Influence of Aerobic Endurance, Sports Speed and Strength to Repeated Sprint Performance in Professional Soccer Players

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ABSTRACT

To establish the contribution of aerobic endurance, speed attributes and strength on repeated sprint ability, male professional soccer players (n=18) were tested at the start of the pre-season for maximal oxygen uptake, velocity at maximal oxygen uptake, velocity at lactate threshold, quadriceps and hamstrings isokinetic strength, first step quickness, acceleration, maximal speed and repeated sprint ability. Pearson’s correlation coefficients [r(90% confidence limits)] were calculated to establish the associations between repeated sprint ability and aerobic endurance, speed and strength. Velocity at maximal oxygen uptake had a likely moderate correlation to repeated sprint ability [r=-0.33(-0.65;0.08) to r=-0.34(-0.65;0.07)] and maximal speed had a likely moderate correlation to repeated sprint ability [r=0.40(0.00;0.69)]. Isokinetic strength of the quadriceps and hamstrings had likely moderate to most likely large correlations.

Key Words: Magnitude-based inferences, Partial correlations, Pre-season testing, Fitness
with repeated sprint ability \([r=-0.45(-0.72;-0.06)\) to \([r=-0.68(-0.85;-0.38)\)]\]. Isokinetic strength was a more important determinant of repeated sprint ability compared to aerobic endurance or speed in professional soccer players at the start of the pre-season. Isokinetic relative strength of the hamstrings \([r=-0.68(-0.85;-0.38)]\) was the most important determinant of repeated sprint ability; however approximately 50% of the variance in repeated sprint ability performance remained unexplained. Our results underscore the multifaceted nature of the factors underlying repeated sprint ability performance.

**INTRODUCTION**

Repeated sprint ability (RSA) has received considerable attention in soccer since it is associated with superior performance (18, 24). However despite the general acknowledgment of its contribution to overall team-sport performance (13, 26), the variables associated to superior RSA performance have yet to be adequately elucidated. Although the reliability and validity of RSA tests has been established (27, 29), different studies use different RSA indices such as mean/total sprint time or % decrement/fatigue index, which may affect the association of RSA to other physical attributes (13, 26).

Previous research has indicated that RSA is related to maximal oxygen uptake (VO\(_2\)\(_{\text{max}}\)) (4, 14) but others have concluded that RSA is more related to locomotor factors, such as velocity at maximal oxygen uptake (v\(\text{VO}_2\)\(_{\text{max}}\)) and maximal sprinting speed (MSS) rather than VO\(_2\)\(_{\text{max}}\) and/or oxygen uptake kinetics (5, 23). Others have also shown a stronger relationship of RSA to submaximal rather than maximal aerobic fitness variables (25). Furthermore studies examining the contribution of sprinting speed to RSA have only assessed MSS (5, 23). However in soccer, the speed over the first steps (first step quickness) and the ability to rapidly increase speed (acceleration) (9) are considered important factors for the many of the decisive phases in the game (12) and are not necessarily related to MSS (20). For example it has been demonstrated that ~50% of the goal scoring situations were preceded by straight light sprinting (12). In addition acceleration (10m sprint performance) and MSS (flying 20m sprint test) share only 39% common variance which means that these attributes are relatively independent in professional soccer players (20). Therefore whilst first step quickness, acceleration and MSS are all considered “speed attributes” their contribution to RSS may differ. To the best of our knowledge there are no available data that evaluated the contribution of first step quickness or acceleration to RSA.

Furthermore whilst the contribution of strength to the various indices of sports speed has been investigated (8, 9, 22), there is very little information regarding the
association between strength and RSA. Based on the few studies that have examined RSA and leg strength, it appears that these variables are not related (19, 22). However these studies recruited amateur American football players (19) or university level soccer and rugby players (22). Therefore the contribution of strength to RSA has not been investigated in professional soccer players.

Therefore the purpose of the present study was to establish the contribution of aerobic endurance, speed attributes and strength variables on RSA indices of professional soccer players. Based on the available literature we hypothesized that the mean sprint time (i.e RSA$_{\text{mean}}$) rather than % sprint decrement (%Dec) will be related to aerobic endurance/speed variables and that neither RSA$_{\text{mean}}$ nor %Dec will be related to strength variables.

