Aerobic endurance training improves soccer performance

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ABSTRACT

HELGERUD, J., L. C. ENGEN, U. WISLØFF, and J. HOFF. Aerobic endurance training improves soccer performance. *Med. Sci. Sports Exerc.*, Vol. 33, No. 11, 2001, pp. 1925–1931. **Purpose:** The aim of the present study was to study the effects of aerobic training on performance during soccer match and soccer specific tests. **Methods:** Nineteen male elite junior soccer players, age 18.1 ± 0.8 yr, randomly assigned to the training group ($N = 9$) and the control group ($N = 10$) participated in the study. The specific aerobic training consisted of interval training, four times 4 min at 90–95% of maximal heart rate, with a 3-min jog in between, twice per week for 8 wk. Players were monitored by video during two matches, one before and one after training. **Results:** In the training group: a) maximal oxygen uptake ($\dot{V}O_{2max}$) increased from 58.1 ± 4.5 mL·kg^{-1}·min^{-1} to 64.3 ± 3.9 mL·kg^{-1}·min^{-1} ($P < 0.01$); b) lactate threshold improved from 47.8 ± 5.3 mL·kg^{-1}·min^{-1} to 55.4 ± 4.1 mL·kg^{-1}·min^{-1} ($P < 0.01$); c) running economy was also improved by 6.7% ($P < 0.05$); d) distance covered during a match increased by 20% in the training group ($P < 0.01$); e) number of sprints increased by 100% ($P < 0.01$); f) number of involvements with the ball increased by 24% ($P < 0.05$); g) the average work intensity during a soccer match, measured as percent of maximal heart rate, was enhanced from 82.7 ± 3.4% to 85.6 ± 3.1% ($P < 0.05$); and h) no changes were found in maximal vertical jumping height, strength, speed, kicking velocity, kicking precision, or quality of passes after the training period. The control group showed no changes in any of the tested parameters. **Conclusion:** Enhanced aerobic endurance in soccer players improved soccer performance by increasing the distance covered, enhancing work intensity, and increasing the number of sprints and involvements with the ball during a match. **Key Words:** $\dot{V}O_{2max}$, LACTATE THRESHOLD, RUNNING ECONOMY, SKILL

Soccer is one of the most widely played and complex sports in the world, where players need technical, tactical, and physical skills to succeed. However, studies to improve soccer performance have often focused on technique and tactics at the expense of physical resources such as endurance, strength, and speed.

The average work intensity, measured as percent of maximal heart rate (f_{cmax}), during a 90-min soccer match is close to the lactate threshold (LT), or 80–90% of f_{cmax} (18). However, expressing intensity as an average over 90 min could result in a substantial loss of specific information. Indeed, soccer matches have periods and situations of high-intensity activity where accumulation of lactate takes place. Therefore, the players need periods of low-intensity activity to remove lactate from the working muscles.

A significant correlation between maximal oxygen uptake ($\dot{V}O_{2max}$) and distance covered during a match was found (20,22). Moreover, the finding that the rank among the best four teams in the Hungarian top soccer division was the same as the rank among their average $\dot{V}O_{2max}$ (2) strengthens the correlation between $\dot{V}O_{2max}$ and performance. This assumption is also supported by the results of Wisløff et al. (24), demonstrating a significant difference in $\dot{V}O_{2max}$ between the top team and a lower placed team in the Norwegian elite division.

A professional soccer player should ideally be able to maintain a high level of intensity throughout the whole game. Some studies, however, have shown a reduction in distance covered, a lower fractional work intensity, reduced f_c, reduced blood sugar levels, and reduced lactate levels in the second half of games compared with the first half (8). In determining aerobic endurance, $\dot{V}O_{2max}$ is considered the most important element. Other important determinants are LT and running economy (gross oxygen cost of running per meter (C_R)) (17). LT is the highest workload, oxygen consumption or heart frequency in dynamic work using large muscle groups, where production and elimination of lactate balances (10). In endurance sports, LT might be a better indicator of aerobic endurance performance than $\dot{V}O_{2max}$ (9). LT might also change without changes in $\dot{V}O_{2max}$, and a higher LT means, theoretically, that a player could maintain a higher average intensity in an activity without accumulation of lactate (10). Costill et al. (6) and Helgerud et al. (9), among others, have shown between-individual variations in C_R. The causes of variability are not well understood, but it seems likely that anatomical traits, mechanical/neuromuscular skills, and storage of elastic energy are important factors (17). Better C_R among well-trained runners compared with recreational runners are documented (9,10). C_R is normally expressed as oxygen consumption ($\dot{V}O_2$) at a standardized workload or $\dot{V}O_2$ per meter when running (7,9). Hoff et al. (13) have shown that aerobic

