Physiological adaptations to soccer specific endurance training in professional youth soccer players

K McMillan, J Helgerud, R Macdonald, J Hoff


ORIGINAL ARTICLE

Due to its acyclic nature and intensity, soccer is classified as a high intensity intermittent team sport. During competitive soccer match play, elite players cover a distance of about 10–12 km at an average intensity close to the anaerobic threshold, being 80–90% of maximal heart frequency (Hfmax) or 70–80% of maximal oxygen uptake (Vo2max). It is estimated that aerobic metabolism provides 90% of the energy cost of soccer match play. Therefore, it is a prerequisite in the modern game for the elite soccer player to have high aerobic endurance fitness. Pate and Kriska have described a model that incorporates the three major factors that account for inter-individual variance in aerobic endurance performance, namely Vo2max, lactate threshold (LT), and work economy (C), with numerous studies supporting this model. The physiological elements of this model can be used when studying the physiological profiles of soccer players and the physiological adaptations to specific training interventions.

Vo2max is considered to be the most important component of endurance performance. Small alterations in LT occur in response to running interventions when LT is expressed as a percentage of Vo2max. Minor changes have been shown for running economy (Ca) after running interventions, although Ca is positively influenced by maximal strength training based on maximal mobilisation of force and rate of force development (RFD). The mean Vo2max of elite soccer players is normally reported to be between 55 and 68 ml kg⁻¹ min⁻¹. These moderate to high values are similar to those found in other team sports, but are substantially lower than elite endurance performers where values close to 90 ml kg⁻¹ min⁻¹ have been found. Individual values higher than 70 ml kg⁻¹ min⁻¹ for modern soccer players have been recently reported. The importance of Vo2max in soccer has been reflected by rank correlation of the most successful teams in the Hungarian 1st Division Championship. Wisloff et al supported this aerobic power-success relationship by demonstrating a clear difference in Vo2max between the top team Rosengborg (67.6 ml kg⁻¹ min⁻¹) and a lower placed team Strindheim (59.9 ml kg⁻¹ min⁻¹) in the Norwegian elite division. The observation of a high correlation between Vo2max and distance covered during match play supports the adoption of training regimes that raise the Vo2max of soccer players to high levels. Smaros reported that in addition to the strong correlation with the total distance covered in the game (r = 0.89), Vo2max also influenced the number of sprints attempted during a match. It has been recently shown that by improving the mean Vo2max of youth soccer players by 11% over an 8 week period, a 20% increase in total distance covered during competitive match play was manifested, along with a 23% increase in involvements with the ball and a 100% increase in the number of sprints performed by each player.

In activities that involve dynamic work with large muscle mass utilisation, as in playing soccer, it is generally assumed that Vo2max is primarily limited by maximal cardiac output. Whereas untrained subjects are limited peripherally, trained individuals are primarily limited centrally, with the maximal oxygen uptake

Abbreviations: 1RM, one repetition maximum; C, work economy; CMJ, counter movement jump; Ca, running economy; Hf, heart frequency; Vo2max, maximal oxygen uptake
stroke volume of the heart being accepted as the major limiting factor of \( V_{O_{2max}} \). Increased stroke volume has recently been shown up to the level of \( V_{O_{2max}} \).

Hoff and Helgerud\(^{15} \) thus argue that continuous interval training for 3–8 min with a working intensity of 90–95% of \( H_{F_{max}} \) should increase \( V_{O_{2max}} \) by increasing the maximal cardiac output by improving stroke volume. Recently, Helgerud et al.\(^{17} \) showed the effectiveness of such a training regime, significantly increasing mean \( V_{O_{2max}} \) and \( C_R \) of soccer players using running and treadmill running as training modes, respectively. Similar physiological load could be obtained by using a specifically designed soccer track where the subject dribbles a soccer ball instead of regular running.\(^{18} \) This might however raise different problems in terms of the subjects and coaches’ control of intensity, control of the ball, etc., that might influence training execution and response.

