THE RELATIONSHIP BETWEEN MAXIMAL AEROBIC PERFORMANCE, REPEATED SPRINT EXERCISE AND REPEATED AGILITY SPRINTING IN SUB-ELITE MALE SOCCER PLAYERS
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Acknowledgments

I would like to give thanks to the nine subjects for giving up their free time to complete the testing procedures, without whom it would not have been possible to complete the study.

I would also like to thank the staff at the physiology lab at University of Wales Institute, Cardiff (UWIC) for providing me with the appropriate training in using the required instruments for testing.

Finally, I would like to thank my supervising tutor, Dr Michael G. Hughes for the guidance he provided me with at each stage of this project.
Abstract

Soccer is a multiple sprint sport in which players are required to have a strong aerobic fitness and simultaneously have the ability to perform repeated-maximal sprints. Conflicting evidence exists regarding the relationship between aerobic fitness and repeated-sprint exercise performance (RSE). The purpose of the present study was to further investigate the relationship between aerobic fitness and RSE performance, extending previous research to include a soccer-specific RSE protocol involving changes-in direction (Repeated-agility sprinting [RAS]). Nine sub-elite male soccer players voluntarily took part in the study (20-years ± 1), each performing a maximal aerobic test ($VO_{2\text{max}}$), a RSE test and a RAS test on three separate days, at least one week apart. The test of RSE performance consisted of 8 x 40-metre sprints with 20-seconds passive recovery, and RAS testing consisted of 8 x 20-metre sprints with three changes in direction and 20-seconds passive recovery between each sprint. Fatigue Index was calculated and used as the performance measure of RSE and RAS. Pearson’s Correlation was performed between aerobic fitness and RSE ($r = 0.298$, $P > 0.05$), aerobic fitness and RAS ($r = 0.037$, $P > 0.05$) and RSE and RAS ($r = 0.754$, $P < 0.05$). The results indicate that $VO_{2\text{max}}$ as an indicator of aerobic fitness has no casual effect on an individual’s ability to perform repeated straight-line or agility sprints. Moreover, the correlation of ($r = 0.754$, $P < 0.05$) between RSE and RAS was interpreted to signify the two parameters as relatively similar qualities, thus either can be regarded as an ecologically valid means of assessing RSE.
CHAPTER I
1. INTRODUCTION

Previous research on the performance of soccer players has focused largely on aspects of technique and tactics at the expense of physical characteristics such as aerobic fitness ($VO_{2\text{max}}$), strength and speed (Helgerud et al., 2001). Sports scientists, coaches, and strength and conditioning practitioners routinely use testing of performance characteristics such as $VO_{2\text{max}}$, strength and speed amongst numerous others to monitor training adaptations (Vescovi and McGuigan, 2008). One study by Wisloff et al. (1998) demonstrated a significant difference in $VO_{2\text{max}}$ between the top team and a lower placed team in an elite Norwegian soccer division, emphasising the importance of such performance characteristics on the performance outcome.

The majority of team sports, require movement patterns that are intermittent in nature and consist of bouts of exercise which are quite brief (≤6-seconds), yet maximal or near maximal in nature, combined with short periods of low to moderate intensity work during recovery (≤60-seconds) (Glaister, 2005). This low to moderate intensity of aerobic performance during recovery remains constant throughout the game, it is therefore imperative that players have a high level of aerobic fitness to compete to the best of their ability. A great deal of research has been conducted on the possible relationship between aerobic fitness and repeated-sprint exercise performance (RSE) (Wadley and Le Rossignol, 1998; Aziz et al., 2000; Tomlin and Wenger, 2001; Bishop et al., 2004; Edge et al., 2006; Glaister et al., 2006; Brown et al., 2007; Castagna et al., 2007). Current literature suggests that recovery from the high intensity intermittent exercise found within team sports is enhanced by an individual having higher levels of aerobic fitness as a result of increased aerobic response, enhanced phosphocreatine (PCr) regeneration and enhanced lactate removal. When performing high intensity intermittent exercise, if the recovery period between exercise bouts is less than a few minutes long, ATP/PCr stores are not fully restored in time for the subsequent exercise bout, thus compromising performance (Glaister, 2005). As the ATP/PCr stores become depleted further during subsequent bouts of high intensity exercise there is an increased reliance on anaerobic glycolysis. The consequence of this reliance on anaerobic glycolysis is an increase in hydrogen ions (H+) which is directly linked to fatigue. Yquel et al. (2002) found that fatigue in RSE was reduced following a period of creatine supplementation, thus reinforcing the link between PCr availability and fatigue.
During recovery periods between sprints, oxygen uptake (VO₂) remains elevated to restore homeostasis by processes such as the replenishment of oxygen into tissue oxygen stores, the metabolism of lactate, the resynthesis of PCr and the removal of intracellular inorganic phosphate (Pi) (Glaister, 2005). If these recovery periods are too short, the metabolic environment is insufficiently restored and the performance during ensuing sprints may be compromised.

