Physical Fitness Components Associated With Performance in a Multiple-Sprint Test

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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 RSTs. 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, \( P < .001 \)), agility (14.55 ± 0.41 seconds vs 15.56 ± 0.30 seconds, \( P < .001 \)), bench press (86 ± 20 kg vs 114 ± 33 kg, \( P = .03 \)), pull-ups (13 ± 4 vs 8 ± 5, \( P = .02 \)), push-ups (56 ± 12 vs 39 ± 13, \( P = .002 \)), and 20-m shuttle-run test (20-m SRT; 133 ± 11 vs 87 ± 12 shuttles, \( P < .001 \)). Body mass, strength, and aerobic power 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 SRT shuttles) + 549.409 (\( R^2 = .66 \)). 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.
influence the performance in the 5-m 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
because speed is associated with the level of performance in a number of sports
characterized by multiple sprints.8-13 The 40-m sprint time of elite participants in
sports characterized by intermittent short-duration, high-intensity bouts of activity
has been shown to be fairly homogeneous—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 performance in the 40-m test only varies by about 20%
among these elite athletes. The relatively low variation in speed (~20%) is in con-
trast 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 athletes 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. The ability to maintain speed after fatigue
induced by repetitive bouts of short-duration, high-intensity exercise might be a
fitness characteristic that is more valuable to participants in multiple-sprint sports
than absolute speed for a single sprint.

The factors associated with performance in the 5-m RST are not well defi ned.
Therefore, the aim of this study was to identify the physiological variables associ-
ated 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 at either the provincial or national level, and the
soccer players were first-division club professionals. Approximately half of the
sample had represented their country at the 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 3-day testing period and being timed at between 5 and 6 seconds for the
40-m sprint. All testing was performed indoors on rubberized flooring at the High
Performance Centre. One of the authors (JD) supervised all testing.

The mass of each subject was measured to the closest 0.1 kg using a digital
scale (Seca model 708, Germany). Height was measured to the nearest centimeter
using a stadiometer (Seca model 708, Germany). After a thorough warm-up, players
performed the following tests.

5-m Repeat-Sprint Test

The 5-m repeat-sprint test (5-m RST) was performed as described by Boddington
et al.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 m apart in a straight line to cover a total distance of 25 m. 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 on an auditory signal sprinted 5 m to a second beacon, touched the ground adjacent to the beacon with a hand, and returned back to the first beacon, again touching down on the ground adjacent to the beacon with a hand. The subject then sprinted 10 m to the third beacon, back to the first beacon, and so on, 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 photoelectric sensors. The photoelectric 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 position, with his toes 30 cm behind the start line. He then sprinted maximally for 40 m through the sensors. The player completed 2 maximal-effort runs separated by a 5- to 10-minute recovery period. Players wore running shoes without spikes. The fastest 10-m and 40-m times for each player were recorded.

**1RM Bench Press**

Upper body strength was measured by a 1-repetition maximum (1RM) bench press and recorded as the maximum weight (kg) that could be lifted in 1 repetition. The player lay supine on a bench with his feet flat on the floor and the hips and shoulders in contact with the bench. An olympic bar was gripped 5 to 10 cm wider than shoulder width, so that when the bar was placed on the chest, the elbow joints were flexed to approximately 90°. The player started this test by lowering the bar in a controlled manner to the center of the chest, touching the chest lightly and then extending upward 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 to 8 repetitions at approximately 30% to 40% of the estimated 1RM, which was based on previous resistance-training experience. A 2-minute self-administered stretching routine for the shoulders and chest was completed, followed by a further 6 repetitions on the bench press at a weight corresponding to 60% of the estimated 1RM. The player then rested for 3 to 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 correctly 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, or extended the arms unevenly or if the bar was touched by the spotter. The 1RM bench-press value was used to calculate the subject’s upper body strength-to-weight ratio (kg/kg) using the allometric modeling ratio 1RM/mass^{0.57} described by Dooman and Vanderburgh.19
Illinois Agility Test

Agility was assessed using the Illinois agility-testing protocol. In brief, the course is marked out in an area 9.15 m × 4.32 m with a cone in each corner to indicate the start, finish, and turning points of the course. Another 4 cones are placed 3.05 m apart in the center 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 2 maximal efforts was recorded.

Strength Endurance

Strength endurance was measured as the maximum number of correctly executed push-ups and pull-ups that a subject could complete within 1 minute.

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 1 minute.

Pull-Ups. The player began hanging (arms fully extended) from the pull-up bar using an underhand grip, with his hands 10 to 15 cm apart. The player then pulled his body up toward 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 was a maximal-effort test and 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

Aerobic endurance was assessed using the 20-m multiple-shuttle-run test (20-m SRT). The first 2 stages of the 20-m SRT were used as familiarization and for a light warm-up before starting the test. Each subject ran back and forth on a 2-m course, starting at a speed of 8.5 km/h (2.36 m/s). The running speed was increased by 0.5 km/h (0.14 m/s) every minute. The running pace was regulated by a prerecorded audio tape, which signaled 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 performed on different days because of the strenuous nature of both tests.
Statistical Analysis

Data are expressed as mean ± SD. 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–Whitney U test was performed to determine the differences between groups that displayed high and low resistance to fatigue. All statistical analyses were performed using Statistica version 7 software (StatSoft, Inc, 2004, www.statsoft.com). Statistical significance was accepted at \( P < .05 \).