The main aim of this study was to intervene in a professional youth soccer team using high intensity interval training with the players dribbling a soccer ball around a specifically designed track. An improvement in \( V_{O_{2max}} \) of similar magnitude as that attained by Helgerud et al.\(^{12} \) for youth players and by Helgerud et al.\(^{13} \) for Champions League players was hypothesised, with no adverse effects on sprinting and jumping ability. A secondary aim of this study was to present normative physiological data on professional youth soccer players.

**METHODS**

**Subjects**

Sixteen male youth soccer players from Celtic Football Club’s U-17’s Youth Academy squad (Glasgow, Scotland, UK) participated in the study. The players studied were all full time professional soccer players and trained on a daily basis. Seven of the players tested are of international standard for their age group. Each subject reviewed and signed consent forms in accordance with the Declaration of Helsinki and the Human Research Review Committee at the Norwegian University of Science and Technology prior to the study. Subjects were informed about the test protocols, but without being informed about the aim of the study. The players’ physical characteristics are presented in table 1.

**Testing**

Each player’s mass and height were recorded upon entering the laboratory. The players then performed a 10 min warm up on a treadmill (Technogym RunRace, Gambettola, Italy) at an intensity of approximately 60–70% of \( V_{O_{2max}} \). Squat jump (SJ) height with no arm swing, counter movement jump (CMJ) height with no arm swing, and RFD were determined using a force platform (Kistler, Winterthur, Switzerland). Jumping height was determined as the centre of mass displacement calculated from force-time characteristics and body mass. The best jump from three attempts was recorded. A 2 min rest period was allowed between efforts. Hands were placed on the hips during the jump tests. RFD was calculated from an SJ performed from a position with a 90° angle in the knee joint (between femur and tibia). RFD was calculated as the force from 10 to 90% of peak external force registered from the force platform divided by the time used to exert that force. The same start and peak force window from the pre-test was used to obtain changes in RFD at the post-test.\(^{15} \) One repetition maximum (1RM) strength was then obtained as the maximal weight the subjects were able to raise in a half squat (90° angle in the knee joint between femur and tibia). Testing was carried out using 5 kg stages and 1–2 min between each trial. 1RM was normally determined using three to five trials.

Then 5 min after completion of the strength testing, each player commenced treadmill testing of \( C_R \) and \( V_{O_{2max}} \). \( C_R \) was measured at 9 km h\(^{-1} \) at a treadmill inclination of 5.5%. The average value of oxygen uptake (\( V_{O_{2max}} \)) between 4 and 4.5 min was used to calculate \( C_R \). The velocity of the treadmill was then increased by 1 km h\(^{-1} \) every minute to a level that brought the subject close to exhaustion after approximately 5–6 min. Inclination of the treadmill was kept constant at 5.5%. Heart frequency (HF) was determined using short range radio telemetry (Polar Accurex Plus, Polar Electro, Kempele, Finland). The highest HF measured throughout the test was recorded as \( H_{F_{max}} \). \( V_{O_{2max}} \) minute ventilation, and breathing frequency were measured using a Cortex Metamax II device (Cortex, Leipzig, Germany), a portable metabolic test system that has been previously validated.\(^{16} \)

On the following day, each player’s sprint acceleration was assessed over a 10 m distance.\(^{17} \) After a 15 min warm up, each player carried out three maximal sprints from a static position (0 m behind first photocell), with each trial separated by 3 min of rest. The sprint tests were performed on an indoor running track and 10 m sprint time was recorded using photocells (Newtest Powertimer, Oulu, Finland).