It has been suggested (Christensen et al., 1960) that the ATP used to fuel muscle contraction during short bouts (≤10-seconds) of intermittent exercise is derived predominantly from aerobic metabolism. This would be explained by the fact that oxygen bound to myoglobin offsets the usual oxygen deficit at the onset of exercise. This store of oxygen bound to myoglobin will be replenished during the recovery between each bout of exercise, thus showing the contribution of aerobic metabolism to overall energy production during this type of maximal, intermittent activity.

Glaister (2005) states that at the onset of a bout of exercise, there is a delay in oxygen uptake by the working muscles, adding that if the duration of the exercise bout is limited to a few seconds, oxygen bound myoglobin may buffer the initial demand of the exercise. Richardson et al. (1995), suggest that the stores of oxygen bound myoglobin are fully replenished within 20-seconds of cessation of exercise. In theory this possibly explains the link between aerobic fitness and RSE. In addition, the fact that PCr resynthesis and removal of accumulated intracellular Pi are oxygen-dependant processes further supports the suggestion that a relationship exists between aerobic fitness and RSE.

In a review by Glaister (2005), it was identified that due to specific limitations associated with the assessment of field-based RSE, the majority of studies choose to investigate this type of activity in laboratory settings using straight-line sprints. Repeated-sprints in a straight-line appear to be non-specific to soccer and other field sports as sprints within field sports such as soccer rarely involve movements in a straight line, they involve more rapid changes in direction known as agility (Little and Williams, 2005). Agility can be defined as a rapid whole body movement with change of velocity or direction (Sheppard and Young, 2006). Recent studies have shown that RSE protocols should be sport specific (Spencer et al., 2006). RSE protocols involving straight line sprints lack validity and sport specific relevance to team-sports. This would suggest a need to address whether
the use of repeated-agility sprinting is a more valid means of assessing the performance capabilities of team sport athletes (Glaister, 2008). Furthermore, straight line RSE potentially disrupts the validity of an investigation into team-sports such as soccer, particularly as straight-line sprinting has been shown to be poorly correlated with agility (Sheppard & Young, 2006).

Whereas previous studies have aimed to identify links between maximal aerobic performance and RSE (Tomlin and Wenger, 2001), the present study aimed to take a more specific look at field sports by including repeated-sprints involving changes in direction (agility). Therefore, it was the purpose of the present study to further investigate the relationships between VO$_{2\text{max}}$ and repeated-sprint exercise, and address the issue of soccer-specific movement patterns by investigating the possible relationship between VO$_{2\text{max}}$ and repeated-agility sprints (RAS).
CHAPTER II
CHAPTER III
3. METHOD

3.1 Pilot Study

As mentioned previously, one of the aims of the present study was to develop a test of repeated-sprint performance involving change of direction in an attempt to address whether the use of repeated-agility sprinting provides a more ecologically valid means of assessing the performance capabilities of team sport athletes. In order to achieve this, there was a need to design a protocol that would provide similar physiological responses to the repeated-straight-line sprint protocol. This was controlled by each sprint lasting the same duration in both the straight-line and change of direction sprinting. Pilot testing was conducted to assess the developed protocol which involved changes in direction, similar to the work performed during the Illinois Agility Run. The final protocol is shown Figure 2.

