ORIGINAL ARTICLE

Soccer specific aerobic endurance training

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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 fulfils 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.

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Physiological, technical, and tactical skills are all important to soccer performance. Factors such as acceleration, running velocity, jumping height, and capacity to release energy are of major importance. Because of the length of a soccer match, at least 90% of the energy release must be aerobic[1]; during a 90 minute match, players run about 10 km[2 3] at an intensity close to anaerobic threshold or 80–90% of maximal heart rate.[1 3 4]

Aerobic endurance performance is dependent on three important elements: maximal oxygen uptake (VO_2MAX), anaerobic threshold, and work economy.[5] VO_2MAX is defined as the highest oxygen uptake that can be achieved during dynamic exercise with large muscle groups.[6] Previous studies have shown a significant relation between VO_2MAX and distance covered during a match,[1 7] and a rank order correlation between VO_2MAX and placement in the league of the best teams in Hungary has been shown.[8] These findings are supported by Wisløff *et al*,[9] who have shown a substantial difference in VO_2MAX in members of the top team compared with those in the lowest placed team in the Norwegian elite league. Recently, Helgerud *et al*[3] showed that interval training (90–95% of maximal heart rate)—running uphill for four periods of four minutes, separated by three minutes active rest at 70% of maximal heart rate, twice a week over nine weeks—increased maximal oxygen uptake by 11% (from 58.1 ml/kg/min to 64.3 ml/kg/min). This resulted in a 20% increase in distance covered during a game, a 23% increase in involvement with the ball, and a 100% increase in the number of sprints, highlighting the advantages of a high VO_2MAX in soccer.

Anaerobic threshold is defined as the highest exercise intensity, heart rate, or oxygen uptake, working dynamically with large muscle groups, in which the production and clearance of lactate is about the same.[10] Anaerobic threshold in absolute terms (ml/kg/min) is important, but is highly dependent on VO_2MAX, and does not seem to change much in percentage of VO_2MAX. Owing to the length of a soccer game, the average exercise intensity cannot be much higher than that corresponding to anaerobic threshold. However, players do not actually exercise for long periods of the game at anaerobic threshold, but either above the threshold (accumulating lactate) or below the threshold (because of the need for lactate clearance).[3]

Work economy (C_R) is defined as oxygen cost at a submaximal exercise intensity, and as much as 20% difference in C_R has been found in trained endurance athletes at similar VO_2MAX level.[10] However, there is a paucity of research into the effect of improved C_R on soccer performance. Helgerud *et al*[3] showed that interval training increases C_R as VO_2MAX increases. Furthermore, a recent study showed that C_R could be improved by maximal strength training without improving VO_2MAX.[11] This approach could be used in future studies to determine the effects of exclusively improved C_R on soccer performance.

Running is usually not the favourite activity of soccer players. However, playing soccer is not believed to provide sufficient exercise intensity over time to improve VO_2MAX very much.[3 9] During interval training, as reported by Helgerud *et al*,[3] intensity is normally monitored and controlled by hear rate monitors. During a game of soccer, however, concentrating on team players and opponents and controlling the ball, or anxiety caused by training or match situations, may lead to heart rates above what reflects the actual workload.[12 13] To achieve valid exercise intensities in soccer specific training, the relation between heart rate and oxygen uptake has to be established.

The aim of this study was to (*a*) design a dribbling track and a playing session that fulfils our criterion of effective aerobic interval training, and (*b*) determine whether heart rate is a valid measure of work intensity in soccer specific endurance training.

METHODS

Subjects

Six male soccer players from a Norwegian first division team volunteered to participate in the three different training modes. Before the study, each subject reviewed and signed consent forms in accordance with the Declaration of Helsinki and the

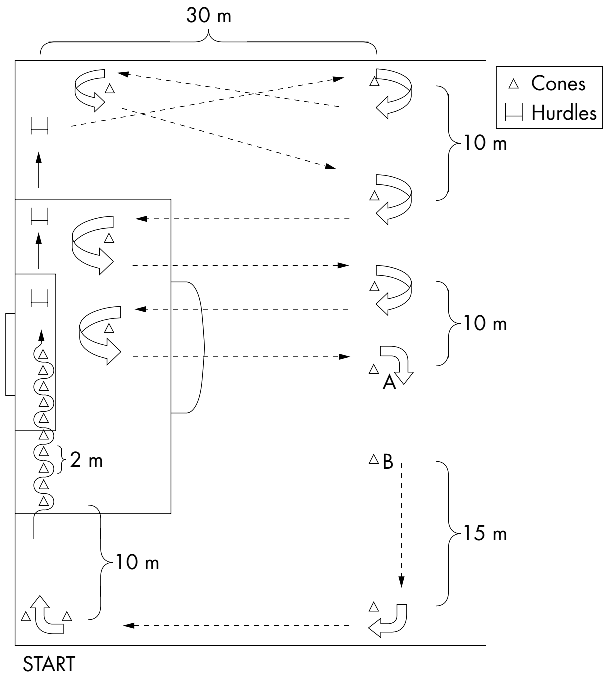

Figure 1 Soccer specific "dribbling track" for measuring maximal oxygen uptake (VO_2MAX). The ball is dribbled in the direction of the arrows, with backward running between points A and B. Subjects were instructed to gradually increase intensity to a level that brought them to VO_2MAX within six minutes.

