Soccer specific aerobic endurance training

J Hoff, U Wisløff, L C Engen, O J Kemi, J Helgerud

Background: In professional soccer, a significant amount of training time is used to improve players' aerobic capacity. However, it is not known whether soccer specific training fulfills the criterion of effective endurance training to improve maximal oxygen uptake, namely an exercise intensity of 90–95% of maximal heart rate in periods of three to eight minutes.

Objective: To determine whether ball dribbling and small group play are appropriate activities for interval training, and whether heart rate in soccer specific training is a valid measure of actual work intensity.

Methods: Six well trained first division soccer players took part in the study. To test whether soccer specific training was effective interval training, players ran in a specially designed dribbling track, as well as participating in small group play (five a side). Laboratory tests were carried out to establish the relation between heart rate and oxygen uptake while running on a treadmill. Corresponding measurements were made on the soccer field using a portable system for measuring oxygen uptake.

Results: Exercise intensity during small group play was 91.3% of maximal heart rate or 84.5% of maximal oxygen uptake. Corresponding values using a dribbling track were 93.5% and 91.7%. No higher heart rate was observed during soccer training.

Conclusions: Soccer specific exercise using ball dribbling or small group play may be performed as aerobic interval training. Heart rate monitoring during soccer specific exercise is a valid indicator of actual exercise intensity.
human research review committee of the Norwegian University of Science and Technology. Subjects were informed about the test protocols, without being informed about the aim of the study. The mean (SD) age of the soccer players was 22.2 (3.3) years, weight was 77.5 (12.4) kg, height was 180.2 (5.5) cm, and maximal heart rate was 198.3 (5.5) beats/min. The laboratory tests were carried out first, and the dribbling course and small group play were carried out in randomised order.

Testing
Laboratory tests
All laboratory tests were performed on the same day. Room temperature was 21–22°C and relative humidity was 50%. Subjects carried out a 20 minute warm up at 50–60% of VO_{2MAX}, running on a treadmill. VO_{2MAX} was determined with the treadmill inclined at 3° (Jaeger LE 5000; Erich Jaeger GmbH, Germany), as described previously. Briefly, running speed was increased by 1 km/h every minute to a level that brought the subjects to VO_{2MAX} after about five minutes. VO_{2MAX} was defined as levelling off of oxygen uptake despite increased exercise intensity, and unhaemolysed blood lactate concentration above 6 mmol/l. Immediately after VO_{2MAX} determination, each subject ran for two minutes at an exercise intensity of 50–60% of VO_{2MAX} directly followed by a supramaximal intensity run, which resulted in exhaustion within three minutes. The highest heart rate (f_{c}), measured by short range radiotelemetry (Polar Sporttester; Polar Electro, Oy, Finland) during the last minute of running, was recorded as f_{cmax}. Oxygen uptake, ventilation (V_{E}), respiratory exchange ratio (R), and breathing frequency (f_{b}) were measured using an Ergoxyscreen Sprint (EOS; Erich Jaeger). Unhaemolysed blood lactate was determined using a lactate analyser (YSI Model 1500 Sport Lactate Analyzer; Yellow Springs Instruments Co, Yellow Springs, Ohio, USA).

Dribbling track
The field running test measurements were performed a minimum of three days and a maximum of nine days after the laboratory test on an indoor high quality soccer field consisting of artificial curled nylon grass filled with sand. All field tests were performed after a 30 minute soccer training warm up period. Figure 1 shows the dribbling track for the endurance training.

The soccer players dribbled the ball through the cones and lifted the ball over the 30 cm high hurdles. Between point A and B the players moved backwards while controlling the ball, before turning and starting on a new round. Players were instructed to increase running intensity gradually to a level that brought them to 90–95% of maximal heart rate after about 60 seconds in the four minute training bout. The players carried out two four minute intervals, separated by a three minute exercise at 70% of maximal heart rate. Heart rate was monitored using Polar heart rate monitors which were continuously observable by the player during the run. The player was also assisted in assessing heart rate by the test leader observing the heart rate transmitted by telemetry (Polar Sport Tester). One person replaced cones and hurdles that fell down. VO_{2}, V_{E}, R, and f_{b} were measured using the portable metabolic test system Metamax II (MMX II) (Cortex Metamax, Leipzig, Germany). The MMX II has been shown to be valid, reliable, and comparable to the EOS used in the laboratory test. Small group play
Small group play was organised as five a side, including a goalkeeper. Several balls were stored in each goal so that they could be rapidly introduced into play to avoid stoppages. Two resting players on each team assisted the playing team by acting as a “wall” on the sidelines of the attacking half of the field.
Table 1  Comparison of respiratory variables between laboratory test and field training