**MATERIALS AND METHODS**

Male soccer players of the same professional club were recruited for the purposes of the present study. Players performed the following tests at the beginning of the preparation period (early July): a) assessment of VO$_2$\text{max}, vvVO$_2$\text{max}, velocity at lactate threshold (vLT) and isokinetic leg strength at the laboratory, b) field sprint tests to determine first step quickness (5m), acceleration (10m) and MSS (30m) and c) a repeated sprint field test consisting of 6 X 35m interspersed with 10 seconds of passive recovery. Testing was completed within one week but on 3 different days separated by 48 hours. Endurance and isokinetic testing was performed first, followed by speed and then RSA testing.

**Participants**

Eighteen professional male soccer players (27.1±5.8 years; 180±6cm; 77.4±4.5 kg; and 10.4±2.8 % body fat) took part in the study. The players had been playing at a professional level for at least 3 years (range: 3-14 years). The aims, benefits, and risks involved with this investigation were explained to all players and the coaching staff and written informed consent was received from all the participants. The experimental protocol complied according to the Declaration of Helsinki for research with human subjects. All procedures were approved by the University of Ioannina, Greece ethics committee.

**Ergospirometric and isokinetic testing**

Athletes reported to the laboratory at a fully hydrated state, having abstained from caffeine for 4 hours and vigorous training for 48 hours. Height and weight were measured using calibrated stadiometer and scale (Seca, Hamburg, Germany). The
players performed an incremental exercise test to volitional exhaustion using a computerized system (CPX Ultima, Medical Graphics, St. Maul, MN, USA) to determine VO$_2$\text{max}, vVO$_2$\text{max} and vLT. The initial speed of the incremental test was set at 10 km\cdot h$^{-1}$ and was increased by 2 km\cdot h$^{-1}$ every 3 minutes until volitional exhaustion (30). At the end of each 3-minute stage capillary blood samples were collected and analyzed for lactate using an automated analyzer (Accutrend, Roche Diagnostics, Mannheim, Germany). Criteria for VO$_2$\text{max} were a) plateau in VO$_2$ (an increase less than 2.1 ml\cdot kg$^{-1}$\cdot min$^{-1}$ despite an increase in running speed), b) respiratory exchange ratio (RER) greater than 1.10, (c) HR +/−2.5\% of age predicted HRmax, and (d) maximal blood lactate after exercise >8 mM. In all cases, at least 3 of 4 criteria were met. vLT was determined using the D$_{\text{max}}$ method (30). Briefly blood lactate values were plotted against speed, and the data were fitted using a third degree polynomial curvilinear regression (30).

Approximately 30 minutes after termination of the ergospirometric assessment, players were tested for maximum torque output of the quadriceps and hamstrings using an isokinetic dynamometer (Biodex, System-3, Biodex Medical Systems Inc, NY, USA). The subjects sat on the dynamometer chair and were secured with body straps while the hip and knee joints were flexed at 90°. For a warm-up, they performed submaximal isokinetic concentric contractions by flexing and extending the knee joint. During testing five maximal concentric reciprocal knee extensions–flexions were performed at angular velocities of 60°/sec$^{-1}$ and 180°/sec$^{-1}$ with 1 minute rest interval between velocities. Peak torque for the quadriceps (Q$_{60}$ and Q$_{180}$) and hamstrings (H$_{60}$ and H$_{180}$) was identified as the highest value during the five repetitions. Peak torque values were also expressed relative to body mass.

**Speed testing**

Testing took place in a natural turf soccer pitch with players wearing their soccer boots. Prior to testing all players completed a standardised warm up of low-intensity running, static and dynamic stretching exercises and short acceleration efforts. Sprint times for 5m, 10m, and 30m were recorded to the nearest 0.001 sec using electronic timing lights (Newtest PowerTimer, Newtest Oy, Oulu, Finland). The players performed all sprints starting from a split stance position. They placed their front foot ∼30cm behind the first photocell. The players started their effort upon hearing an audio signal from the system. Every player performed 3 attempts and the best sprint time was used in the subsequent analysis.

