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Physiology of Soccer
An Update

Tomas Stølen,[1] *Karim Chamari*,[2] *Carlo Castagna*[3] and *Ulrik Wisløff*[4,5]

1 Human Movement Science Section, Faculty of Social Sciences and Technology Management, Norwegian University of Science and Technology, Trondheim, Norway
2 Unité de Recherche 'Évaluation, Sport, Santé' – National Center of Medicine and Science in Sport (CNMSS), El Menzah, Tunis, Tunisia
3 School of Sport and Exercise Sciences, Faculty of Medicine and Surgery, University of Rome Tor Vergata, Rome, Italy
4 Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, Trondheim, Norway
5 Department of Cardiology, St. Olavs Hospital, Trondheim, Norway

Contents

Abstract

Soccer is the most popular sport in the world and is performed by men and women, children and adults with different levels of expertise. Soccer performance depends upon a myriad of factors such as technical/biomechanical, tactical, mental and physiological areas. One of the reasons that soccer is so popular worldwide is that players may not need to have an extraordinary capacity within any of these performance areas, but possess a reasonable level within all areas. However, there are trends towards more systematic training and selection influencing the anthropometric profiles of players who compete at the highest level. As with other activities, soccer is not a science, but science may help improve performance. Efforts to improve soccer performance often focus on technique and tactics at the expense of physical fitness.

During a 90-minute game, elite-level players run about 10km at an average intensity close to the anaerobic threshold (80–90% of maximal heart rate). Within this endurance context, numerous explosive bursts of activity are required, including jumping, kicking, tackling, turning, sprinting, changing pace, and sustaining forceful contractions to maintain balance and control of the ball against defensive pressure. The best teams continue to increase their physical capacities, whilst the less well ranked have similar values as reported 30 years ago. Whether this is a result of fewer assessments and training resources, selling the best players, and/or knowledge of how to perform effective exercise training regimens in less well ranked teams, is not known. As there do exist teams from lower divisions with as high aerobic capacity as professional teams, the latter factor probably plays an important role.

This article provides an update on the physiology of soccer players and referees, and relevant physiological tests. It also gives examples of effective strength- and endurance-training programmes to improve on-field performance. The cited literature has been accumulated by computer searching of relevant databases and a review of the authors' extensive files. From a total of 9893 papers covering topics discussed in this article, 843 were selected for closer scrutiny, excluding studies where information was redundant, insufficient or the experimental design was inadequate. In this article, 181 were selected and discussed. The information may have important implications for the safety and success of soccer players and hopefully it should be understood and acted upon by coaches and individual soccer players.

Soccer is the most popular sport in the world,[1] performed by men and women, children and adults with different levels of expertise. As with other sports, soccer is not a science but science may help improve performance.[1] The performance depends upon a myriad of factors such as technical, tactical, physical, physiological and mental areas. This article provides an overview of important literature in soccer physiology, describes relevant physiological tests and gives examples of effective strength and endurance training regimens to improve on-field soccer performance not highlighted in previous reviews. Furthermore, this article presents up-to-date data about the physiology of soccer referees.

1. Physical Demands

Distances covered at top level are in the order of 10–12km for the field players, and about 4km for the goalkeeper (table I). Several studies report that the midfield players run the longest distances during a game and that professional players run longer distances than non-professionals.[2-4] The exercise intensity is reduced and the distance covered is 5–10% less in the second half compared with the first.[4-8] During a soccer game, a sprint bout occurs approximately every 90 seconds, each lasting an average of 2–4 seconds.[7,9] Sprinting constitutes 1–11% of the total distance covered during a match[4-6,9] corresponding to 0.5–3.0% of effective play time (i.e. the time when the ball is in play).[5,7,9-11] In the endurance context of the game, each player performs 1000–1400 mainly short activities[4,7-9] changing every 4–6 seconds. Activities performed are: 10–20 sprints; high-intensity running approximately every 70 seconds; about 15 tackles; 10 headings; 50 involvements with the ball; about 30 passes as well as changing pace and sustaining forceful contractions to maintain balance and control of the ball against defensive pressure.[3,5,7-12] Withers et al.[5] noted that the fullbacks sprinted more than twice as much as the central-defenders (2.5 times longer), whilst the midfielders and the attackers sprinted significantly more than central-defenders (1.6–1.7 times longer). This is in line with Mohr et al.[4] who reported that fullbacks and attackers sprinted significantly longer than central-backs and midfielders.