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TABLE 1. Physical and physiological characteristics of players (± SD).

N	Age (yr)	Height (cm)	Mass (kg)	[Hb] ($g \cdot dL^{-1}$)	Hct (%)	VC (L)	FEV_1/VC (%)
19	18.1 (0.8)	181.3 (5.6)	72.2 (11.1)	14.3 (1.1)	43.7 (1.6)	5.14 (0.88)	88.5 (3.2)

[Hb], hemoglobin concentration in blood; Hct, hematocrit; VC, vital capacity; FEV_1, forced expiratory volume in 1 s.

performance can be increased by improving C_R with a strength training regimen, without affecting $\dot{V}O_{2max}$ or LT.

Several studies describe the physiological, tactical, and technical parameters during a soccer match, which characterize players at different levels (4,24). Cross-sectional studies show a correlation between $\dot{V}O_{2max}$ and these selected parameters (20,22); however, the basic question is whether this is a cause-and-effect phenomenon. Intervention studies concerning the effect of improving aerobic endurance on soccer performance have not, to date, been reported.

This study was carried out to evaluate the effects of a training protocol, aimed to improve aerobic endurance, on soccer performance. The hypothesis was that increased aerobic endurance can improve distance covered, work intensity, number of sprints, and number of involvements with the ball during a soccer match.

METHODS

Two Norwegian junior men elite teams, Nardo and Strindheim, took part in the study. The subjects had been playing soccer for more than 8 yr. Both teams had been among the most successful teams in Norway for the last 5 yr. Six of the players tested were members of the Norwegian national junior team. Players within each team were randomly assigned into either a training group (TG, $N = 9$) or a control group (CG, $N = 10$), so that each team had members in both groups. In repeated determination of $\dot{V}O_{2max}$ on the same subject, the standard deviation is 3%, including both biological and methodological variables (3). The actual number of subjects in the present study thus permitted detection of a 4.5% difference between groups ($P = 0.05$, power $= 0.90$). Each subject reviewed and signed consent forms approved by the Human Research Review Committee before the study. The subjects were only informed how to perform the physical and physiological tests; no information was given about the video analysis during the games. The head coaches spent equal time with their subjects in the TG and the CG. The athletes were truly unaware of the tested hypothesis. The physical and physiological characteristics of the subjects are presented in Table 1.

Training protocol. The aerobic training intervention consisted of interval training, consisting of four times 4 min each of running at an exercise intensity of 90–95% of f_{cmax} for each player, separated by periods of 3 min jogging at 50–60% of f_{cmax}. The interval training was administered as an extension of the regular training, twice per week over an 8-wk period in the beginning of the season. A regular week of training consisted of four times 1.5 h of practice and one game. Technical, tactical, strength, and sprint training were performed. About 1 h of each practice was organized as playing sessions in both teams. Endurance training was organized purely as part of these playing sessions. No extra strength training was performed. When the TG carried out interval training, the CG performed extra technical training such as heading drills, practicing free kicks, and exercises related to receiving the ball and changing direction.

Measurements. All players within a given team were tested on the same day, and the tests were performed in the same order. When entering the laboratory, hemoglobin (Hb), hematocrit (Hct), and lung function were measured for normative data comparisons. For Hb and Hct determination, blood was drawn from a fingertip and analyzed immediately using the Refletron (Boehringer Mannheim, Frankfurt, Germany) and Ames microspin (Bayer Diagnostic, Munich, Germany) devices, respectively. Vital capacity (VC) and forced expiratory volume in 1 s (FEV_1) were determined using a flow screen (Hoechberg, Germany). After these preliminary tests, subjects completed a 20-min warm-up at approximately 50–60% of $\dot{V}O_{2max}$. Vertical jump height was determined using a force platform with software specifically developed for the platform (BioWare, Kistler Instrumente AG, Winterthur, Switzerland). Jumping height was determined as the center of mass displacement calculated from force development and measured body mass. Strength testing consisted of one repetition maximum of bench press and of squats (90° angle of the knee joints) repetition performed with a competition standard Olympic style bar and weights (T-100G, Eleiko Sport, Halmstad, Sweden).