**RSA testing**

The RSA test was performed according to a previously validated protocol (29). In summary, the test consisted of 6 x 35m maximal straight line sprint efforts separated by 10 seconds of recovery (including deceleration). The same equipment as
with speed testing was also used for the RSA test (Newtest PowerTimer, Newtest Oy, Oulu, Finland). Participants started their sprint upon hearing an audio signal from the system. Upon finishing they were allowed a short deceleration phase and they had to get ready for the next sprint. The time for each run was measured by two photocells placed apart at precisely 35m and the start for each sprint (10 seconds interval) occurred with an audio signal from the photocell system. Mean time (RSA\textsubscript{mean}) was calculated as the average of the 6 sprints, while percent decrement (% Dec) was determined as \(\frac{\text{RSA}_{\text{mean}}}{\text{RSA}_{\text{best}}}\) and expressed as percent (24).

Statistical analysis

Data in the text and figures are presented as means (SD) unless stated otherwise. The distribution of each variable was examined with the Kolmogorov-Smirnov normality test. Pearson’s correlation coefficients were calculated to establish the correlations between RSA indices and aerobic endurance, speed attributes and strength variables. Furthermore because performance at the first sprint is a major determinant of fatigue during repeated sprints, correlations were further adjusted for best sprint using partial correlations (5). The magnitudes of the correlations [r(90% confidence limits)] were assessed with the following thresholds: \(\leq 0.1\), trivial; \(>0.1–0.3\), small; \(>0.3–0.5\), moderate; \(>0.5–0.7\), large; \(>0.7–0.9\), very large; and \(>0.9–1.0\), almost perfect (5, 17). In addition quantitative chances that the effect statistic was beneficial or detrimental were assessed qualitatively as follows: <1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99%, very likely; and >99%, almost certain (17). If the 90% confidence intervals overlapped small positive and negative values, the magnitude was deemed unclear; otherwise the magnitude was deemed to be the observed magnitude (5, 17).

RESULTS

The relationships between the RSA indices and aerobic endurance, speed attributes and strength variables are presented in Table 1. There was likely moderate negative correlation between \(\text{RSA}_{\text{mean}}\) and \(v\text{VO}_2\text{max}\), a likely moderate positive correlation between \(\text{RSA}_{\text{mean}}\) and acceleration (10m) and a very likely large positive correlation between \(\text{RSA}_{\text{mean}}\) and MSS. Regarding isokinetic strength there was a likely moderate negative correlation between \(\text{RSA}_{\text{mean}}\) and \(H_{60}^\text{60^\circ}, Q_{180}^\text{180^\circ}, H_{60}\text{(rel)}^\text{60}, \text{and } Q_{180}\text{(rel)}^\text{180}\text{(rel)}^\text{rel}\) a very likely large negative correlation between \(\text{RSA}_{\text{mean}}\) and \(H_{180}\) and a most likely large negative correlation with \(H_{180}\text{(rel)}^\text{180}\text{(rel)}^\text{rel}\). For %Dec there was a likely moderate negative correlation with \(Q_{60}^\text{60}\) and \(H_{60}\), and a likely large negative correlation with \(H_{60}^\text{(rel)}\).
### Table 1

*Relationships between RSA indices and aerobic endurance, speed attributes and strength variables. Correlation coefficients [r(90% Confidence limits)] and magnitude of the correlation.*