3.2 Participants

Subjects were recruited from the University of Wales Institute, Cardiff (UWIC) ($n = 9$) and were aged (values shown as mean ± SD) 20-years ± 1-year, of height 174.9 cm ± 7.0 and of mass 75.0 kg ± 7.2. Each subject was required to be currently participating at a competitive, sub-elite level of performance in soccer. In this case, they were required to be playing regularly at a minimum standard of their local county senior league. Prior to testing, each subject was given information on the test procedures and asked to provide informed consent. They were informed that they were free to withdraw from the study at any point. Due to the nature of the maximal aerobic test requiring subjects to perform demanding exercise to volitional exhaustion, each subject completed pre-activity health questionnaires on the day of testing to ensure there was no health or safety reason why they should not partake in testing.

3.3 Instruments

All testing was carried out in the Sport and Exercise Physiology Lab at the University of Wales Institute, Cardiff (UWIC) and at the National Indoor Athletics Centre (NIAC). Before testing commenced, the subjects had their height recorded using a standard
stadiometer (Holtain Fixed Stadiometer, Holtain Ltd) and their mass recorded using digital weighing scales (SECA, Model 770, Vogel and Halke, Germany). Subjects’ heart rate was recorded using non-invasive telemetry during the test for maximal aerobic performance (Polar Heart Monitors, S610, Polar Electro, Finland). The maximal aerobic test was conducted in the laboratory on a motorised treadmill (Quasar, 4.0, Cosmos sports and medical, Nussdorf-Traunstein, Germany). Online gas analysis was performed using a computerised breath by breath system (Oxycon Pro, Jaeger and Viaysis Healthcare, Warwick, United Kingdom). Timing Gates (Smartspeed, Fusion Sport, Brisbane, Australia) were used to record times for tests of repeated-sprint ability and repeated-agility sprinting.

3.4 Test Procedure

Subjects were required to visit the university on three separate occasions. In the first session, they visited the Sport and Exercise Physiology Laboratory where they took part in a test of maximal aerobic performance on a motorised treadmill. Maximal aerobic performance was determined by VO$_{2\text{max}}$, widely accepted as an appropriate measure of aerobic fitness, representing the maximum rate at which aerobic metabolism can supply energy (Tomlin and Wenger, 2001).

3.4.1 Maximal Aerobic Performance

The protocol administered for the test of maximal aerobic performance has been previously administered by Aziz et al. (2000). The treadmill was set to a speed of 10 km/h which remains constant for the duration of the test. There was an increase in gradient of 2% at the end of each minute for the first 5-minutes and then a further increase of 1% at the end of each minute thereafter until volitional exhaustion. VO$_{2\text{max}}$ at exhaustion was defined by achieving an RER $>1.15$, Heart rate within 5% of age predicted heart rate max and an RPE $>17$. Heart rate was recorded throughout the test, along with expired air, via a mouthpiece. VO$_{2\text{max}}$ was taken as the highest VO$_2$ achieved during the last 30-seconds of the test.
3.4.2 Repeated-Sprint Exercise Testing

During the second visit to the university, subjects visited the National Indoor Athletics Centre (NIAC), where they were required to perform 8 x 40-metre maximal sprints on the indoor running track, with 20-seconds recovery between each sprint. Subjects were counted down into each sprint and began on the test administrators signal. Verbal encouragement was provided to each subject by the same test administrator during testing. Times for each sprint were recorded using timing gates and fatigue index was subsequently calculated. The Fatigue index was calculated using the following equation;

\[
\%\text{Fatigue} = \left( \frac{\text{fastest sprint time} - \text{slowest sprint time}}{\text{fastest sprint time}} \right) \times 100
\]

3.4.3 Repeated-Agility Sprint Testing

Similar to the second visit, subjects’ third visit was also to NIAC, where they were required to perform 8 repeated sprints of agility on the same surface as the sprint tests were conducted on. A specifically designed agility run (Figure 2) was designed to replicate the approximate duration of the 6-second (40-metre) sprint engaged in during the RSE test (see pilot study). Times for each run were recorded using timing gates and verbal encouragement was provided to each subject by the same test administrator. A fatigue index was subsequently calculated for the tests of repeated agility sprinting using the same formula mentioned previously.

