0.41	(7)	15.56	±	0.30	(7)	0.001
1 RM Bench Press (kg)*	86	±	20	(17)	114	±	33	(24)	0.007
kg/kg	7.35	±	1.37	(13)	8.08	±	1.70	(24)	0.18
Pull Ups*	13	±	4	(12)	8	±	5	(14)	0.005
Push Ups*	56	±	12	(18)	39	±	13	(10)	0.001
20 m-SRT (shuttles)*	133	±	11	(8)	87	±	12	(8)	<0.001

5 m-RST : 5m repeat sprint test, *Agility* : Illinois agility test, *kg/kg* : strength to weight ratio calculated according to the formula: 1RM / body weight (kg)$^{0.57}$ [(19)], *Pull ups* : maximum number of pull ups which can be completed, *Push Ups* : maximum number of push ups completed in 1 minute, *20 m-SRT* : 20 m shuttle run test.