A 40-m sprint test, a technical test, and a test of maximal kicking velocity followed the strength tests. The time for the first test was measured using photocells (Brower Timing Systems, South Draper, UT) at the start, at 10 m, and at 40 m. Each subject had two trials separated by 5 min of rest. When ready to sprint, the subjects decided themselves when to start the sprint test from a static position, with the time being recorded when the subjects intercepted the photocell beam. The technical test was performed using 10 Select senior balls with an air pressure of 0.8 bar. The balls were placed 16 m from a goal, which was in turn divided into five zones. If the ball was kicked into the 50-cm-wide center zone it was worth 3 points, 2 points if it was placed into an inner zone 25 cm each side of the center zone, and 1 point if placed into an outer zone reaching an additional 25 cm out from the inner second zone. The subject was given 1 min to use his "preferential foot" to get the highest score possible. The technical test was repeated immediately after the $\dot{V}O_{2max}$ test to verify fatiguing effect on technical skills. Measurement of maximal kicking velocity was performed using a Panasonic (Tokyo, Japan) Wv-F350 E video camera recorded at 50 Hz. The subject was free to decide the length of the in-run. A centimeter scale was mounted on the wall parallel to the direction of the shot, giving the opportunity to calculate the speed of the ball as a fraction of the distance covered on the video picture. Each player was given two trials. The best trial was used in the data handling.

Following the strength, sprint, and technical tests, LT and $\dot{V}O_{2max}$ were determined during treadmill running at 3° inclination. The protocol used for measuring LT and $\dot{V}O_{2max}$ has been described previously (10). Briefly, LT determination began with a 10-min warm-up at 50–60% of $\dot{V}O_{2max}$, followed by measurement of baseline blood lactate concentration ($[la^-]_b$). LT was taken as the power output, $\dot{V}O_2$, or f_c that gave a $\Delta[la^-]_b$ of 1.5 mmol·L^{-1} above baseline using 5-min work bouts during a continuous, graded protocol. Subjects performed 5-min exercise stages progressing in intensity between 60 and 95% of $\dot{V}O_{2max}$. Running speed was increased by 1 km·h^{-1} at each stage, after a 20-s pause for blood sampling from a fingertip. The above-described protocol for LT was derived from a previous study (10). Values for running speed, $\dot{V}O_2$, f_c, and $[la^-]_b$ were recorded during a series of running sessions. Each test was performed at constant speed over a period of 20 min, and on separate days. The highest exercise intensity during the constant speed tests, where the $[la^-]_b$ increased < 1 mmol·L^{-1} during the last 15 min, was then defined as LT. The values from the constant speed tests were then compared with values from the graded tests. From the results of these studies, it was concluded that LT, using the graded protocol, was reached at a $\dot{V}O_2$ that gave on average $[la^-]_b$ 1.5 mmol·L^{-1} (ranging from 1.3–1.7 mmol·L^{-1}) higher than those found immediately after the warm-up period.

After measuring LT, treadmill speed was increased to a level that brought the subject to $\dot{V}O_{2max}$ and to exhaustion after about 3 min. C_R was calculated at LT, the maximal exercise intensity at which it has been shown that a reliable relationship exists between intensity and $\dot{V}O_2$ (9). The highest f_c during the last minute was taken as f_{cmax}, measured by short-range radio telemetry (Polar Sporttester, Polar Electro, Finland). $\dot{V}O_2$, maximal minute ventilation ($\dot{V}_E$), respiratory exchange ratio (R), and breathing frequency were measured during each exercise stage using an Ergo Oxyscreen (Jaeger EOS sprint, Germany). Unhemolyzed blood lactate $[la^-]_b$ was determined using a YSI Model 1500 Sport Lactate Analyzer (Yellow Springs Instrument Co., Yellow Springs, OH).

