Endurance training and testing with the ball in young elite soccer players

K Chamari, Y Hachana, F Kaouech, R Jeddi, I Moussa-Chamari, U Wisløff

Background: The aerobic capacity of soccer players substantially influences their technical performance and tactical choices. Thus, the assessment of soccer players’ aerobic performance should be of interest for soccer coaches in order to evaluate and improve their endurance training sessions. In this study, we present a new test to assess aerobic performance in soccer by means of a specific dribbling track: the Hoff test. We further determined whether improvement in maximal oxygen uptake was reflected in increased distance covered in the Hoff test.

Methods: We tested 18 male soccer players (14 years old) both in the laboratory and using the Hoff test before and after 8 weeks of soccer training.

Results: The distance covered in the Hoff test correlated significantly with maximum oxygen uptake, and improved by 9.6% during the 8 week training period, while maximum oxygen uptake and running economy improved by 12 and 10%, respectively. Backward multiple regression showed maximum oxygen uptake to be the main explanatory variable for the distance covered in the Hoff test.

Conclusion: The present study demonstrated a significant correlation between laboratory testing of VO$_{2\text{max}}$ and performance in the Hoff test. Furthermore, training induced improvements in VO$_{2\text{max}}$ were reflected in improved performance in the Hoff test. We suggest that it should be a goal for active U-15 soccer players to cover more than 2100 metres in the Hoff test, as this requires a VO$_{2\text{max}}$ of above 200 ml/kg$^{0.75}$/min, which should serve as a minimum in modern soccer.

MATERIALS AND METHODS

Subjects

Eighteen male soccer players (mean (SD) age 14 (0.4) years) volunteered to participate in the study and provided written informed consent in accordance with the Declaration of Helsinki. The university ethics committee approved the study protocol. The subjects could withdraw from the study at any time. The players’ physical characteristics are presented in table 1. Percentage of body fat was calculated according to the formula of Siri based on four skin fold measurements (biceps, triceps, subscapularis, and suprailiac). All the subjects were informally involved with the test protocols, but not the aim of the study. During the weekends, they participated in the national soccer championship as regular players in their respective club teams. At the time of the experiment, their averaged weekly training programmes included six training sessions per week (each session lasting for about 90 minutes), mainly in soccer training.

The experiment was performed just after mid season—that is, 5–8 months after the beginning of the competitive season. The subjects were tested at the laboratory and in field tests, before and after a period of 2 months of training. Each player was instructed and verbally encouraged to give maximum effort at all tests.

Laboratory testing

Laboratory testing occurred at 1400–1700, at a mean (SD) temperature of 19.5 (1) ºC, atmospheric pressure of 1019.3 (9.7) mmHg; humidity of 74.5 (3)% (the January tests); and 19.8 (0.5) ºC, 1021.8 (1) mmHg, and 69.5 (0.6)% at the post-test (March). The subjects were wearing shorts and running...
Table 1 Results from the physiological tests

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass, kg</td>
<td>60.5 (5.2)</td>
<td>63.6 (5.7)*</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>11.6 (3.4)</td>
<td>11.0 (3.2)</td>
</tr>
<tr>
<td>Maximum heart rate, beats/min</td>
<td>198 (7)</td>
<td>197 (7)</td>
</tr>
<tr>
<td>Maximum oxygen uptake (l/min)</td>
<td>3.49 [0.4]</td>
<td>4.00 [0.5]*</td>
</tr>
<tr>
<td>ml/kg/min†</td>
<td>65.3 [5.0]</td>
<td>70.7 [4.3]</td>
</tr>
<tr>
<td>ml/kg/m²/min†</td>
<td>176 [18]</td>
<td>194 [16]</td>
</tr>
<tr>
<td>Running economy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ml/kg/min at 7 km/h</td>
<td>38.8 [2.1]</td>
<td>33.6 [2.2]*</td>
</tr>
<tr>
<td>ml/kg/m²</td>
<td>0.33 [0.02]</td>
<td>0.29 [0.02]*</td>
</tr>
<tr>
<td>ml/kg/m²⁰⁰/min</td>
<td>0.90 [0.04]</td>
<td>0.81 [0.05]*</td>
</tr>
<tr>
<td>Anaerobic threshold, %VO₂max</td>
<td>87.8 [4.3]</td>
<td>88.2 [4.9]</td>
</tr>
<tr>
<td>Treadmill speed at VO₂max, km/h</td>
<td>13.8 [1.2]</td>
<td>14.6 [1.4]</td>
</tr>
<tr>
<td>Maximum treadmill speed,</td>
<td>15.3 [1.4]</td>
<td>15.8 [1.1]</td>
</tr>
<tr>
<td>end of VO₂max, km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance covered in the Hoff test, metres</td>
<td>1771 (137)</td>
<td>1942 (154)*</td>
</tr>
</tbody>
</table>

Data are means (SD). *Significantly different from pre-test, p<0.01; †per kg lean body mass.