Strength and power are equally as important as endurance in soccer. Maximal strength refers to the highest force that can be performed by the neuromuscular system during one maximum voluntary contraction (one repetition maximum [1RM]), whereas power is the product of strength and speed and refers to the ability of the neuromuscular system to produce the greatest possible impulse in a given time period. Maximal strength is one basic quality that influences power performance; an increase in maximal strength is usually connected with an improvement in relative strength and therefore with improvement of power abilities. A significant relationship has been observed between 1RM and acceleration and movement velocity.[23,24] This maximal strength/power performance relationship is supported by jump test results as well as in 30m sprint results.[25,26] By increasing the available force of muscular contraction in appropriate muscles or muscle groups, acceleration and speed may improve in skills critical to soccer such as turning, sprinting and changing pace.[1] High levels of maximal strength in upper and lower limbs may also prevent injuries in soccer.[27] Furthermore, Lehnhart et al.[28] showed that introducing a strength training regimen reduced the number of injuries by about 50%. From this it should be obvious that superior technical and individual (and team) tactical ability in soccer can only be consistently demonstrated throughout the course of a 90-minute competition by soccer players with high endurance capacity and strength.

1.1 Game Intensity

Because of the game duration, soccer is mainly dependent upon aerobic metabolism. The average work intensity, measured as percentage of maximal heart rate (HR_{max}), during a 90-minute soccer match is close to the anaerobic threshold (the highest exercise intensity where the production and removal of lactate is equal; normally between 80–90% of HR_{max} in soccer players) [table II]. It would be physiologically impossible to keep a higher average intensity over a longer period of time due to the resultant accumulation of blood lactate. However, expressing game intensity as an average over 90 minutes, or for each half, could result in a substantial loss of specific information. Indeed, soccer matches show periods and situations of high-intensity activity where accumulation of lactate takes place. Therefore, the players need periods of low-intensity activ-

Table I. Distance covered in different positions in male and female soccer players

Study	Level/country (sex)	n	Distance covered (m) according to playing position, no. of players in parentheses				Method of measurement
			unspecified	defender	midfielder	attack	
Agnevik[12]	Division 1/Sweden (M)	10	10 200				Cine film
Bangsbo et al.[7]	Division 1 and 2/Denmark (M)	14		10 100 (4)	11 400 (7)	10 500 (3)	Video
Bangsbo[1]	Elite/Denmark (F)	1	9 500 (1)[a]				Video
Brewer and Davis[13]	Elite/Sweden (F)		>8 500				
Ekblom[3]	Division 1 and 4/Sweden (M)	44		9 600	10 600	10 100	Hand notation
	Division 2/Germany (M)	10	9 800 (10)				
Helgerud et al.[10]	Elite juniors/Norway (M)	10	9 107 (10)				Video
	Training group (M)	9	1 035 (9)				
Knowles and Brooke[14]	Professional/England (M)	40	4 834				Hand notation
Mohr et al.[4]	Division 1/Denmark (M)	24	1 033 (24)				Video
	Top team/Italy (M)	18	1 086 (18)				Video
	Combining both teams (M)	42		9 740 (11) CB 10 980 (9) FB	11 000 (13)	10 480 (9)	
Ohashi et al.[15]	National/Japan (M)	2	9 845 (2)				Trigonometry
	League/Japan (M)	2	10 824 (2)				
Reilly and Thomas[9]	Division 1/England (M)	32		7 759 (7) CB	9 805 (11)	8 397 (14)	Tape recorder
		8		8 245 (8) FB			
Rienzi et al.[8]	EPL/England (M)	6	10 104 (6)				Video
	International/SA (M)	17	8 638 (17)				
	EPL/SA international (M)	23		8 695 (9)	9 960 (10)	7 736 (4)	
Saltin[16]	Non-elite/Sweden (M)	5	12 000				Cine film
Smaros[17]	Division 2/Finland (M)	7	7 100 (7)				TV cameras
Thatcher and Batterham[18]	EPL first-team/England (M)	12	9 741 (12)				
	EPL U-19/England (M)	12	10 274 (12)				
Van Gool et al.[6]	University team/Belgium (M)	7		9 902 (2)	10 710 (3)	9 820 (2)	Cine film
Vianni[19]	Level unknown/Russia (M)		17 000				
Wade[20]	Professional/England (M)		1 600–5 486				
Whitehead[2]	Division 1/England (M)	2		11 472 (1)	13 827 (1)		Hand notation
	Division 2/England (M)	2		10 826 (1)	11 184 (1)		
	Top amateur/England (M)	2		9 679 (1)	9 084 (1)		
	College/England (M)	2		6 609 (1)	8 754 (1)		
Winterbottom[21]	Professional/England (M)		3 361				
Withers et al.[5]	National league/Australia (M)	15		10 169 (5) CB	12 194 (5)	11 766 (5)	Video
		5		11 980 (5) FB			
Zelenka et al.[22]	Professional/Czech (M)	1				11 500	