$\dot{V}O_{2max}$ expressed as mL·kg^{-1}·min^{-1} implies linearity between oxygen uptake and body mass, which is not the case (5). When expressing $\dot{V}O_{2max}$ as mL·kg^{-1}·min^{-1}, light individuals are overestimated in terms of work capacity (e.g., endurance athletes) and heavy individuals are underestimated. The opposite is true when evaluating oxygen cost of running at submaximal workloads. Consequently, Wisløff et al. (24), Helgerud (9), and Bergh et al. (5) have concluded that when comparisons among people of different body mass are made for running, oxygen uptake should be expressed as mL·kg$^{-0.75}$·min^{-1}.

Video analysis. Players were monitored by a video system during two regular games, played on a neutral field, before and after the training period. During games, f_c was measured using a heart rate monitor (Polar Sporttester). The f_c measurements were divided into different intensity zones on the basis of percent f_{cmax}: $< 70\%$, 70–85%, 85–90%, 90–95%, and $> 95\%$. Time spent in different intensity zones was calculated. Because of injuries, data were collected on eight subjects in both groups. All games were played on a high-quality indoor field consisting of artificial curled nylon grass filled with sand. Video recordings were made using a single Panasonic M2 video camera 5 m from the sideline, 10 m higher than the field. A Videomedia (Panasonic) VLC 32 editing table made slow motion and frame-by-frame analyses possible. A Wacom Digitizer SD-421-E digital board (Wacom Co., Ltd, Saitama, Japan) and a marking pen, with specially designed software (Arntzen Engineering, Trondheim, Norway) for PC was used to follow movements and to determine distances covered during the game. The following parameters were measured from the video recordings:

Distance covered by a player.
Number of passes, defined as a trial to reach a team player with the ball.
Number of involvements with the ball, defined as all situations where the player is in physical contact with the ball or in direct pressure on an opponent in possession of the ball.
Number of sprints, sprinting for at least 2 s.

Similar parameters for soccer performance have been used in earlier studies (4,25). Before the match analyses were carried out, a thorough reliability testing of the methods for video analyses was performed. The coefficient of reliability was 0.922 for the number of sprints, 0.970 for the number of involvements with the ball, 0.998 for passes, and 0.898 for distance covered during the match (unpublished results).

Statistical analysis. All the results are reported as means ± standard deviation (SD). An ANOVA analysis for repeated measurement was used to determine differences among tests and between groups. Changes from pre- to posttraining in $\dot{V}O_{2max}$, LT, or C_R given in percent is calculated on the basis of the unit mL·kg$^{-0.75}$·min^{-1}. Results were accepted as significant at $P < 0.05$. Group size and statistical power were estimated using nQuery Advisor software (Version 3.0, Statistical Solutions Ltd., Cork, Ireland).

RESULTS

During the training period, three subjects in the TG dropped out because of illness and injuries not related to the training protocol. During the soccer matches, it was not possible to take heart frequency measurements from two subjects in the CG, and three subjects in the CG were unable to play in the soccer matches. There were no differences between the groups in terms of $\dot{V}O_{2max}$ before training, although the TG showed an increase in $\dot{V}O_{2max}$ of 10.8% ($P < 0.05$) after the training period (Table 2).

In the TG, LT and C_R were improved by 16% ($P < 0.05$) and 6.7% ($P < 0.05$), respectively. LT was not statistically changed expressed as percent $\dot{V}O_{2max}$, but in terms of running speed at LT (ν_{Th}) it increased from 11.1 km·h^{-1} to 13.5

TABLE 2. Results from physiological tests (± SD).