<table>
<thead>
<tr>
<th>RSA&lt;sub&gt;mean&lt;/sub&gt;</th>
<th>r(90%CI) magnitude</th>
<th>RSA&lt;sub&gt;%Dec&lt;/sub&gt;</th>
<th>r(90%CI) magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VO₂max (abs)</strong></td>
<td>-0.10(-0.48;0.31), p=0.69,</td>
<td>Unclear</td>
<td>0.14(-0.28;0.51), p=0.59,</td>
</tr>
<tr>
<td><strong>VO₂max (rel)</strong></td>
<td>-0.09, p=0.71,</td>
<td>Trivial</td>
<td>-0.09, p=0.73,</td>
</tr>
<tr>
<td><strong>vVO₂max</strong></td>
<td>-0.36(-0.66;0.05), p=0.15,</td>
<td>Likely moderate</td>
<td>-0.12(-0.50;0.30), p=0.64,</td>
</tr>
<tr>
<td><strong>vLT</strong></td>
<td>0.01, p=0.97,</td>
<td>Trivial</td>
<td>-0.05, p=0.85,</td>
</tr>
<tr>
<td><strong>5m</strong></td>
<td>0.06, p=0.82,</td>
<td>Trivial</td>
<td>-0.25(-0.59;0.17), p=0.32,</td>
</tr>
<tr>
<td><strong>10m</strong></td>
<td>0.36(-0.05;0.66), p=0.15,</td>
<td>Likely moderate</td>
<td>-0.18(-0.54;0.24), p=0.48,</td>
</tr>
<tr>
<td><strong>30m</strong></td>
<td>0.61(0.28;0.81), p&lt;0.01,</td>
<td>Very likely large</td>
<td>-0.08, p=0.76,</td>
</tr>
<tr>
<td><strong>Q&lt;sub&gt;60&lt;/sub&gt;</strong></td>
<td>-0.25(-0.59;0.17), p=0.31,</td>
<td>Unclear</td>
<td>-0.36(-0.64;0.09), p=0.14,</td>
</tr>
<tr>
<td><strong>H&lt;sub&gt;60&lt;/sub&gt;</strong></td>
<td>-0.32(-0.64;0.09), p=0.20,</td>
<td>Likely moderate</td>
<td>0.19(-0.23;0.55), p=0.44,</td>
</tr>
<tr>
<td><strong>Q&lt;sub&gt;180&lt;/sub&gt;</strong></td>
<td>-0.41(-0.70;0.01), p=0.09,</td>
<td>Likely moderate</td>
<td>-0.22(-0.57;0.20), p=0.38,</td>
</tr>
<tr>
<td><strong>H&lt;sub&gt;180&lt;/sub&gt;</strong></td>
<td>-0.63(-0.82;-0.31), p&lt;0.01,</td>
<td>Very likely large</td>
<td>0.01, p=0.97,</td>
</tr>
<tr>
<td><strong>Q&lt;sub&gt;60&lt;/sub&gt; (rel)</strong></td>
<td>-0.25(-0.59;0.17), p=0.32,</td>
<td>Unclear</td>
<td>-0.51(-0.76;-0.14), p=0.03,</td>
</tr>
<tr>
<td><strong>H&lt;sub&gt;60&lt;/sub&gt; (rel)</strong></td>
<td>-0.40(-0.64;0.09), p=0.10,</td>
<td>Likely moderate</td>
<td>0.07, p=0.77,</td>
</tr>
<tr>
<td><strong>Q&lt;sub&gt;180&lt;/sub&gt; (rel)</strong></td>
<td>-0.40(-0.64;0.09), p=0.10,</td>
<td>Likely moderate</td>
<td>-0.39(-0.68;0.01), p=0.11,</td>
</tr>
<tr>
<td><strong>H&lt;sub&gt;180&lt;/sub&gt; (rel)</strong></td>
<td>-0.72(-0.87;-0.45), p&lt;0.01,</td>
<td>Most likely very large</td>
<td>-0.16(-0.53;0.23), p=0.54,</td>
</tr>
</tbody>
</table>

When considering correlations adjusted for best sprint, the magnitudes of the correlations were identical for RSA<sub>mean</sub> and %Dec (Table 2). RSA indices had a likely moderate negative correlation with vVO₂max, Q<sub>60</sub>, Q<sub>180</sub> and H<sub>180</sub>, a likely moderate
positive correlation with MSS, a very likely large negative correlation with $Q_{60(\text{rel})}$ and $Q_{180(\text{rel})}$ and a most likely large negative correlation with $H_{180(\text{rel})}$.