a 80-minute game.

CB = central-back; **Czech** = Czech Republic; **EPL** = English Premier League; **F** = female; **FB** = full-back; **M** = male; **SA** = South America; **U** = under.

Table II. Heart rate in male and female soccer players

Study	Level/country (sex)	n	Type of match (min)	HR (beats/min)	HR_{max} (%)
Agnevik[12]	Division 1/Sweden (M)	1	League (90)	175	93
Ali and Farrally[33]	Semi-professional/Scotland (M)	9	League (90)	172	
	University/Scotland (M)	9	League (90)	167	
	Recreational/Scotland (M)	9	League (90)	168	
Bangsbo[1]	League/Denmark (M)	6	League (90)	~159	
	Elite/Denmark (F)	1	International (80)	170	
Brewer and Davis[13]	Elite/Sweden (F)		League	175[a]	89–91[a]
Helgerud et al.[10]	Elite juniors/Norway (M)	8	League (90)		82.2
	Training group/Norway (M)	9	League (90)		85.6
Mohr et al.[34]	Division 4/Denmark (M)	9	Friendly (90)	160	
	Division 4/Denmark (M)	16	Friendly (90)	162	
Ogushi et al.[32]	League/Japan (M)	2	Friendly (90)	161	
Reilly[35]	League/England (M)		Friendly (90)	157	
Seliger[36]	Unknown/Czech (M)		Model (10)	165	80
Strøyer et al.[37]	Elite beginning of puberty/Denmark (M)	9	League	175	86.8
	Elite end of puberty/Denmark (M)	7	League	176	87.1
Van Gool et al.[6]	University/Belgium (M)	7	Friendly (90)	167	

a Indicates an average of three matches.

Czech = Czech Republic; **F** = female; **HR** = heart rate; **HR_{max}** = maximal heart rate; **M** = male.

ity to remove lactate from the working muscles. In relative terms, there is little or no difference between the exercise intensity in professional and non-professional soccer, but the absolute intensity is higher in professionals.[3] No-one has yet managed to provide accurate and valid data when measuring oxygen uptake ($\dot{V}O_2$) during a soccer match. The values measured[29-32] are probably underestimated, since the equipment most likely inhibited the performance.