Results

Descriptive data for all 224 hockey, rugby, and soccer players are shown in Table 1. The top graph in Figure 1 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 13% of the variance in 5-m RST performance was accounted for by variance in 40-m speed (\( r = .36 \)) compared with 3%, which was accounted for by 10-m speed (\( r = .16 \)). In the lower graph in Figure 1, 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 2 groups—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 was classified as a group of athletes who had a superior resistance to fatigue, and the LO group was classified

<table>
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<tr>
<th>Table 1 Results of Outcome Measures for Entire Group*</th>
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<tr>
<td>Mean ± SD</td>
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<td>----------------</td>
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<tr>
<td>Mass (kg)</td>
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<tr>
<td>Height (cm)</td>
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<td>10-m time (s)</td>
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<td>40-m time (s)</td>
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<td>5-m RST (m)</td>
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<td>Agility (s)</td>
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<td>1RM bench press (kg)</td>
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<td>Pull-ups</td>
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<td>Push-ups</td>
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<td>20-m SRT (shuttles)</td>
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*5-m RST indicates 5-m repeat-sprint test; agility, Illinois agility test; kg/kg, strength-to-weight ratio calculated according to the formula 1RM/body weight (kg); pull-ups, maximum number of pull-ups that can be completed; push-ups, maximum number of push-ups completed in 1 minute; and 20-m SRT, 20-m shuttle-run test.
as a group with low resistance to fatigue, based on their 40-m speeds. It is evident from the bottom graph in Figure 1 that there are clusters of athletes from different sports within these 2 groups. The HI group consisted of mostly hockey players, and most of the LO group were 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 2 groups (Table 2). The HI and LO groups differed significantly in mass, height, agility, 1RM 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 versus 658 ± 180 m (mean ± SD, \(P < .001\)). Multiple-regression analysis indicated that together, mass, 1RM 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 following 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 accounts only for approximately 13% of the variation in 5-m RST performance in elite participants in sports characterized by high-intensity, short-duration, intermittent exercise and whose 40-m sprint times lie between 5 and 6 seconds. This group of subjects was chosen because they are representative of the majority of elite multiple-sprint sportsmen. The correlation between 10-m sprint time and 5-m RST performance is even weaker (\(r = .16\)). These results suggest that speed does not influence performance in the 5-m RST to the same extent as other physical fitness components.

Speed consists of a number of components, all of which are independent qualities, namely, acceleration speed, maximum speed, and speed endurance. Perfor-

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<th>Low</th>
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<tr>
<td>Mean ± SD</td>
<td>n</td>
</tr>
<tr>
<td><strong>Mass (kg)</strong></td>
<td>76.9 ± 11.6</td>
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<tr>
<td><strong>Height (cm)</strong></td>
<td>180 ± 6</td>
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<tr>
<td><strong>10-m time (s)</strong></td>
<td>1.79 ± 0.08</td>
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<td><strong>40-m time (s)</strong></td>
<td>5.43 ± 0.17</td>
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<tr>
<td><strong>5-m RST (m)</strong></td>
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<tr>
<td><strong>Agility (s)</strong></td>
<td>14.55 ± 0.41</td>
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<td><strong>1RM bench press (kg)</strong></td>
<td>86 ± 20</td>
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<td><strong>kg/kg</strong></td>
<td>7.35 ± 1.37</td>
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<td><strong>Pull-ups</strong></td>
<td>13 ± 4</td>
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<td><strong>Push-ups</strong></td>
<td>56 ± 12</td>
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<tr>
<td><strong>20-m SRT (shuttles)</strong></td>
<td>133 ± 11</td>
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*5-m RST indicates 5-m repeat-sprint test; agility, Illinois agility test; kg/kg, strength-to-weight ratio\(^{13}\) calculated according to the formula 1RM/body weight (kg)\(^{5,57}\); pull-ups, maximum number of pull-ups that can be completed; push-ups, maximum number of push-ups completed in 1 minute; and 20-m SRT, 20-m shuttle-run test.
Performance in a Multiple-Sprint Test

Performance in the 10-m sprint is influenced by acceleration speed, whereas performance in the 40-m sprint depends on both acceleration speed and maximum speed. The fact that 10-m and 40-m sprint times are so poorly related to performance in the 5-m RST might be the result of a number of factors. For example, whereas a subject would normally start a sprint test fully rested, in the 5-m RST the subject must complete sprint stages of varying distance with no rest and after 180° turns. These repeated acceleration/deceleration actions have a fatiguing effect on the subject. It is very likely that the relationship of 40-m sprint time to 5-m RST performance would be improved in a group of subjects with a more diverse range of 40-m sprint times than the subjects in this study (5 to 6 seconds).