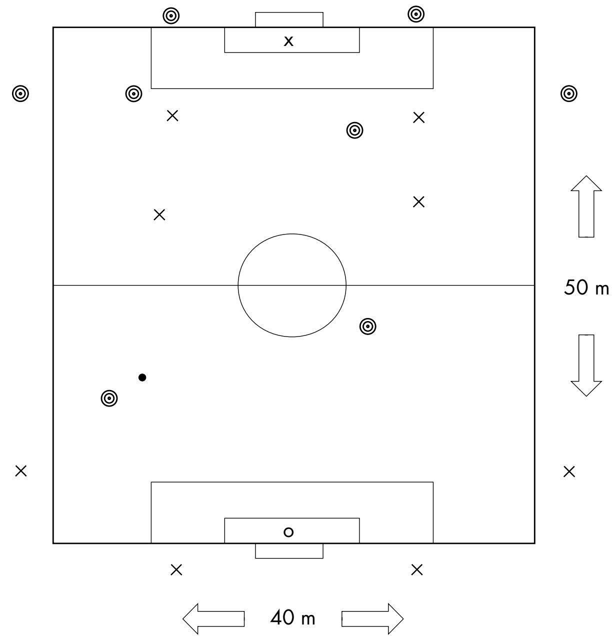

Figure 2 Small group play: five a side football, including a goalkeeper. Several balls were stored in each goal so that they could be rapidly introduced into play to avoid stoppages. Two resting players on each team assisted the playing team by acting as a "wall" on the sidelines of the attacking half of the field.

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.[10] 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 (VE), respiratory exchange ratio (R), and breathing frequency (f_b) were measured using an Ergooxyscreen 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, VE, 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.[14]

Small group play

Small group play was organised as five a side, including goalkeepers as shown in fig 2. Pilot studies indicated that it would be necessary to use four minute periods of play to reach at least three minutes in the high intensity zone. Intensity was sought to be as high as possible through the four minute playing periods. Two four minute playing periods were carried out, separated by three minutes of active rest. Pilot studies showed that active coaching by encouragement and constructive messages was necessary to achieve a high enough intensity for some of the players. The measuring equipment was similar to that used for the dribbling track.

Table 1 Comparison of respiratory variables between laboratory test and field training

	Laboratory max test	Dribbling track	Small group play
f_c (beats/min)	198.3 (7.9)	185.5 (6.7)	181.0 (4.4)*
VO_2 (litres/min)	5.22 (0.68)	4.74 (0.53)	4.42 (0.61)
VO_2 (ml/kg/min)	67.8 (7.6)	62.2 (5.0)	57.3 (3.9)
VO_2 (ml/0.75 kg/min)	200.4 (19.4)	181.8 (10.5)	171.8 (10.0)
Th_{an} (ml/kg/min)	50.9 (4.0)		
Th_{an} (ml/0.75 kg/min)	150.4 (7.7)		
Th_{an} (beats/min)	178.3 (8.8)		
R (VCO_2/VO_2)	1.16 (0.07)	0.99 (0.07)	0.94 (0.07)
V_E (litres/min)	174.6 (20.7)	138.7 (21.3)	132.0 (15.3)
f_b (breaths/min)	55.8 (6.4)	49.6 (2.8)	48.8 (7.2)

Data are mean (SD).
VO_2MAX, Maximal oxygen uptake; f_{cmax}, maximal heart rate; f_{bmax}, maximal breathing frequency; V_E, ventilation; R, respiratory exchange ratio; VCO_2, carbon dioxide output; VO_2, oxygen uptake; Th_{an}, 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.

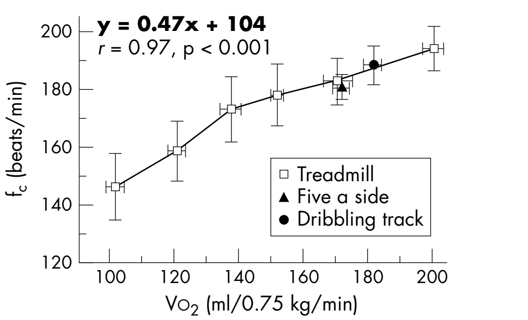

Figure 3 Correlation between VO_2 and f_c at different submaximal velocities during treadmill testing (r = 0.844, p<0.01). A linear regression is shown.

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[3 9] 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_{cmax} or 84.5% of VO_2MAX. Corresponding intensity in the dribbling track was 93.5% of f_{cmax} or 91.7% of VO_2MAX. f_c corresponding to 90–95% of f_{cmax} 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 VO_2 and f_c measured at several submaximal intensities on the treadmill (correlation coefficient r = 0.844, $p<0.01$). The VO_2-f_c relation in either of the soccer specific training situations was not significantly different from running on the treadmill (fig 3). f_c was higher on the dribbling track than during small group play ($p<0.05$).

Average VO_2 and the corresponding f_c were similar in both playing sessions, whereas, during the dribbling course, VO_2 was significantly ($p<0.05$) reduced by 3.9%, with unchanged f_c in the second interval. The players with the highest VO_2MAX showed the lowest percentage of VO_2MAX 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 VO_2MAX and corresponding soccer performance.[3] 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.[1] The fact that players with the highest VO_2MAX had the lowest percentage of VO_2MAX 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 VO_2MAX 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 VO_2MAX.

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 VO_2MAX.[14] Therefore, VO_2MAX 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 VO_2 based on f_c 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_{cmax}. 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_{cmax} 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.[16] The high intensity—close to V_{O_2MAX}—also limits the length of the working periods and the number of intervals that it is possible to carry out. Helgerud *et al*[3] used 4 × 4 minute intervals, which seemed to be very effective for soccer players with a V_{O_2MAX} 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 V_{O_2MAX} than that reported previously,[4] but in line with results reported by Wisløff *et al*.[9] 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 V_{O_2MAX} 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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Take home message

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.