Ogushi et al.[32] used Douglas bags (the equipment weighing 1200g), measuring $\dot{V}O_2$ in periods of about 3 minutes in two players. They found an average $\dot{V}O_2$ of 35 and 38 mL/kg/min in the first half and 29 and 30 mL/kg/min in the second. This corresponded to 56–61% and 47–49% of maximal oxygen uptake ($\dot{V}O_{2max}$) for the two players in the first and second half, respectively, which is substantially lower than reported in other studies.[10,37] The distances covered during the $\dot{V}O_2$ recordings were 11% shorter when compared with those not wearing the Douglas bags, which partly explain the low $\dot{V}O_2$ values observed. There is good reason to believe that the use of Douglas bags, due to their size (and limited time for gas sampling), reduced the involvement in duels, tackles and other energy-demanding activities in the match, and, thus, underestimated the energy demands in soccer. New portable gas analysers (~500g) allow valid results, but at present no such study has been performed. Establishing the relationship between heart rate (HR) and $\dot{V}O_2$ during a game allows accurate indirect measurement of $\dot{V}O_2$ during soccer matches. Establishing each player's relationship between HR and $\dot{V}O_2$ (the HR–$\dot{V}O_2$ relationship) may accurately reflect the energy expenditure in steady-state exercise. However, some authors[32] question the HR–$\dot{V}O_2$ relationship in intermittent exercise. Static contractions, exercise with small muscle groups and psychological and thermal stresses, will elevate the HR at a given $\dot{V}O_2$; i.e. changing the HR–$\dot{V}O_2$ line.[38] However, in soccer, with dynamic work with large muscle groups, one might expect the HR–$\dot{V}O_2$ line to be a good estimate of energy expenditure.[1,39] Balsom et al.[40] suggested that HR increases disproportionately to the $\dot{V}O_2$ after sprinting activities. This accounts only for a minor overestimation of the $\dot{V}O_2$ in soccer, since sprinting accounts for about 1% of the total game time. Bangsbo[1] showed that HR–$\dot{V}O_2$ line is valid, in intermittent exercise, by comparing intermittent exercise and continuous exercise in a laboratory test on a treadmill. The same HR–$\dot{V}O_2$ relationship was found over a large range of intensities[1] and is supported by recent data.[39,41]

If we assume that the HR–$\dot{V}O_2$ line may be used for an accurate estimation of $\dot{V}O_2$ in soccer, an average exercise intensity of 85% of HR_{max} will correspond to about 75% of $\dot{V}O_{2max}$.[38] This corresponds to an average $\dot{V}O_2$ of 45.0, 48.8 and 52.5 mL/kg/min for a player with 60, 65 and 70 mL/kg/min in $\dot{V}O_{2max}$, respectively, and probably reflects the energy expenditure in modern soccer. For a player weighing 75kg this corresponds to 1519, 1645 and 1772 kcal expended during a game (1L oxygen/min corresponds to 5 kcal) assuming the following values of 60, 65 and 70 mL/kg/min in $\dot{V}O_{2max}$, respectively.

In a previous study, we found a difference of about 5 mL/kg/min in running economy between seniors and cadets during treadmill running at 9 km/hour (unpublished data). Running economy is referred to as the ratio between work intensity and $\dot{V}O_2$.[42] At a given work intensity, $\dot{V}O_2$ may vary considerably between subjects with similar $\dot{V}O_{2max}$. This is also evident in highly trained subjects.[43] In elite endurance athletes with a relatively narrow range in $\dot{V}O_{2max}$, running economy has been found to differ as much as 20%[44] and correlate with performance.[43] The causes of inter-individual variations in gross oxygen cost of activity at a standard work-intensity are not well understood, but it seems likely that anatomical trait, mechanical skill, neuromuscular skill and storage of elastic energy are important.[45] In practical terms, 5 mL/kg/min lower $\dot{V}O_2$ at the same exercise intensity means that the senior players exercised with approximately 10 beats/min less relative to individual HR_{max} compared with cadets. Alternatively, seniors could exercise at the same relative HR but at a higher absolute exercise intensity. The senior players reached the same relative HR (in percentage of HR_{max}) as cadets when exercising at approximately 10 km/hour. Thus, a change in exercise intensity of 1 km/hour lead to a change in metabolism of about 5 mL/kg/min and increased the HR by approximately 10 beats/min to cope with the increased energy/oxygen