	TG (N = 9)		CG (N = 10)	
	Pretraining	Posttraining	Pretraining	Posttraining
$\dot{V}O_{2max}$				
$L \cdot min^{-1}$	4.25 (1.9)	4.59 (1.4)*	4.06 (0.95)	4.11 (0.99)
$mL \cdot kg^{-1} \cdot min^{-1}$	58.1 (4.5)	64.3 (3.9)*	58.4 (4.3)	59.5 (4.4)
$mL \cdot kg^{-0.75} \cdot min^{-1}$	169.9 (9.6)	188.3 (10.6)*	169.2 (9.7)	170.3 (9.8)
LT				
$L \cdot min^{-1}$	3.5 (0.4)	3.96 (0.3)*	3.5 (0.4)	3.46 (0.4)
$mL \cdot kg^{-1} \cdot min^{-1}$	47.8 (5.3)	55.4 (4.1)*	49.5 (3.3)	50.0 (4.1)
$mL \cdot kg^{-0.75} \cdot min^{-1}$	139.9 (15.5)	162.3 (12.2)*	143.7 (15.2)	143.2 (10.9)
% $\dot{V}O_{2max}$	82.4 (3.1)	86.3 (2.1)	86.2 (3.7)	84.2 (2.8)
% f_{cmax}	87.4 (2.3)	87.6 (2.4)	89.2 (3.1)	88.7 (4.2)
ν_{LT} ($km \cdot h^{-1}$)	11.1 (0.7)	13.5 (0.4)*	11.7 (0.4)	11.5 (0.2)
Running economy				
$mL \cdot kg^{-0.75} \cdot m^{-1}$	0.75 (0.05)	0.70 (0.04)*	0.75 (0.04)	0.74 (0.04)
f_{cmax} ($beats \cdot min^{-1}$)	202 (5.5)	203 (5.7)	202 (6.3)	202 (6.3)
$[la^-]_b$ ($mmol \cdot L^{-1}$)	8.1 (1.5)	8.5 (1.9)	7.8 (1.4)	7.9 (1.5)
R	1.17 (0.1)	1.18 (0.1)	1.18 (0.1)	1.18 (0.1)

ν_{LT}, running velocity at LT (3° inclination); $[la^-]_b$ ($mmol \cdot L^{-1}$), blood lactate concentration after $\dot{V}O_{2max}$ testing; R, respiratory exchange ratio.
* $P < 0.05$.

$km \cdot h^{-1}$ ($P < 0.05$). C_R was constant within the range 60–95% $\dot{V}O_{2max}$.

Results from video analyses during games are given in Table 3. The TG increased the distance covered during a game by 20% ($P < 0.01$). The average increase in the number of sprints per player during a match for the TG was 100% ($P < 0.001$), and the number of involvements with the ball increased by 24.1% ($P < 0.05$). The number of passes and the distribution between successful and not successful passes did not change.

Table 4 reflects the work intensity reported as average heart rate in percent of f_{cmax}, during the first and the second halves, as well as during the whole game. From before to after training the TG increased the average percent of f_{cmax} in the game during the second half and during the whole game ($P < 0.05$) (Table 4).

Figure 1 shows the time spent in the different intensity zones (see Methods) in the first and second halves, before and after training. Figure 1 also shows time spent at different intensities during the game after training. The TG had a significantly smaller decline in average percent of f_{cmax} in the second half, at posttraining ($P < 0.05$), and spent 19 min longer in the high-intensity zone (> 90% of f_{cmax}) compared with the CG at the posttraining game ($P < 0.05$). No changes were found in either group in the tests involving speed, strength, jumping height, kicking velocity, and technical test (passing precision) (Table 5).

DISCUSSION

The protocol used to improve the aerobic endurance in this study increased $\dot{V}O_{2max}$ by 10.8% in the TG. No significant changes took place in the CG after the same period of time. This improvement in $\dot{V}O_{2max}$ from endurance training was in accordance with previous studies (21). Given the standard deviation in repeated determination of $\dot{V}O_{2max}$ (3), the number of subjects studied permitted detection of a 4.5% difference between groups ($P = 0.05$, power = 0.90). The average $\dot{V}O_{2max}$ after training for the TG in the present study is above what is often reported for soccer players. Other studies have shown that the average $\dot{V}O_{2max}$ for international level male soccer players ranges from 55–68 $mL \cdot kg^{-1} \cdot min^{-1}$, with individual values higher than 70 $mL \cdot kg^{-1} \cdot min^{-1}$ (18,24). These values are similar to those found in other team sports, but substantially lower than elite performers in endurance sports, where values close to 90 $mL \cdot kg^{-1} \cdot min^{-1}$ have commonly been found. The fact that no changes occurred in the $\dot{V}O_{2max}$ of the control group is probably because of the lack of high-intensity endurance training during regular soccer practice.