**Table 2**

*Relationships between RSA indices and aerobic endurance, speed attributes and strength variables after controlling for the effect of best sprint.*

*Partial correlation coefficients [$r(90\% \text{ CI})$] and magnitude of the correlation.*

<table>
<thead>
<tr>
<th>RSA_{mean}</th>
<th>%Dec</th>
<th>RSA_{mean}</th>
<th>%Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r$</td>
<td>magnitude</td>
<td>$r$</td>
<td>magnitude</td>
</tr>
<tr>
<td>$\text{VO}_2\text{max (abs)}$</td>
<td>0.04, p=0.88</td>
<td>Trivial</td>
<td>0.04, p=0.88</td>
</tr>
<tr>
<td>$\text{VO}_2\text{max (rel)}$</td>
<td>-0.14(-0.51;0.28), p=0.60</td>
<td>Unclear</td>
<td>-0.12(-0.50;0.30), p=0.64</td>
</tr>
<tr>
<td>$v\text{VO}_2\text{max}$</td>
<td>-0.34(-0.65;0.07), p=0.18</td>
<td>Likely moderate</td>
<td>-0.33(-0.65;0.08), p=0.20</td>
</tr>
<tr>
<td>$\text{vLT}$</td>
<td>-0.04, p=0.87</td>
<td>Trivial</td>
<td>-0.02, p=0.93</td>
</tr>
<tr>
<td>$5\text{m}$</td>
<td>-0.16(-0.53;0.26), p=0.54</td>
<td>Unclear</td>
<td>-0.16(-0.53;0.26), p=0.53</td>
</tr>
<tr>
<td>$10\text{m}$</td>
<td>0.11(-0.30;0.49), p=0.69</td>
<td>Unclear</td>
<td>0.11(-0.30;0.49), p=0.69</td>
</tr>
<tr>
<td>$30\text{m}$</td>
<td>0.40(0.00;0.69), p=0.10</td>
<td>Likely moderate</td>
<td>0.40(0.00;0.69), p=0.10</td>
</tr>
<tr>
<td>$Q_{60}$</td>
<td>-0.46(-0.73;-0.07), p=0.06</td>
<td>Likely moderate</td>
<td>-0.45(-0.72;-0.06), p=0.07</td>
</tr>
<tr>
<td>$H_{60}$</td>
<td>-0.06, p=0.83</td>
<td>Trivial</td>
<td>-0.07, p=0.80</td>
</tr>
<tr>
<td>$Q_{180}$</td>
<td>-0.46(-0.73;-0.07), p=0.06</td>
<td>Likely moderate</td>
<td>-0.47(-0.73;-0.09), p=0.06</td>
</tr>
<tr>
<td>$H_{180}$</td>
<td>-0.58(-0.80;-0.23), p=0.01</td>
<td>Very likely large</td>
<td>-0.57(-0.79;-0.22), p=0.02</td>
</tr>
<tr>
<td>$Q_{60(\text{rel})}$</td>
<td>-0.22(-0.57;0.20), p=0.40</td>
<td>Unclear</td>
<td>-0.22(-0.57;0.20), p=0.40</td>
</tr>
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<td>$H_{60(\text{rel})}$</td>
<td>-0.58(-0.80;-0.23), p=0.01</td>
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<td>-0.57(-0.79;-0.22), p=0.02</td>
</tr>
<tr>
<td>$Q_{180(\text{rel})}$</td>
<td>-0.68(-0.85;-0.38), p&lt;0.01</td>
<td>Most likely large</td>
<td>-0.67(-0.84;-0.37), p&lt;0.01</td>
</tr>
</tbody>
</table>
DISCUSSION

The major finding of the present study was that isokinetic strength of the quadriceps and hamstring is a more important determinant of RSA indices in professional soccer players at the start of the pre-season period compared to either aerobic endurance or speed indices. Furthermore, our results demonstrated that isokinetic relative strength of the hamstrings \( (H_{180(\text{rel})}) \) rather than quadriceps was the most important determinant of RSA.