<table>
<thead>
<tr>
<th></th>
<th>Laboratory max test</th>
<th>Dribbling track</th>
<th>Small group play</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_r$ (beats/min)</td>
<td>198.3 (7.9)</td>
<td>185.5 (6.7)</td>
<td>181.0 (4.4)*</td>
</tr>
<tr>
<td>$V_O_2$ (litres/min)</td>
<td>5.22 (0.68)</td>
<td>4.74 (0.53)</td>
<td>4.42 (0.61)</td>
</tr>
<tr>
<td>$V_O_2$ (ml/kg/min)</td>
<td>67.8 (7.6)</td>
<td>62.2 (5.0)</td>
<td>57.3 (3.9)</td>
</tr>
<tr>
<td>$V_O_2$ (ml/0.75 kg/min)</td>
<td>200.4 (19.4)</td>
<td>181.8 (10.5)</td>
<td>171.8 (10.0)</td>
</tr>
<tr>
<td>$Th_r$ (ml/kg/min)</td>
<td>50.9 (4.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Th_r$ (ml/0.75 kg/min)</td>
<td>150.4 (7.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Th_b$ (beats/min)</td>
<td>178.3 (8.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R$ (VCO$_2$/VO$_2$)</td>
<td>1.16 (0.07)</td>
<td>0.99 (0.07)</td>
<td>0.94 (0.07)</td>
</tr>
<tr>
<td>$V_l$ (litres/min)</td>
<td>174.6 (20.7)</td>
<td>138.7 (21.3)</td>
<td>132.0 (15.3)</td>
</tr>
<tr>
<td>$f_r$ (breaths/min)</td>
<td>55.8 (6.4)</td>
<td>49.6 (2.8)</td>
<td>48.8 (7.2)</td>
</tr>
</tbody>
</table>

Data are mean (SD).

$V_O_2$MAX, Maximal oxygen uptake; $f_r$, maximal heart rate; $f_b$, maximal breathing frequency; $V_l$, ventilation; $R$, respiratory exchange ratio; $VCO_2$, carbon dioxide output; $VO_2$, oxygen uptake; $Th_r$, anaerobic threshold.

*Significantly different from value obtained on dribbling track, p<0.05. All training and soccer play values are significantly different from the laboratory max test.

Figure 3  Correlation between $V_O_2$ and $f_r$ at different submaximal velocities during treadmill testing [r = 0.844, p<0.01]. A linear regression is shown.

Statistical analysis

Data are expressed as means (SD). The Kruskall-Wallis test was used to evaluate differences between tests. Spearman correlation coefficients were used when appropriate. Cautious calculations from previous studies$^1$ -$^8$ and pilot experiments showed that six players were enough to test the hypothesis with a statistical power of 0.90 (p<0.05).

RESULTS

During small group play, exercise intensity was 91.3% of $f_{max}$ or 84.5% of $V_O_2$MAX. Corresponding intensity in the dribbling track was 93.5% of $f_{max}$ or 91.7% of $V_O_2$MAX. $f_r$, corresponding to 90–95% of $f_{max}$ was reached after 61.5 (10.8) seconds on the dribbling track, and after 62.5 (12.5) seconds in small group play (table 1).

Figure 3 shows the relation between $V_O_2$ and $f_r$ measured at several submaximal intensities on the treadmill (correlation coefficient $r = 0.844$, p<0.01). The $V_O_2$-$f_r$ relation in either of the soccer specific training situations was not significantly different from running on the treadmill (fig 3). $f_r$ was higher on the dribbling track than during small group play (p<0.05).

Average $V_O_2$ and the corresponding $f_r$ were similar in both playing sessions, whereas, during the dribbling course, $V_O_2$ was significantly (p<0.05) reduced by 3.9%, with unchanged $f_r$ in the second interval. The players with the highest $V_O_2$MAX showed the lowest percentage of $V_O_2$MAX during the small group play.