**Training intervention**

The aerobic training intervention consisted of interval training, comprising four bouts of 4 min work periods dribbling a soccer ball (Mitre ISO League, Mitre, Wilmslow, Cheshire, UK) around a specially designed track (fig 1) on an artificial field-turf pitch. Training cones used in the dribbling circuit were 0.3 m high and 0.15 m wide. Hurdle height was set at 0.5 m. Working intensity was at 90–95% of each player’s \( H_{F_{max}} \) with work periods separated by 3 min of jogging at 70% of \( H_{F_{max}} \). All players wore a Polar Team System heart rate belt and monitor (Polar Electro) throughout the interval training. The interval training was performed two times a week at the end of the soccer training session, on the same days and time of day throughout the intervention period. No emphasis was placed on improving strength, sprinting, or jumping performance throughout the intervention period. The 10 week intervention period was carried out directly after the off-season intermission period, encompassing the 6 week pre-season preparation period and the first 4 weeks of the competitive season.

**Allometric scaling**

Oxygen uptake is a measure of power and, in order to be independent of absolute body mass, should be expressed in ml per kg lean body mass raised to a power of 0.67.\(^{39} \) \( V_{O_{2max}} \) expressed as ml kg\(^{-1} \) min\(^{-1} \) implies 1 : 1 linearity between oxygen uptake and body mass, which is not the case.\(^{36} \) When expressing \( V_{O_{2max}} \) as ml kg\(^{-1/2} \) min\(^{-1} \), light individuals are over-estimated in terms of work capacity and heavy individuals are under-estimated. The opposite is true when evaluating the oxygen cost of running at sub-maximal workloads. When comparisons amongst people of different body mass are made for running, oxygen uptake should be expressed as ml kg\(^{-0.75} \) min\(^{-1} \) : \(^{31} \) Expressing \( V_{O_{2max}} \) in relation to the power 0.67 or 0.75 may not be critical as long as the unit approximates the theoretical value and not the traditional body mass.\(^{11} \)

<table>
<thead>
<tr>
<th>Physical characteristics of players (n = 11)</th>
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<tbody>
<tr>
<td>Age (years)</td>
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<tr>
<td>16.5 (0.4)</td>
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</tbody>
</table>

Values are mean (SD).
Statistical analysis
All results are reported as means and standard deviations (SD) calculated by conventional procedures. Differences from pre- to post-training were calculated using a t-test, with results accepted as significant at p < 0.05. Changes from pre-to post-training in \( \text{VO}_{2\text{max}} \) and \( C_R \) given in per cent are calculated on the basis of the unit ml kg\(^{-0.75}\) min\(^{-1}\).

RESULTS
During the 10 week, twice a week intervention, the players in this study completed 16 (80%) of the scheduled 20 interval training sessions. Four sessions were uncompleted due to the players competing in a 1 week tournament and mid-week competitive matches. Five players of the 16 assessed pre-intervention were withdrawn from the study due to injuries not connected with the training intervention (three players) and unavailability at the post-intervention session (two players).

The 10 week aerobic training intervention manifested significant improvements in \( \text{VO}_{2\text{max}} \) (table 2) of 9\% (p<0.001). The mean \( \text{VO}_{2\text{max}} \) increased from 4.45 (0.37) to 4.87 (0.45) l min\(^{-1}\), which equates to a change from 63.4 (5.6) to 69.8 (6.6) ml kg\(^{-1}\) min\(^{-1}\), or 183.3 (13.2) to 201.5 (16.2) ml kg\(^{-0.75}\) min\(^{-1}\). Mean body mass was unchanged after the intervention period.

When treadmill running at 9 km h\(^{-1}\) at an inclination of 5.5\%, \( C_R \) was unchanged by the intervention. However, mean HF at this workload decreased significantly from 162 (14) to 154 (14) beats min\(^{-1}\) (p<0.05).

No significant changes in RFD and 10 m sprint performance were evident. \( \text{SJ} \) and \( \text{CMJ} \) height increased from 37.7 (6.2) to 40.3 (6.1) cm and 52.0 (4) to 53.4 (4.2) cm, respectively (p<0.05).