Table III. Activity profile distances covered in different intensities in male soccer players

Study	Level/country	Position	n	Distance covered (m) according to mode of movement (numbers/text in parentheses indicate speed)				
				walk	jog	stride/cruise	sprint	back
Bangsbo et al.[7]	Division 1 and 2/Denmark		14	3600[a]	5200[b]	2100	300	
Castagna et al.[47]	Young/Italy		11	1144[a]	3200	986	468	114
Knowles and Brooke[14]	Professional/England		40	1703	2610		520	
Mohr et al.[4]	Division 1/Denmark		24			1900	410	
	Top team/Italy		18			2430	650	
	Combining both teams	FB	9			2460	640	
		CD	11			1690	440	
		M	13			2230	440	
		A	9			2280	690	
Ohashi et al.[15]	League/Japan		4	7709 (0–4 m/sec)		2035 (4–6 m/sec)	589 (6–10 m/sec)	
Reilly and Thomas[9]	Division 1/England	FB	8	2292	2902	1583	783	668
		CB	7	1777	2910	1598	830	651
		M	11	2029	4040	2159	1059	510
		A	14	2309	2771	1755	1066	495
Rienzi et al.[8]	International/SA		17	3251[a]	4119[b]	923	345	
	EPL/England		6	3068[a]	6111[b]	887	268	
	International/EPL	D	9	3256[a]	4507[b]	701	231	
		M	10	3023[a]	5511[b]	1110	316	
		A	4	3533[a]	2746[b]	900	557	
Saltin[16]	Non-elite/Sweden		5	2340	5880		2880	
Thatcher and Batterham[18]	EPL first team/England	D	4				253	
	EPL first team/England	M	4				387	
	EPL first team/England	A	4				306	
	EPL U-19/England	D	4	2572	3956		360	1114[c]
	EPL U-19/England	M	4	2442	5243		247	1301[c]
	EPL U-19/England	A	4	2961	4993		222	803[c]
Van Gool et al.[6]	University players/Belgium	D	2	4449 (low)	4859 (medium)		595 (high)	
		M	3	4182 (low)	5704 (medium)		823 (high)	
		A	2	4621 (low)	4333 (medium)		867 (high)	
Wade[20]	Professional/England			1372–3652		229–1829[d]		
Whitehead[2]	Division 1/England	M	1	2150	4604	2281	1894	
		D	1	2593	3545	2753	2593	
	Division 2/England	M	1	4910	4183	1096	1007	
		D	1	4190	2966	2079	1591	

Continued next page

Table III. Contd

Study	Level/country	Position	n	Distance covered (m) according to mode of movement (numbers/text in parentheses indicate speed)				
				walk	jog	stride/cruise	sprint	back
	Top amateur/England	M	1	3824	3397	945	908	
		D	1	4104	2575	1820	1181	
	College/England	M	1	3563	2968	1348	875	
		D	1	3133	1870	1071	529	
Winterbottom[21]	Professional/England			2347		1015[d]		
Withers et al.[5]	National league/Australia	FB	5	2839	5391	1737	946	1066
		CB	5	3081	3854	1271	397	1556
		M	5	2670	6085	1841	646	951
		A	5	3506	5224	1177	682	1188

a Including backwards walking.

b Including sideways and backwards jogging.

c Including sideways jogging.

d Speed running.

A = attacker; **CB** = central-back; **CD** = central defender; **D** = defender; **EPL** = English Premier League; **FB** = full-back; **M** = midfield player; **SA** = South America; **U** = under.

demand. Translating the differences in running speed between seniors and cadets into differences in distance covered during a 90-minute game, yield a difference of about 1500m per player. Although this is a theoretical consideration, Hoff and Helgerud[46] estimated that a 5% improvement in running economy could increase match distance by approximately 1000m.