Our first hypothesis was that RSA_{mean} rather than %Dec will be related to aerobic endurance and speed variables. Our results indicated that RSA_{mean} had a likely moderate negative correlation with \( vV_{02\text{max}} \), a likely moderate positive correlation with acceleration and a very likely large negative correlation with MSS, whilst correlations between %Dec and aerobic endurance or speed performance variables were either trivial or unclear. The lack of relationship between %Dec and endurance or speed variables has also been reported in the literature (5, Table 4). However, partial correlations controlling for the best sprint showed similar correlations to \( vV_{02\text{max}} \) and MSS for both RSA_{mean} and %Dec (5). For example, the previous study demonstrated identical correlation coefficients between RSA_{mean} and %Dec when partial correlations were adjusted for best sprint (5, Figure 2). Thus, controlling for the effect of best sprint on RSA_{mean} may be of importance when attempting to assess the contribution of aerobic endurance or speed performance indices to RSA_{mean} and % Dec and may explain the inconsistency in the relationship between RSA indices and fitness (5, 11). Our results further demonstrated that \( V_{02\text{max}} \) and \( vLT \) had trivial or unclear relationships with RSA indices. Regarding \( V_{02\text{max}} \), previous studies have reported a lack of correlation between RSA and \( V_{02\text{max}} \) (1, 4, 7). However, other investigators have in fact reported significant correlations between \( V_{02\text{max}} \) and RSA indices (3, 14). The difference reported by these studies could be due to the different characteristics of the RSA protocols employed (number of sprints, sprinting distance, duration and nature of recovery) (12, 26). Furthermore, it has been proposed that the lack of association between \( V_{02\text{max}} \) and RSA could be due to the fact that \( V_{02\text{max}} \) is determined primarily by central factors (2) while RSA performance may be more associated with peripheral factors (26). In support of this it has been shown that repeated sprint indices were more strongly correlated to \( vLT \) than \( V_{02\text{max}} \) (25). However, in our study \( vLT \) was not related to either RSA_{mean} or % Dec. This apparent discrepancy may be explained by the difference in the nature of the protocols (6 X 35m with 10 seconds passive recovery vs. 7 X 34.2m with 25 seconds active recovery). From the configuration of these two RSA tests, our protocol has less than half the recovery time of the other protocol and as such is much more dependent on anaerobic resources. More importantly in our study the last sprint was significantly slower compared to all other sprints whilst in
the previous study the last sprint was not significantly different from the previous 3 sprints (25). In fact, these authors reported a plateau in performance decrement between sprints 4-7 which may be indicative of some type of pacing and may explain the differences in the correlations with vLT. Finally, in the present study a mathematically derived vLT was chosen via the Dmax method, whilst the previous study used a fixed blood lactate concentration of 3.5mM (25).

Whilst RSA indices did not correlate with VO$_2$max and vLT, they did show likely moderate correlations with vVSe$_2$max and MSS. Our results are in agreement with a previous investigation (5) although the strength of the correlations is clearly weaker in our study. It has been proposed that vVSe$_2$max and MSS represent the locomotor profile of an athlete i.e. the maximal speeds that are supported by aerobic and anaerobic powers respectively and as such can be related to maximal running efforts lasting from few seconds to several minutes (6). Furthermore other studies have also verified that RSA is related to either maximal speed (10, 23) or vVO2max (25). Finally the correlations between RSA indices and both first step quickness and acceleration were unclear. To the best of our knowledge there are no other studies that have assessed the contribution of these speed attributes to RSA. More studies with probably larger samples are needed to clarify the relationship (if any) between RSA and first step quickness and acceleration.

Our second hypothesis was that neither RSA$_{\text{mean}}$ nor %Dec will be related to strength variables. Our results indicated that RSA$_{\text{mean}}$ had a likely moderate negative correlation with H$_{60}$, Q$_{180}$, H$_{60(\text{rel})}$ and Q$_{180(\text{rel})}$, a very likely large negative correlation with H$_{180}$ and a most likely large negative correlation with H$_{180(\text{rel})}$ whilst for % Dec there was a likely moderate negative correlation with Q$_{60}$ and H$_{60}$ and a likely large negative correlation with H$_{60(\text{rel})}$. Adjusting for the effect of best sprint produced some small changes and RSA indices had a likely moderate negative correlation with Q$_{60}$, Q$_{180}$ and H$_{180}$, a very likely large negative correlation with Q$_{60(\text{rel})}$ and Q$_{180(\text{rel})}$ and a most likely large negative correlation with H$_{180(\text{rel})}$. Thus, after controlling for the effect of best sprint, both RSA indices showed identical correlations with strength indices as was the case with vVSe$_2$max and MSS.