The TG showed an improvement in LT in absolute terms but not relative to $\dot{V}O_{2max}$. In studies using the present LT procedure, well-trained long-distance runners have LT at about 85% $\dot{V}O_{2max}$ (9,10). This is in line with the present results for soccer players. Another LT protocol derived from fixed blood lactate values (e.g., 2 or 4 $mmol \cdot L^{-1}$) would

TABLE 3. Video analyses from soccer matches at pretest and posttest, as average numbers per player and match (± SD).

	TG (N = 9)		CG (N = 10)	
	Pretraining	Posttraining	Pretraining	Posttraining
No. of sprints	6.2 (2.2)	12.4 (4.3)**	6.4 (2.4)	7.5 (2.7)
No. of involvements with ball	47.4 (5.5)	58.8 (6.9)*	50.1 (6.1)	52.4 (6.7)
No. of passes	28.5 (3.5)	30.7 (3.9)	24.8 (3.1)	26.9 (3.9)
Successful passes	19.4 (2.1)	23.5 (2.7)	16.6 (2.0)	18.7 (2.3)
Unsuccessful passes	9.1 (1.9)	7.2 (1.4)	8.2 (1.7)	8.2 (1.8)
Distance covered (m)	8619 (1237)	10,335 (1608)**	9076 (1512)	9137 (1565)

* $P < 0.05$; ** $P < 0.01$.

TABLE 4. Average heart frequency during match (% f_{cmax}) (± SD).

	First Half	Second Half	Total
Pretraining			
CG (N = 8)	83.0 (3.0)	80.0 (2.0)	81.7 (3.3)
TG (N = 9)	84.0 (4.0)	81.2 (2.1)	82.7 (3.4)
Posttraining			
CG (N = 8)	84.2 (3.0)	81.1 (4.2)	82.6 (4.1)
TG (N = 9)	86.3 (3.2)	85.0 (3.0)*	85.6 (3.1)*

* $P < 0.05$.

give the same change in scores from before to after training, which was the focus of this study. The training protocol used in this study was not specifically designed to improve LT. Such a training regimen would normally imply the utilization of work intensity of between 85 and 90% of f_{cmax} (17). Improvements in $\dot{V}O_{2max}$ are, however, normally followed by improved LT. The improvement in LT is therefore a result of the change in $\dot{V}O_{2max}$ and C_R. The TG spent 19 min more than the CG in the high-intensity zone (> 90% of f_{cmax}). This is probably because of increased $\dot{V}O_{2max}$ in the TG, since the fractional utilization of $\dot{V}O_{2max}$ has been shown to be partly dependent on the state of training (9). The ability to perform for longer periods of time at the same relative exercise intensity is, however, more a function of efficiency in usage of glycogen. Thus, the amount of glycogen and the training status of the muscles involved in the exercise are decisive for the maintenance of a specific relative work intensity. Endurance training in soccer, more than a training regimen aimed to improve LT only, should thus emphasize improvement in $\dot{V}O_{2max}$ and, in turn, improve LT.

C_R was also improved by 6.7% in the TG as a result of the training protocol. Improved C_R would, however, be expected on the basis of their more extensive running during practice compared with the CG. More running practice has been shown to affect C_R (9). A question remains, however, whether or not the "soccer specific" work economy of the players was improved. This means the oxygen cost of carrying and trapping the ball, and starting, stopping, and changing direction. This was not addressed in this study. C_R in the present study was higher than that reported earlier (9,10). The reason for this is probably that these studies have used horizontal or 1° inclination treadmill during running, whereas the present study was carried out on 3° inclination. This gives higher $\dot{V}O_2$ at the same speed resulting in higher C_R (lower economy). The C_R was constant within the running velocities just below and higher than LT, and this is consistent with data obtained by Di Prampero et al. (7) and Helgerud (9).