As can be seen from table III there is a large variation in distances covered at different intensities. There are also notable differences between leagues and playing divisions in different countries. This may partly be explained by vague definitions of the intensities described in some studies. To avoid this, game intensity should be expressed as a percentage of HR_{max} as well as by describing the number and duration of sprints performed and number of involvements with the ball per game, which should be reasonably easy to define regardless of the players' level. To test each player's HR_{max}, we recommend uphill running either on a treadmill or outdoor. The players should perform a thorough warm-up for about 20 minutes before running two to three 4-minute runs close to maximum effort; in the last run they should run to exhaustion starting from the second minute of submaximal running. The highest HR recorded, by a HR monitor, should be used as the individual's HR_{max}. For us, this was achievable regardless of age (<12 years) and sex. We highly recommend measuring each player's HR_{max}, and don't use different available equations as we frequently experience players >35 years and <20 years with HR_{max} >220 and <180 beats/min, respectively. Using the traditional formula, 220 – age, will in most cases be very misleading.

Recently, Strøyer et al.[37] reported that HRs during soccer matches were higher in young elite soccer players than in non-elite counterparts of the same age (12 years). The average HR during games was similar in young elite players in early puberty (177 beats/min in the first half vs 174 in the second half) and end of puberty (178 vs 173 beats/min). Early-puberty elite players had higher $\dot{V}O_2$ related to body mass (m_b) [mL/kg/min] than non-elite players during both match halves. The elite players at the end of puberty showed higher absolute $\dot{V}O_2$ values during match play than young elite players, but identical relative aerobic loads. Finally, with respect to time–motion analysis, the main difference found was that the frequency of standing activity was significantly higher among the non-elite players compared with the elite players.[37]

There is a lack of studies addressing the issue of possible cultural and/or geographical differences in distance covered and time spent in different intensity zones, as most research published so far concerns European teams. In this context, Rienzi et al.[8] reported that English premier league players covered about 15km more as a team compared with South American international players. Whether this reflected differences in aerobic capacity or in playing style/tactics is not known. Measuring the exercise intensity and distance covered in several teams from different continents during a world cup in soccer, as well as assessing teams at similar levels from different leagues, could add important knowledge to the physiology of international soccer (table II).

1.2 Anaerobic Periods in Soccer

Although aerobic metabolism dominates the energy delivery during a soccer game, the most decisive actions are covered by means of anaerobic metabolism. To perform short sprints, jumps, tackles, and duel play, anaerobic energy release is determinant with regard to who is sprinting fastest or jumping highest. This is often crucial for the match outcome.[48]

Figure 1 summarises the lactate profile during the two halves in soccer games in elite and non-elite soccer players. It appears that the elite players tax

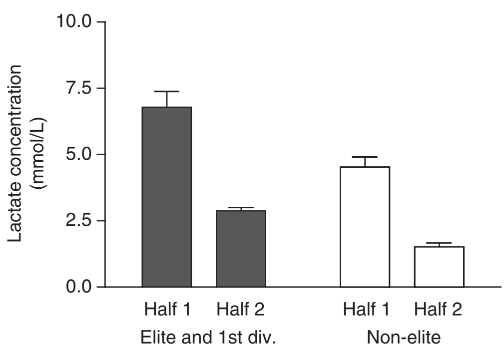

Fig. 1. Lactate concentration in elite and non-elite soccer players. The data are based on average values presented in table IV. **div.** = division.

the anaerobic system to a higher degree than non-elite players. It is important to note that the lactate concentration measured in soccer depends largely on the activity pattern of the player in the 5 minutes preceding blood sampling. Indeed, it has been shown that the lactate value was positively correlated to the amount of work performed just before the sampling.[1] All of the data presented in table IV show lower lactate concentrations in the second half compared with the first. These observations are in accordance with the reduced distance covered and lower intensity reported in most of the studies.[4-9]