Surprisingly our results refuted our hypothesis and also are at odds with previous studies (19, 22). For example Newman et al, 2004 (22) investigated the relationships between isokinetic knee strength, single-sprint and repeated-sprint ability in a sample of university-level rugby and soccer players and reported that although isokinetic extension and flexion torque was correlated to single-sprint performance no measure of isokinetic strength was found to be related with the RSA ability. Similarly in a more recent study it was reported that no measure of isokinetic strength was related to RSA indices with the exception of a significant but weak correlation between knee flexion strength (240°·sec$^{-1}$) and percentage of performance decrement from 10-20m (19). Furthermore in this study isokinetic strength was additionally not related to single sprint performance (19). It should be pointed
out that both Newman et al, 2004 (22) and Kin-Isler et al, 2008 (19) recruited amateur or university-level athletes whilst in our study we recruited professional soccer players and this may, at least in part, explain the contradictory results. Furthermore it has previously been reported that concentric force production at the knee is an important parameter in the execution of a sprint stride (21) and measures of force relative to body mass are more likely to be related to sprint performance than are absolute values (28). Indeed in our study the strength of correlation for $Q_{60}$, $Q_{180}$ and $H_{180}$ improved when expressed as relative strength. Moreover the strongest relationship was identified for the hamstrings at the higher isokinetic velocity. This is line with previous data highlighting the importance of knee flexor musculature in generating propulsion during the stance phase of running (15). The lack of association between strength and RSA ability in the previous studies was, at least in part, attributed to the apparent dissociation in the energetics specificity. Both Newman et al, 2004 (22) and Kin-Isler et al, 2008 (19) proposed that the differences in the metabolic pathway between peak torque production (phosphagen energy system) and RSA (glycolytic energy system) explain the lack of relationship between them. However, previous studies indicate that strength improvements may, at least in part, be associated with RSA improvements (11, 16). For example resistance training can improve both first-sprint performance (8–9%) and/or the sprint decrement score (~20%) (11, 16). However, it appears that although heavy resistance training may improve an initial sprint, it may not necessarily improve RSA performance (11). Furthermore it has been proposed that factors additional to improvements in maximal strength alone may also be involved in RSA improvements, since greater RSA improvements have been reported when sets of resistance training were separated by 20 seconds, compared with 80 seconds of rest, despite half the increase in maximal leg strength (20% vs 46%) (16). This suggests that resistance training associated with high metabolic load rather than resistance training that maximizes strength gains may best improve RSA, possibly via greater improvements in $H^+$ regulation (11). Thus, although strength may play a role in RSA ability, it appears that other factors are of importance as well. This is in line with our observations that $H_{180[rel]}$, which had the highest correlation with the RSA indices was able to explain only half of the variance in RSA performance.

A limitation of the present study is the use of a convenience sample (i.e. soccer club) which limits the generalization of the findings. Goalkeepers were excluded from the study given the different fitness characteristics compared to outfield players. Furthermore not all players were available at the time of testing to be included in the study (i.e. new transfers arriving at a later time). In addition interpreting our results requires caution since correlation does not imply cause and effect. Additionally the present as well other studies (19, 22, 25) have only assessed the relationships at one time point only (i.e. pre-season) and therefore the cross-sectional design further limits the generalization of the findings. Future studies should
In conclusion, our study demonstrated that RSA of professional soccer players at the beginning of the pre-season period is more related to strength than aerobic endurance indices or speed attributes. To the best of our knowledge this is the first study to demonstrate an association between strength and RSA indices. This has important training implications since most studies have attempted to associate RSA indices to either endurance or speed variables. However our results indicate a potential role of strength training in the development of RSA. Furthermore strength of the hamstrings was the single most important determinant of RSA which probably highlights the role of this muscle group as extensor of the hip especially under fatiguing conditions. Future studies should exploit this possibility with larger samples or soccer specific interventions.

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