In this study, the work intensity during soccer matches was studied through an analysis of f_c during matches. At pretraining, there were no differences between the TG and the CG. However, the TG improved their average intensity at posttraining. In practical terms, as the results presented in Table 3 show, this means that a player from the CG, having a f_{cmax} of 200 beats·min^{-1}, at posttraining would have an average f_c of 165 beats·min^{-1}, whereas a player from the TG, with the same f_{cmax}, would have an average intensity of 171 beats·min^{-1}. The time spent in the different intensity zones in this experiment correspond with the findings from Rhode and Espersen (19). Improved work intensity as a result of the intervention seems logical, as the average distance covered during a game for the TG increased by 1716 m and the average number of sprints per player increased from 6 to 12. These results support the findings from Smaros (20) showing that the players with the highest $\dot{V}O_{2max}$ had the highest

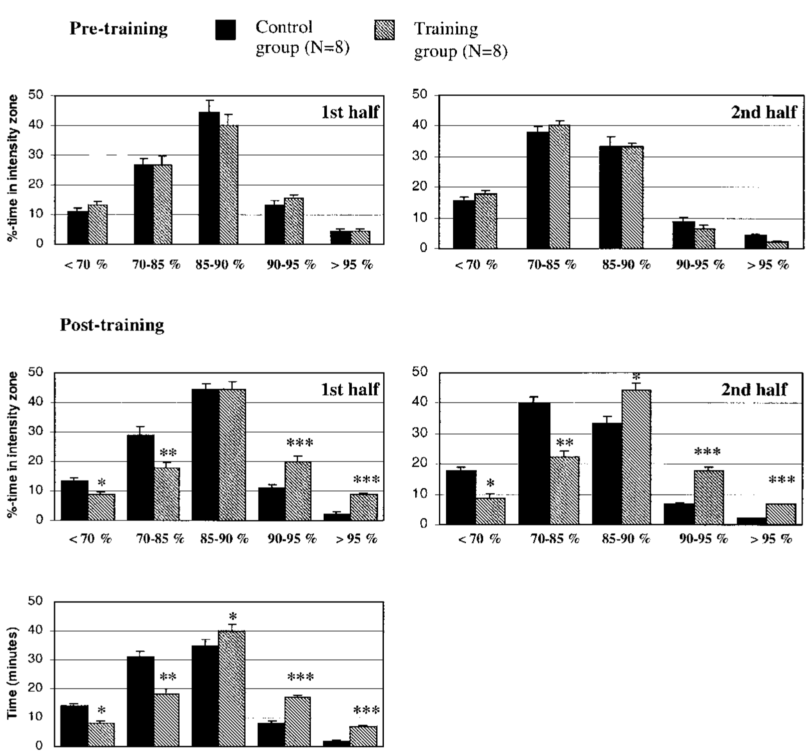

FIGURE 1—*Upper panels* show time spent in the different intensity zones in first and second halves before training. Intensities are expressed in relation to maximal heart rate. *Middle panels* show the corresponding values after training. *Lower panel* shows time spent at different intensities during the game after training. Values are mean ± SD. Significantly different from training group, *P < 0.05; **P < 0.01; ***P < 0.001.

TABLE 5. Results from the strength, speed, jump, and technical tests (± SD).

	TG ($N = 9$)		CG ($N = 10$)	
	Pretraining	**Posttraining**	**Pretraining**	**Posttraining**
Running velocity (s)				
10 m	1.88 (0.06)	1.87 (0.05)	1.89 (0.06)	1.89 (0.06)
40 m	5.58 (0.16)	5.56 (0.15)	5.61 (0.18)	5.62 (0.19)
Strength (kg)				
1RM bench press	60.3 (12.7)	59.8 (11.5)	55.8 (10.6)	55.5 (10.4)
1RM 90° squat	146.1 (26.4)	141.9 (25.8)	137.3 (25.1)	129.1 (23.3)
Vertical jump (cm)	54.9 (4.7)	54.7 (3.8)	52.0 (3.7)	52.4 (4.1)
Kicking				
Velocity ($km \cdot h^{-1}$)	106.0 (4.9)	108.0 (6.1)	98.5 (11.5)	99.0 (12.6)
Technique (points):				
First trial	17.4 (5.3)	19.0 (6.9)	18.5 (6.7)	16.2 (4.6)
After $\dot{V}O_{2max}$ test	18.8 (6.1)	16.3 (4.1)	16.2 (5.7)	14.5 (3.8)

number of sprints and took part in more decisive situations during a match than those with a lower $\dot{V}O_{2max}$. The results in the present study also agree with those of Bangsbo et al. (4), who found that the average number of sprints in matches completed by Danish elite players was 19, an activity that covered less than 1 min of the entire game.