DISCUSSION
The training intervention used in this study elevated mean \( \text{VO}_{2\text{max}} \) by 6.4 ml kg\(^{-1}\) min\(^{-1}\) or 9.0\%. Mean \( \text{VO}_{2\text{max}} \) increased from a typical soccer player value of 63.4 (5.6) to 69.8 (6.6) ml kg\(^{-1}\) min\(^{-1}\), or 183.3 (13.2) to 201.5 (16.2) ml kg\(^{-0.75}\) min\(^{-1}\). Removing the goalkeeper's \( \text{VO}_{2\text{max}} \) value from the pre- and post-intervention results shows an improvement in mean \( \text{VO}_{2\text{max}} \) from 64.7 (3.9) to 70.9 (5.7) ml kg\(^{-1}\) min\(^{-1}\), or 186.3 (9.2) to 204.0 (14.8) ml kg\(^{-0.75}\) min\(^{-1}\) for the outfield players (n = 10).
The authors of this study are aware that this study would have benefited from data from a control group. The use of controls is difficult, if not impossible, when dealing with professional soccer clubs and players. However, control group data from a previous study by Helgerud et al. can be referred to. The control group performed additional technical training whilst the training group performed high intensity aerobic interval training (4 × 4 min intervals at 90–95% \( \text{Hf}_{\text{max}} \)) twice a week for 8 weeks. The \( \text{Vo}_{2\text{max}} \) of the training group improved by 11% over the 8 week intervention, but the \( \text{Vo}_{2\text{max}} \) of the control group was unchanged (58.4 (4.3) to 59.5 (4.4) ml kg\(^{-1}\) min\(^{-1}\)).

The \( \text{Cr} \) of the players in this study was not significantly changed after the intervention training. This is in contrast to the findings of Helgerud et al. who reported an improved \( \text{Cr} \) of 6.7% in junior players, but of only 3.7% when using treadmill training with elite players, with the latter improvement explained by gains arising from concurrent maximal strength training. It should be noted that the training intervention of Helgerud et al. involved straight line running only, therefore an improved \( \text{Cr} \) may be expected for junior players with relatively low endurance values on the basis of more running practice. The aerobic endurance intervention in the present study was carried out dribbling a soccer ball around a specially designed track. Dribbling a soccer ball around the track raises the oxygen demand when compared to running, as does the frequent changes in direction and pace involved. Hoff et al. reported that a mean exercise intensity of 93.5% \( \text{Hf}_{\text{max}} \) when dribbling a soccer ball around the track corresponded to 91.7% \( \text{Vo}_{2\text{max}} \). \( \text{Cr} \) was unchanged in the present study, but it can be postulated that soccer specific work economy may have improved somewhat, with relevant gains not detectable by conventional treadmill testing.

Although \( \text{Cr} \) was unchanged after the intervention period, mean \( \text{Hf} \) for treadmill running at 9 km h\(^{-1}\) at 5.5% inclination decreased significantly from 162 (14) to 154 (14) beats min\(^{-1}\) (p < 0.001). This decrease in \( \text{Hf} \) could be attributed to an increased \( \text{Vo}_{2\text{max}} \). A reduction in sub-maximal \( \text{Hf} \) of approximately 10 min\(^{-1}\) is indicative of an increase in \( \text{Vo}_{2\text{max}} \) of approximately 3–5 ml kg\(^{-1}\) min\(^{-1}\).12

Several authors have concluded that endurance training inhibits or interferes with strength.14–16 and therefore power performance.16 IRM half squat strength was measured pre- and post-intervention in the present study, but due to the players being limited by technique and apprehension as they were not familiar with this exercise movement, the recorded values for the pre-intervention assessment results were artificially low. During the final 4 weeks of the endurance training intervention period technical training for carrying out a safe half squat was performed twice a week using an unloaded Olympic bar. Therefore, only post-intervention squat strength scores for the players in this study are reported. RFD and 10 m sprint times in the present study were unaffected by the aerobic intervention program and the lifting technique program, although jumping height improved significantly over the 10 week period (p < 0.05).