The next finding of the study was that mass, height, agility, 1RM bench press, pull-ups, push-ups, and 20-m SRT shuttles differed between the HI and LO resistance-to-fatigue groups. Of these differences, mass was clearly notable as a factor that substantially affected fatigue resistance. This finding was expected because a subject with a greater mass must perform a greater absolute amount of work than a lighter subject during any form of weight-bearing activity. This difficulty for heavier subjects is compounded by the fact that a greater amount of force is required for a larger object to overcome inertia when accelerating and decelerating. Therefore, there is a greater chance of heavier subjects’ becoming fatigued more quickly in the 5-m RST than would lighter subjects.

A paradoxical finding in this study was that upper body strength (1RM bench press) was lower in the group with high resistance to fatigue (Table 2); however, according to the multiple-regression analysis, the same measure was positively correlated with fatigue resistance. These findings are explained by the fact that increased physical strength is associated with an increase in muscle mass, and thus subjects with the higher 1RM bench press presumably also have a higher body mass, which as discussed earlier is associated with fatigue in the 5-m RST. This is supported by the finding that there were no differences in strength-to-mass ratio (kg/kg) between the HI and LO groups (Table 2).

Mass was a confounding factor in a number of the other fitness tests performed in this study. The agility, pull-up, push-up, and 20-m RST tests are all weight-bearing tests and thus affected by the subject’s mass. Because improved performance in these tests appears to be associated with improved fatigue resistance, these findings further confirm that fatigue resistance is generally higher in subjects with a lower body mass. The practical implication of these findings is that a decrease in body mass would have a favorable effect on agility, strength endurance, and aerobic power tests, as well fatigue resistance.

The findings in this study indicate that increases in body mass, even the increases associated with gains in strength, may have a negative effect on fatigue resistance. Although increases in strength might improve fatigue resistance, this effect is offset by the fatiguing effect of increased body mass. The practical implication of this finding is that participants in multiple-sprint sports should aim to increase their relative strength without any concurrent increase in body mass. A further implication of these findings is that in sports such as rugby, where a premium is placed on physical strength, there is probably a critical point for each player above which increases in strength and mass are no longer beneficial to a player’s overall performance.

Data were not available concerning body-fat percentage of the subjects tested in this study. This was unfortunate because it is anticipated that increased fat mass
would reduce the resistance to fatigue. 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 because of substantial differences in variance between the 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 fulfill all 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 2 groups. This outcome confirms that factors other than body mass appear to have an effect on fatigue resistance.

Aerobic power is one of the factors that were positively correlated with fatigue resistance. Although this study was not designed to examine cause-and-effect relationships, it is tempting to speculate that fatigue resistance may be improved by increases in aerobic power. The mechanisms by which repeat-sprint performance is improved by aerobic fitness have been extensively reviewed by Glaister24 and are beyond the scope of this study. Although 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 2 tests suggests that these energy systems cannot be tested independently of one another.

Height and agility were also shown to be discriminating factors between the HI and LO fatigue-resistance groups (Table 2). The difference in fatigue resistance between taller and shorter subjects might be accounted for by associated differences in mass, as well as the difference in turning mechanics, in which the taller subject must stoop lower, thus expending more energy. Agility is a skill-dependent component of physical fitness that relates to the ability to rapidly change the position of the entire body in space with speed and accuracy. In this test, agility was shown to be different between the HI and LO fatigue-resistance groups. This relationship is presumably related to both the height and mass of the subject, as well as the similarity between the 2 tests, which both require a number of 180° turns. However, measures of agility are test specific, and, consequently, if a different agility test was used, the results and relationship to fatigue resistance may have been different. Nevertheless, it is logical to conclude that the ability of a subject to perform complex coordinated movements quickly and economically must contribute to fatigue resistance.

A multiple-regression analysis was performed to determine which of the above-mentioned factors best predict 5-m RST performance. The results of this analysis indicate that a combination of mass, 1RM bench press, and number of 20-m SRT shuttles can predict up to 66% of the variation in 5-m RST performance. This indicates that fatigue resistance is a complex characteristic that cannot be simply explained by a single factor. Although it is clear that there must be some relationship between body mass, strength, aerobic power, and fatigue resistance, it cannot be concluded that these are cause-and-effect relationships. To define these relationships more clearly, interventional studies that examine the effect of training programs designed to decrease body mass or increase aerobic power on fatigue resistance need to be conducted.

An unexpected finding of this study was the clustering of various sports into the HI and LO fatigue-resistance groups. The bottom graph in Figure 1 shows that
the majority of the HI group were hockey players (n = 20 out of 21), whereas 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, \( P < .05 \)) and taller (185 cm vs 178 cm, \( P < .05 \)). Even though 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 better performance in the 5-m RST.

**Practical Applications**

These findings suggest that several training interventions could improve the resistance to fatigue as measured during the 5-m RST. For example, decreasing a player’s body mass may improve performance in the 5-m RST. Although the loss of body mass may not be desirable for players in contact sports, such as rugby, for which increased size is an advantage, players can aim to minimize their body-fat percentage, thus decreasing the mass that does not directly contribute to muscle function and movement. Gains in strength and muscle endurance that do not result in an increase in body mass might also improve fatigue resistance during intermittent, short-duration, high-intensity activities. Training that 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 characterized 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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