Distance covered during a match differed a lot in the measures performed in the early 1970s (14). Recently, however, measurements have become more reliable, and top-level differences are now considered to be quite small. Recent studies showing the distances covered by male players are 10,245 m (23), 9,845 m (16), 10,800 m for Danish elite players (4), and 11,527 m for Australian elite players (25).

The results in the present study showed that an improved $\dot{V}O_{2max}$ gives an enhanced potential to cover a longer running distance at a higher intensity. The distances covered by the subjects correspond with several other studies (16,23). After the training protocol, the TG covered 10,335 m in 61.30 min of effective playing time. Although the TG covered on average 1716 m more at posttraining than at the pretraining match, it is important to note how these improvements are mirrored into soccer performance. An increase of 24% in number of involvements with the ball in the TG, whereas no changes were observed in the CG, shows that a player with higher $\dot{V}O_{2max}$ is able to be involved in more situations, increasing his/her possibility to influence the end result of a match. The TG had 47.4 and 58.8 involvements with the ball throughout a match at pretraining and posttraining, respectively. This is in line with the findings from Withers et al. (25), who showed that Australian elite soccer players on average were involved with the ball 50 times per match.

No differences were found for the quality of passes during a match in the two groups after the training period. However, the average work intensity during a match increased in the TG at posttraining, and still they were able to keep up the quality of passes. Motor skill training at a high intensity level might be the type of training that can alter the percentage of successful passes. The increased number of involvements during the match, however, was not followed by an improved number of passes. The reason seems to be that the evaluation of passes is much more related to technical skill than the evaluation of involvements. The number of passes in the present study was on average 30 per player and match after training, in line with earlier findings (15).

No changes were observed in one-repetition maximum (1RM) squat strength or bench press strength, in vertical jumping height, or in running velocity for any of the groups as expected from the endurance training protocol. On the other hand, one might still expect that regular soccer training should improve some of these skills. In accordance with earlier studies (11,13), the results in the present study also show that aerobic training does not have a negative impact on the strength, speed, and jumping ability. In addition, maximal kicking velocity was not altered by the training protocol, in agreement with previous research showing that improved rate of force development or improved coordination seems to be the trigger mechanism behind velocity development (1,12).

Furthermore, in the present study no changes occurred in the technical kicking, either between groups or between testing conditions, even though lactate values averaged 8.1 $mmol \cdot L^{-1}$ in each group after the $\dot{V}O_{2max}$ determination. However, the technical kicking test used in the present study was not familiar to the players and might have created some initial anxiety, which still would not explain lack of differences after training. Another explanation might be that the technical test used in the present study was too easy for the subjects and thus no differentiation was forthcoming between subjects with or without high levels of blood lactate.

Ideally, endurance training for soccer players should be carried out using the ball. The players might then additionally develop technical and tactical skills similar to situations experienced during the game. Player motivation is also normally considered to be higher when the ball is used. However, the work intensity often is reduced when more technical and tactical elements are involved. Bangsbo et al. (4) showed that playing four against four on a field half the size of a regular soccer field requires higher work intensity than when the field size is reduced to one third of a regular soccer field. If the goal is to train at an intensity zone between 90 and 95% of f_{cmax}, this is difficult to organize in a match situation, especially for teams in lower divisions. Heart rate monitoring systems and a training regimen, where the intensity is relatively easily regulated, are probably necessary to expect similar developments as in this experiment.

CONCLUSION

In the present study, enhancing maximal oxygen uptake led to improved soccer performance, substantiated as distance covered, level of work intensity, number of sprints, and number of involvements with the ball during a match. The increased aerobic endurance had no negative influence on maximal jumping height, strength, speed, kicking velocity, or kicking precision.

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