Therefore, it appears that power related performance was not hindered by the aerobic interval training regime used in the present study. Similarly, Helgerud et al. showed substantial gains in \( \text{Vo}_{2\text{max}} \) from an 8 week endurance training intervention with no reduction in sprinting and jumping abilities.

High intensity aerobic 4 min intervals are an effective tool for increasing \( \text{Vo}_{2\text{max}} \) in soccer players, with the training effect of each session being approximately 0.5%. The results from this study and that of Helgerud et al.10 demonstrate that it is possible to elevate the \( \text{Vo}_{2\text{max}} \) of youth soccer players from typical values (for example, 58–64 ml kg\(^{-1}\) min\(^{-1}\)) to

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Pre- and post-training intervention physiological results (n = 11)</th>
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<tbody>
<tr>
<td></td>
<td>Pre-training</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>70.6 (8.1)</td>
</tr>
<tr>
<td>( \text{Vo}_{2\text{max}} )</td>
<td>1 l min(^{-1})</td>
</tr>
<tr>
<td>( \text{ml kg}^{-1} \text{min}^{-1} )</td>
<td>63.4 (5.8)</td>
</tr>
<tr>
<td>( \text{ml kg}^{-0.75} \text{min}^{-1} )</td>
<td>183.2 (12.2)</td>
</tr>
<tr>
<td>( \text{Cr} )</td>
<td>9 km h(^{-1}), 5% inclination</td>
</tr>
<tr>
<td>Hf (beats min(^{-1}))</td>
<td>162 (1.4)</td>
</tr>
<tr>
<td>Strength</td>
<td></td>
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<tr>
<td>1RM half squat (kg)</td>
<td>–</td>
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<tr>
<td>Relative strength</td>
<td>–</td>
</tr>
<tr>
<td>( \text{kg kg}^{-1} \text{bm} )</td>
<td>–</td>
</tr>
<tr>
<td>Relative strength</td>
<td>–</td>
</tr>
<tr>
<td>( \text{kg kg}^{-1} \text{bm}^{-0.5} )</td>
<td>–</td>
</tr>
<tr>
<td>Sprint test</td>
<td></td>
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<tr>
<td>10 m (s)</td>
<td>1.96 (0.07)</td>
</tr>
<tr>
<td>Force platform tests</td>
<td></td>
</tr>
<tr>
<td>RFD (N s(^{-1}))</td>
<td>3553 (1492)</td>
</tr>
<tr>
<td>SJ (cm)</td>
<td>37.7 (6.2)</td>
</tr>
<tr>
<td>CHW (cm)</td>
<td>52.0 (4.2)</td>
</tr>
</tbody>
</table>

*\( p < 0.05 \), **\( p < 0.001 \), significantly different from pre-intervention value.
Improving $\text{VO}_{2\text{max}}$ in soccer players has previously been shown to significantly increase work rate during competitive soccer match play. It has previously been demonstrated that the $\text{VO}_{2\text{max}}$ of soccer players can be increased by performing high intensity aerobic interval training at 90–95% $\text{Hf}_{\text{max}}$ using conventional running.

In conclusion, high intensity aerobic interval training can be effectively performed by dribbling a soccer ball around a specially designed track. The addition of high intensity interval training at 90–95% $\text{Hf}_{\text{max}}$ to the training regimes of professional youth soccer players can elevate $\text{VO}_{2\text{max}}$ levels from low to moderate values to that of elite Champions League soccer players, with no negative interference effects on strength, jumping ability, and sprint performance.

What is already known on this topic

What this study adds

This study has shown that high intensity aerobic interval training designed to increase $\text{VO}_{2\text{max}}$ can be performed effectively by dribbling a soccer ball around a specially designed track. Performing high intensity aerobic interval training in addition to conventional soccer training can elevate the $\text{VO}_{2\text{max}}$ of soccer players to levels approaching 70 ml kg$^{-1}$ min$^{-1}$.

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Competing interests: none declared

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doi: 10.1136/bjsm.2004.012526

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