DISCUSSION

The major finding of this study is that specifically designed soccer training fulfils the criteria for aerobic interval training. Furthermore, heart rate monitoring is a valid measure of actual exercise intensity in these types of training modes.

The results therefore show that it is possible to perform soccer specific endurance training in the form of specially designed small group play or on a dribbling track, within the intensity zone for effectively developing $V_O_2$MAX and corresponding soccer performance. It should be emphasised that this requires good organisation, as satisfactory exercise intensity was not reached during small group play without active coaching—that is, constructive instructions and encouragement to the players when necessary. Several factors must be considered when designing soccer specific aerobic endurance training. Firstly, intensity has to be higher than in normal soccer matches. This can be achieved by altering the number of players and field size and reducing the time the ball is out of play. The fact that players with the highest $V_O_2$MAX had the lowest percentage of $V_O_2$MAX during small group play indicates that the playing situation designed for this experiment may have a ceiling effect for developing aerobic endurance. Therefore, players with a high $V_O_2$MAX may have to train on the dribbling track because higher exercise intensity is achievable in this way than during small group play, or they may have to run uphill to have the same training response as players with lower $V_O_2$MAX.

A problem to be considered when designing a dribbling track is that soccer is played on a flat surface, and research has shown that subjects running on a flat surface may not be able to reach exercise intensities close to $V_O_2$MAX.$^{15}$ Therefore, $V_O_2$MAX is usually measured with the treadmill at a 3° inclination. In the design of the dribbling track, the inclination should be compensated for by changes in pace and direction, both of which increase workload. Intermittent work—that is, part of the time is spent standing still, as seen in soccer play—may overestimate $V_O_2$ based on $f_r$ measurements compared with a continuous workload. The dribbling track should therefore be designed to be continuous, but allow for some variation in exercise intensity. Previously, the measuring equipment has been too complicated for field testing of soccer players, both in terms of weight and size. Smaller and lighter (800 g) equipment—for example, Metamax Cortex II—has been tested in our laboratory and found to be valid, reliable, and comparable to the EOS Sprint used for the laboratory measurements.$^{15}$

On the dribbling track, the soccer players could have exercised at an intensity considerably higher than that shown in this experiment. In fact, in line with observations from running training (without a ball), the players had to be told to reduce their intensity in the first interval, so as not to exceed the planned intensity of 90–95% of $f_{max}$. Higher exercise intensities lead to increased lactate levels and a lower aerobic training response, and often result in fatigue and failure to
complete the planned training session. A work intensity of 90–95% of \( F_{\max} \) is higher than the anaerobic threshold. Activity during pauses is thus important to reduce lactate build up in the muscles and subsequently in the blood. The high intensity—close to \( VO_{2\max} \)—also limits the length of the working periods and the number of intervals that it is possible to carry out. Helgerud et al. used 4 × 4 minute intervals, which seemed to be very effective for soccer players with a \( VO_{2\max} \) in the range 55–65 ml. Better trained subjects would probably have optimised training responses through somewhat longer interval periods or a higher number of intervals, and the opposite is probably true for less trained subjects.

The soccer players in this experiment showed a higher \( VO_{2\max} \) than that reported previously, but in line with results reported by Wisløff et al. However, the players in our study do not represent a whole team, and, as volunteers for an endurance experiment, they probably have a genetic predisposition for endurance performance. Therefore, the \( VO_{2\max} \) results cannot be generalised to all groups of soccer players. Monitoring heart rate during play would give the coach valuable information about training effects.

Conclusions

High intensity, aerobic, endurance interval training can be carried out in a more soccer specific way than plain running. A specially designed dribbling track and small group play can produce the intended work intensity. Heart rate is shown to be a valid and reliable indicator of oxygen uptake in small group play with no, or only short, stops, as well as on the dribbling track, as shown in this experiment.

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The single most important physiological parameter that describes the amount of work carried out during a soccer match is maximal oxygen uptake, which is most effectively trained at an intensity of 90–95% of maximal heart rate, normally by running. By using small group play and a specifically designed dribbling track, soccer players, who are more readily motivated by playing with a ball, no longer need to carry out plain running to improve their maximal oxygen uptake.

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