The rate of lactate removal or clearance depends on lactate concentration, activity in the recovery period and aerobic capacity. The higher the lactate concentration, the higher the removal rate.[1] It is important to note that the players with higher $\dot{V}O_{2max}$ may have lower blood lactate concentrations because of an enhanced recovery from high-intensity intermittent exercise through: increased aerobic response; improved lactate removal; and enhanced phosphocreatine regeneration.[53] On the other hand, they may have similar blood lactate concentrations exercising at a higher absolute intensity compared with their less fit counterparts. Indeed, increased $\dot{V}O_{2max}$ results in lower blood and muscle lactate levels for the same absolute submaximal workload because of decreased production of lactate as a result of increased reliance on the aerobic energy system and increased lactate clearance.[53,54] An exercise intensity of about 70% of HR_{max} removes blood lactate most efficiently[38,55,56] (table IV).

2. Physiological Profile

2.1 Maximal Aerobic Capacity

2.1.1 Adult Male Soccer Players

The $\dot{V}O_{2max}$ in male out-field soccer players varies from about 50–75 mL/kg/min (155–205 mL/kg$^{0.75}$/min), whilst the goalkeepers have 50–55 mL/kg/min (155–160 mL/kg$^{0.75}$/min) [table IV]. It seems like aerobic capacity among high-performance teams has been elevated over the last decade,[57,58] compared with those reported in the 1980s.[3,59,60] Anaerobic threshold is reported to be between 76.6% and 90.3% of HR_{max}, which is in the

Table IV. Blood lactate in male and female soccer players (numbers in parentheses indicate range)

Study	Level/country (sex)	n	Lactate 1st half (mmol/L)		Lactate 2nd half (mmol/L)	
			during	end	during	end
Agnevik[12]	Division 1/Sweden (M)	10				10.0 (–15.5)
Bangsbo et al.[7]	Division 1 and 2/Denmark (M)	14	4.9 (2.1–10.3)		3.7 (1.8–5.2)	4.4 (2.1–6.9)
Bangsbo[1]	League/Denmark (M)		4.1 (2.9–6.0)	2.6 (2.0–3.6)	2.4 (1.6–3.9)	2.7 (1.6–4.6)
	League/Denmark (M)		6.6 (4.3–9.3)	3.9 (2.8–5.4)	4.0 (2.5–6.2)	3.9 (2.3–6.4)
Brewer and Davis[13]	Elite/Sweden (F)			5.1 ± 2.1		4.6 ± 2.1
Capranica et al.[49]	Young/Italy (M)	6		3.1–8.1 (during match)		
Ekblom[3]	Division 1/Sweden (M)			9.5 (6.9–14.3)		7.2 (4.5–10.8)
	Division 2/Sweden (M)			8.0 (5.1–11.5)		6.6 (3.1–11.0)
	Division 3/Sweden (M)			5.5 (3.0–12.6)		4.2 (3.2–8.0)
	Division 4/Sweden (M)			4.0 (1.9–6.3)		3.9 (1.0–8.5)
Gerish et al.[50]	Top amateurs/Germany (M)	59		5.6 ± 2.0[a]		4.7 ± 2.2[a]
	University/Germany (M)		6.8 ± 1.0	5.9 ± 2.0	5.1 ± 1.6	4.9 ± 1.7
Rohde and Esperson[51]	Division 1 and 2/Denmark (M)	22		5.1 ± 1.6		3.9 ± 1.6
Smaros[17]	Division 2/Finland (M)	7		4.9 ± 1.9		4.1 ± 1.3
Smith et al.[52]	College/England (M)	6		5.2 ± 1.2 (during match)		

a Median.

F = female; **M** = male.

range of HRs reported during matches (table II and table V).

2.1.2 Young Soccer Players

Traditionally, junior soccer players have lower $\dot{V}O_{2max}$ (<60 mL/kg/min) than seniors (table V); however, there are exceptions. Helgerud et al.[10] found a $\dot{V}O_{2max}$ of 64.3 mL/kg/min in juniors and the under-18 national team of Hungary had an average value of 73.9 mL/kg/min (212.7 mL/kg$^{0.75}$/min).[63] Strøyer et al.[37] observed higher $\dot{V}O_{2max}$ values for the midfielders/attackers than for the defenders (65 vs 58 mL/kg/min, respectively, for young elite soccer players at the end of puberty, i.e. 14 years of age).