Maximum incremental treadmill test

The subjects ran on a 5.5% slope motorised treadmill (Ergo XELG 90; Woodway, Weil, Germany) for 4 minutes at 7 km/h, followed by a 1 km/h increment every minute till exhaustion, which occurred within 10–15 minutes for all players. The following criteria were met by all players when testing VO₂max: (a) a levelling off of VO₂ despite treadmill speed increase; (b) a respiratory gas exchange ratio >1.1, and (c) blood lactate >6 mmol/l. The highest heart rate (HR) attained at exhaustion was considered as HRmax.

Cardiorespiratory variables were determined using a breath by breath system (ZAN 680; Oberthulba, Germany) allowing continuous measurement of HR, oxygen uptake, and lung ventilation. Prior to each test, the gas analysers were calibrated with gases of known concentrations and the ventilatory membrane calibrated with a 1-l syringe. HR was calibrated with a 6 mmol/l. The highest heart rate (HR) was determined from a six lead ECG with 12 derivations. HR and the respiratory data were provided once every 30 seconds with the values averaged over the last 10 respiratory cycles on a sliding technique basis. The smallest and highest velocities associated with VO₂max, (VO₂max and vpeakVO₂max, resp) were determined according to Bilsal and Koltsztzin and Paavolaĭnen et al. and respiratory compensation threshold (ThZ_req) as described by Beaver et al. When expressing VO₂max as ml/kg/min, light individuals are overestimated in terms of work capacity and heavy individuals are underestimated. Consequently, Bergh et al., Wisloff et al., Helgerud et al., and Hoff et al. have expressed oxygen uptake expressed as ml/kg/m²/min for comparisons between athletes and soccer players of different body masses. Indeed, VO₂max does not increase in direct proportion to body mass. 2.5

Dimensional scaling of geometrically similar individuals suggests that the cross sectional area of the aorta will increase in proportion to the square of the height (L²), whereas body mass is dependent on body volume, which varies according to L³. Consequently, VO₂max, which is primarily limited by maximum cardiac output, should be proportional to body mass (m₀) raised to the power of 0.67 (m₀⁰.⁶⁷). This dimensional scaling approach was supported by Bergh et al., who found that VO₂max relative to body mass raised to the power of 0.75 was indicative of performance capacity in running. Despite the fact that the theoretically correct m₀⁰.⁶⁷ should be used, most published papers on soccer players use the ml/kg/0.⁷⁵/min expression. Wisloff et al. suggested that expressing VO₂max in relation to m₀⁰.⁶⁷ or m₀⁰.⁷⁵ may not be critical as long as the unit approximates the theoretical value and not the traditional m₀. Dimensional scaling should ideally be based on fat free mass, because fat has very low metabolic activity.

Field testing

The field test was performed in the same afternoon for all subjects, between 3 and 7 days after the laboratory testing. The Hoff test was performed from 1600 to 1830 in ambient conditions of 15°C, 1017 mmHg, and 87% humidity for the January test, and 20°C, 1021 mmHg, and 75% humidity for the post-test (March). The tests were performed on the same natural grass soccer field and the subjects were wearing soccer specific sportswear. As the pre-test was performed under a light rain, the grass was intentionally wetted prior to the re-test.

The Hoff test

This test is presented for the first time in the present study. It is performed on a track that was proposed for the first time by Hoff et al. for training purposes. The Hoff track distances (fig 1) have been modified to reach a total distance of exactly 290 m per tour. As proposed by Hoff et al., the player moved a soccer ball through the track by dribbling. The purpose of the test was to cover the maximum distance during a 10-minute period. Each player was informed of the elapsed time at 5 minutes (halfway through the test), and at 9 minutes (when only 1 minute of the test remained). Five subjects were tested at a time. The test starting signal was given for one subject every minute. Thus, the assessor timing the test had 4 minutes for starting the five subjects and then switched to the halfway test signal that occurred in the successive minute for the first player. Then, when the assessor announced the halfway test signal for the fifth player (minute 9), he simultaneously began the last minute signal for the first player. In order to be easily identified, the players were coloured T shirts that were always assigned in the same order to the players numbered 1 to 5. Four days before the first Hoff test, the subjects performed a pre-test in order to get used to the testing pace so as to obtain maximum performance during the experiment.