3.5 Data Analysis

The Statistical Package for Social Sciences (SPSS v15.0) was used to perform the statistical analysis. Tests of Pearson’s correlation were performed between Aerobic performance (VO\textsubscript{2max}) scores and the fatigue indexes calculated from the RSE test and RAS test for each subject to identify any possible relationships between these variables. A test of Pearson’s correlation was also performed between the fatigue index scores obtained from both the RSE and RAS tests in order to identify any relationship between
repeated-straight-line and repeated-agility sprinting. The level of significance set as $P < 0.05$.

**Figure 2.** A diagramatic representation of the specifically designed agility run
CHAPTER IV
4. Results

The physiological characteristics of participants are summarised in Table 1 with values expressed as mean ± SD. Subjects were aged 20-years ±1 of height 174.9 cm ±6.9 and of mass 75.0 kg ±7.3.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Stature (cm)</th>
<th>Body Mass (kg)</th>
<th>VO_{2\text{max}} (ml/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 (±1)</td>
<td>174.9 (±6.9)</td>
<td>75.0 (±7.3)</td>
<td>57.6 (±5.6)</td>
</tr>
</tbody>
</table>

The mean sprint times and fastest sprint times for RAS were shown to be significantly quicker than the RSE mean and fastest sprints (\(P = 0.001\) and \(P = 0.000\)). Although shown to be significantly different, when observing the mean sprint times in Table 2 above, it is clear that the mean difference of approximately 0.5-seconds is minimal and not likely to have any physiological significance. Similarly, a significant difference (\(P = 0.001\)) was shown to exist between the fatigue index scores of the two sprint protocols, thus identifying a larger rate of fatigue during the repeated-straight-line sprint protocol.

<table>
<thead>
<tr>
<th>Fatigue Index* (%)</th>
<th>Mean Sprint Time* (sec)</th>
<th>Fastest Sprint Time* (sec)</th>
</tr>
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<tbody>
<tr>
<td>RSE 14.5(±6.6)</td>
<td>6.0(±0.3)</td>
<td>5.6(±0.2)</td>
</tr>
<tr>
<td>RAS 7.2(±6.0)</td>
<td>6.5(±0.3)</td>
<td>6.3(±0.3)</td>
</tr>
</tbody>
</table>

*significant difference (\(P < 0.05\))

For the analysis of relationships between maximal aerobic fitness (\(VO_{2\text{max}}\)), Repeated-Sprint Ability (Fatigue Index) and Repeated-Agility Sprinting (Fatigue Index), a test of
Pearson’s Correlation was performed and the results of the test placed into a correlation matrix (Table 3). As is evident from observing the correlation matrix, no significant correlation was found to exist between maximal aerobic fitness and either repeated-sprint ability or repeated-agility sprinting.

**Table 3 – Correlation Matrix of measured parameters (Pearson’s Correlation)**

<table>
<thead>
<tr>
<th></th>
<th>VO$_{2\text{max}}$</th>
<th>RSE F.I.</th>
<th>RAS F.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO$_{2\text{max}}$</td>
<td>n/a</td>
<td>0.298</td>
<td>0.037</td>
</tr>
<tr>
<td>RSE F.I.</td>
<td>0.298</td>
<td>n/a</td>
<td><strong>0.754</strong>*</td>
</tr>
<tr>
<td>RAS F.I.</td>
<td>0.037</td>
<td><strong>0.754</strong>*</td>
<td>n/a</td>
</tr>
</tbody>
</table>

(emboldened*) denotes a significant correlation ($P < 0.05$)

Correlations between VO$_{2\text{max}}$ and repeated-sprint ability ($r = 0.30$), and between VO$_{2\text{max}}$ and repeated-agility sprinting ($r = 0.04$) were not statistically significant leading to the suggestion no relationship exists between maximal aerobic performance and repeated sprint ability involving either straight-line sprints or sprints requiring changes in direction (agility). However, a significant correlation ($r = 0.75$) was found between repeated-sprint and repeated agility fatigue indexes (Figure 3).

Table 4 summarises the correlations of VO$_{2\text{max}}$ and the alternative factors associated with repeated sprint performance. VO$_{2\text{max}}$ was shown to have no significant correlation with any of the measured factors. However, in the case of both RSE and RAS, mean sprint time was shown to be significantly correlated with fastest sprint time during both repeated-straight-line sprinting and repeated-agility sprinting.
Table 4 – Correlations of alternative factors influencing repeated-sprint performance with VO$_{2\text{max}}$

<table>
<thead>
<tr>
<th></th>
<th>VO$_{2\text{max}}$</th>
<th>RSE mean sprint time</th>
<th>RSE fastest sprint</th>
<th>RAS mean sprint time</th>
<th>RAS fastest sprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO$_{2\text{max}}$</td>
<td>n/a</td>
<td>0.327</td>
<td>0.162</td>
<td>0.376</td>
<td>0.389</td>
</tr>
<tr>
<td>RSE mean sprint time</td>
<td>0.327</td>
<td>n/a</td>
<td><strong>0.917</strong>*</td>
<td>0.419</td>
<td>0.086</td>
</tr>
<tr>
<td>RSE fastest sprint</td>
<td>0.162</td>
<td><strong>0.917</strong>*</td>
<td>n/a</td>
<td>0.281</td>
<td>0.002</td>
</tr>
<tr>
<td>RAS mean sprint time</td>
<td>0.376</td>
<td>0.419</td>
<td>0.281</td>
<td>n/a</td>
<td><strong>0.897</strong>*</td>
</tr>
<tr>
<td>RAS fastest sprint</td>
<td>0.389</td>
<td>0.086</td>
<td>0.002</td>
<td><strong>0.897</strong>*</td>
<td>n/a</td>
</tr>
</tbody>
</table>

(emboldened*) denotes a significant correlation ($P < 0.05$)

Figure 3. identifies the correlation between RSE and RAS agility Fatigue index scores
Figure 4. shows the lack of a relationship between VO$_{2\text{max}}$ and RSE Fatigue Indexes

Figure 5. lack of relationship between VO$_{2\text{max}}$ and RAS Fatigue Indexes
CHAPTER VI
6. Conclusions

The aim of the present study was to further previous research and establish a relationship between maximal aerobic performance and repeated-sprint exercise performance. It is essential for soccer players to have a strong aerobic fitness base, as players who exhibit a greater VO$_{2\text{max}}$ have been shown to perform up to 100% more sprints during a match, and being involved in 24% more events (Helgerud et al., 2001). Moreover, as much as 11% of all activity performed in a soccer match is classified as RSE, and appears to demonstrate the more crucial moments of competition (Reilly et al., 2000). As a result, soccer players must strike a balance between their ability to repeatedly perform high-intensity sprints, whilst simultaneously have a large enough aerobic capacity to sustain the low-moderate intensity work lasting the duration of the match.

Anecdotally, coaches, strength and conditioning coaches, and sport scientists suggest a relationship between aerobic fitness and RSE performance. However, in line with previous investigations (Wadley and Le Rossignol, 1998; Aziz et al., 2000; Castagna et al., 2007), the present study identified low correlations between aerobic fitness and RSE ($r = 0.298$) and aerobic fitness and RAS ($r = 0.037$). As such, this would suggest no relationship exists between these parameters and they are distinctly specific qualities. This leads to the suggestion that coaches should implement training protocols that are specific to aerobic fitness and further protocols that specifically train the anaerobic components of RSE. Furthermore, this was the first study of its kind to investigate the possibility of RAS being a more ecologically valid means of assessing RSE performance when dealing with team-sport athletes. A statistically significant correlation ($r = 0.037$) was found to exist between straight-line RSE and RAS, thus the two can be identified as producing relatively similar physiological responses. As such, contrary to previous research by Young et al. (1996), it could be suggested that a training protocol for either of these relatively similar qualities, would result in an improvement of both.
There is a requirement for a larger body of research to be conducted on the ecological validity of using RAS as a means of assessing RSE performance in team-sport athletes. Moreover, additional investigations are required to examine the effects of aerobic fitness on different RSE and RAS protocols to determine the possibility of longer duration protocols requiring a greater contribution from the aerobic system.
REFERENCES
REFERENCES