Training

The players underwent a period of 8 weeks of regular soccer training during which two sessions per week were included on Tuesday and Wednesday. This training programme was designed in order to improve the player’s endurance. Every Tuesday the training sessions consisted of 4×4 minutes on the Hoff track, separated by 3 minutes of active recovery. Subjects were equipped with cardiofrequency meters (Polar S-610; Polar Electro, Kempele, Finland) in order to measure HR. The training consisted of dribbling the ball along the Hoff track in order to reach 90–95% of individual HRmax during the 4 minute periods and 60–70% HRmax during the active recovery periods. Players were informed of their target HRs and could easily maintain the aforementioned ranges after one or two training sessions. On Wednesdays the players took part in a different training procedure, consisting of 4×4 minutes on a 20 m square in a small group play (4 v 4 players) interspersed with 3 minutes of two players passing and juggling with the ball. The game rules were different each week: two or three maximum touches per player; compulsory pass to a player situated out of the square after five successive passes; no possibility of direct back pass. The main goal was to achieve the maximum number of passes, each five passes being considered as one point. As for the Hoff training sessions, players used HR monitors in order to try to reach the 90–95% HRmax during the 4 minutes of drills. This was not always reached as, depending on the ball loss,
some uncontrolled resting periods allowed game intensity decreases.

**Blood sampling and determination of blood lactate concentration**

Blood samples were collected 3.5 minutes after VO\textsubscript{2max} and after the Hoff tests. The 20 μl samples of capillary blood were withdrawn from an earlobe with Microzym micropipettes. They were stored in tubes containing 180 μl of a haemolytic solution to ensure good preservation of the samples at room temperature. Blood lactate concentration was subsequently measured using an enzymatic method (Microzym L; Setric Génie Industriel, Toulouse, France).

**Statistics**

Values are expressed as means (SD). A Pearson correlation matrix was performed between the variables of the Hoff field and laboratory tests. A backward multiple regression analysis was used when appropriate. A value of p<0.05 was considered statistically significant.

**RESULTS**

During treadmill testing, the oxygen uptake levelled off despite increased running speed. Respiratory exchange ratio was 1.2 (0.3), and blood lactate concentration 9.5 (1.3) mmol/l (that is, the true VO\textsubscript{2max} was reached). During the last 2 minutes of the Hoff test the HR was <5 beats/min from maximum, and post-test blood lactate concentration was 10.4 (1.6) mmol/l.

After training, the distance covered in the Hoff test increased by 9.6% while maximum oxygen uptake increased by 14.5%, 7.5%, and 12% expressed absolutely (l/min), traditionally (ml/kg/min), and appropriately scaled (ml/kg\textsuperscript{0.75}/min), respectively (table 1). Energy cost of running measured at 7 km/h decreased by 14% when expressed in the traditional way (ml/kg/m) and by 10% using appropriate scaling procedures (ml/kg\textsuperscript{0.75}/m). Submaximal HR while running at 7 km/h decreased by 9 beats/min, indicating improved stroke volume. Anaerobic threshold did not change during the experimental period.

There were correlations between VO\textsubscript{2max} (R = 0.68, p<0.01; fig 2), time to exhaustion during the treadmill test (R = 0.71, p<0.01), running economy expressed as ml/kg\textsuperscript{0.75} lean body mass/min (R = -0.62, p<0.02) and distance covered in the Hoff test. Backward multiple regression showed VO\textsubscript{2max} to be the main explanatory variable for distance covered in the Hoff test. The regression coefficient (SE) was 5.0 (1.4), p = 0.003; residual SD 3.0, and adjusted R\textsuperscript{2} = 0.44.

**Figure 1** The player has to conduct the ball in a forward run through the track. The track width is of 35 m, length is 55 m on the right and only 51.5 m on the other side. The distance from cone 7 to the gate 8 is performed with backward dribbling. There are three hurdles (30–35 cm height), 22 cones (two cones for the backward run gate and two for the starting line). Total distance per lap: 290 m; hurdle 3 to cone 1: 30.5 m; distance separating cones 1, 2, 3, 4, 5, 6, and 7: 25.5 m each.

**Figure 2** The relationship between distance covered in the Hoff test and maximum oxygen uptake. Data presented are the post-test results, but a similar relationship existed at pre-test. Solid line represents linear regression, dotted lines 95% confidence interval. R = 0.68; p<0.01.
DISCUSSION

This study showed that the Hoff test performance significantly correlated with laboratory measured VO\(_{2\text{max}}\) and that improvement in VO\(_{2\text{max}}\) was reflected in improved performance in the Hoff test.

The fact that such a ball dribbling field test correlated with aerobic performance is certainly of great interest for the soccer coaches. Indeed, it is generally easier to ask soccer players to make an effort with the ball than without. The performance in the Hoff test was closely related to VO\(_{2\text{max}}\) during treadmill running, but the relation was not strong enough to directly predict VO\(_{2\text{max}}\) from the test performance, as expected from previous literature.\(^1\) Fig 2 gives examples of performance interpretation. For example, predicting VO\(_{2\text{max}}\) from running 1900 metres in the Hoff test is meaningless, as values varied between 150 and 210 ml/kg\(^{0.75}\)/min. These data suggest that the present test is not greatly different from other indirect tests to predict VO\(_{2\text{max}}\); however, the presence of the ball in a dribbling form is certainly a critical motivational point as to its use by soccer teams in order to assess their players’ aerobic performance. Furthermore, fig 2 shows that all players covering more than 2100 metres in the Hoff test had a VO\(_{2\text{max}}\) >200 ml/kg\(^{0.75}\)/min, and those who ran <1900 metres had <200 ml/kg\(^{0.75}\)/min, which has been suggested as a minimum value for active soccer players.\(^2\)

Thus, we suggest that the goal in the Hoff test should be to have U-15 players running a distance of >2100 metres over the 10 minutes of test. This corresponds to 7.25 Hoff track turns—that is, the player has to reach cone 1 after having begun the eighth turn (2112 m).

The present study VO\(_{2\text{max}}\) results for youth players are among the highest ever reported for a youth club soccer team and are in the order of those observed in under 16 national teams.\(^1\)\(^5\)\(^6\) Furthermore, VO\(_{2\text{max}}\) was substantially higher than that reported for 8 year old soccer players;\(^2\) but are in the normal range of what is reported for senior elite players.\(^7\)

However, the values are not at all impressive considering the advantages of a high VO\(_{2\text{max}}\) in modern soccer. A very effective interval training programme, increasing VO\(_{2\text{max}}\) by 11% and 7% respectively, had the consequence that the team in total ran 18 000 metres more at a higher intensity, which also influenced the on field performance, apart from just running.\(^3\) The fact that backward multiple regression showed VO\(_{2\text{max}}\) to be the main explanatory variable for the distance covered in the Hoff test was not surprising, as the Hoff test is mainly covered by aerobic metabolism, also supported by the significant correlation between the two tests.

The present gain in work economy and VO\(_{2\text{max}}\) are substantial, but in line with previous studies in our laboratory.\(^4\) The present data also demonstrate how imprecise is the classical approach of expressing oxygen uptake in direct relation to body mass (that is as ml/kg/min) when evaluating changes in aerobic capacity over a period of time in subjects differing in body weight. As can be seen from table 1, running economy expressed traditionally as ml/kg/m was improved by 14%, while expressing oxygen uptake using appropriate scaling procedures as ml/kg\(^{0.75}\)/min gives an improvement of about 10%. This gives an excellent example of how imprecise it is to use the traditional expression form because the significant bodyweight gain in the present study automatically gives an improved work economy using the classical approach. This would also have been true even if the weight gain was due only to increased body fat, which, however, was not the case in the present study. The opposite is true for VO\(_{2\text{max}}\) as a gain in bodyweight automatically will reduce the VO\(_{2\text{max}}\) expressed traditionally, regardless of the increased body mass by more fat or muscle hypertrophy. Thus, expressed as ml/kg/min, VO\(_{2\text{max}}\) increased by 7.5%, while using the correct expression gives a gain of 12%, which makes more sense as the players now have more trained muscle tissue than before the experimental period (with similar body fat). We therefore emphasise the need for using scaling procedures in future studies of soccer players differing in body weight, both for appropriate evaluation of tests and for designing exercise regimens.

CONCLUSION

The present study demonstrated a significant correlation between laboratory testing of VO\(_{2\text{max}}\) and performance in the Hoff test. Furthermore, improvement in VO\(_{2\text{max}}\) was reflected in improved performance in the test. We suggest that it should be a goal for active U-15 soccer players to cover more than 2100 metres in the Hoff test as this requires a VO\(_{2\text{max}}\) of above 200 ml/kg\(^{0.75}\)/min, which should serve as a minimum for modern soccer. However, to precisely measure VO\(_{2\text{max}}\) accurately, there is no substitute, and probably never will be one, for using gas analysers either in the laboratory or in the field.

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Conflict of interests: none declared

REFERENCES

ANNOUNCEMENT

THE PAUL WEST MEMORIAL GRANT FOR SPORT AND EXERCISE MEDICINE RESEARCH IN SCOTLAND
The Scottish Branch of the British Association of Sport and Exercise Medicine and the family of Paul West are pleased to announce the above grant, which will be awarded annually. The award will be approximately £350. The research must be carried out in Scotland and concern the physically active population. Applications must to be submitted to the Award Committee by 31 April 2005.

Further details will be available from Mrs Yvonne Gilbert (BASEM), Scotland Administrator, c/o Royal College of Surgeons of Edinburgh, Nicolson Street, Edinburgh, EH8 9DW; tel: +44 (0)131 527 3409; email: y.gilbert@rcsed.ac.uk. Contact her as soon as possible to register interest and to receive more details.
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