Some studies report that young soccer players have similar $\dot{V}O_{2max}$, but lower running economy than adults when expressed in mL/kg/min.[84] Nevertheless, when expressed appropriately, i.e. in mL/kg$^{0.75}$/min the results are quite different. Chamari et al.[85] showed that under-15 players had similar $\dot{V}O_{2max}$, but lower running economy when expressed classically, compared with senior elite players. However, using appropriate scaling procedures showed that young soccer players had significantly lower $\dot{V}O_{2max}$, but similar running economy compared with their senior counterparts. Dimensional scaling of geometrically similar individuals suggests that $\dot{V}O_{2max}$, which is primarily limited by maximal cardiac output, should be proportional to m_b raised to the power of 0.67.[38] Empirical studies have shown that $\dot{V}O_2$, depending upon the group studied, should be expressed in relation to m_b (ideally lean m_b) raised to the power of 0.75–0.94, over a wide range of bodyweights.[42,86-89] Since senior players might be consistently heavier, compared with youth players, their $\dot{V}O_{2max}$ might be underestimated and energy cost of running overestimated using the traditional expression, mL/kg/min.

In line with Svedenhag,[90] expressing $\dot{V}O_2$ in direct relation to m_b (i.e. kg$^{1.0}$), or according to appropriate scaling procedures, may influence the evaluation and the design of an exercise regimen. Subjects A and B from a previous study (table VI) illustrate this point. Expressing $\dot{V}O_2$ traditionally as mL/lm_b/min (where lm_b = lean m_b in kg), subject A has a better running economy but a lower $\dot{V}O_{2max}$ than subject B. A natural conclusion from this may be to design an exercise training programme to improve the poorer functional capacity. However, using appropriate scaling procedures, the subjects have comparable values, or even an opposite result, to the initial analysis. Thus, appropriate scaling may certainly affect the evaluation and the resultant training programme in efforts to improve capacity.

What is often mixed up in the discussion of how to express $\dot{V}O_2$ in relation to m_b is the relationship between aerobic performance and aerobic capacity. As we know that aerobic capacity certainly influences the on-field performance,[10] it is reasonable to give this some priority when designing a training schedule for a season. From table VI it should be obvious that one needs some knowledge of appropriate scaling procedures when evaluating players' aerobic capacity (i.e. $\dot{V}O_{2max}$, running economy and anaerobic threshold) when designing an appropriate individual training programme. However, even though improving, for example, $\dot{V}O_{2max}$, which improves the player's ability to run longer, faster and be more involved in duels in each game, is not a guarantee as aerobic performance is influenced by a myriad of factors such as team tactics, opponents, energy intake. Thus aerobic performance *per se* should not be governed by the statistical adjustments of allometry, whilst aerobic capacity, which is an important basis for aerobic performance, should (table VI).

2.1.3 Female Soccer Players

Previous research suggests that both female and male players tax the aerobic and anaerobic energy systems to a similar level,[91] but female soccer players appear to run a shorter distance compared with male players.[92,93] Unfortunately, few studies have examined the physiological profile of female soccer players. There is a reported $\dot{V}O_{2max}$ of 38.6–57.6 mL/kg/min or 109.7–160.3 mL/kg$^{0.75}$/min (table VII). The Danish nationals, as a team, had 100 mL/kg/min higher $\dot{V}O_{2max}$ than the least fit team. The huge differences observed may have a connection with the level of women's soccer in general. Differences in physical resources, determined as strength and endurance parameters, between male and female elite soccer teams, are similar to their sedentary counterparts. This means that compared with sedentary counterparts within the

Table V. Physiological profile of male soccer players (±SD)

Study	Level/country	n	Position	Anthropometry[a]		$\dot{V}O_{2max}$[a,b]			AT
				height (cm)	weight (kg)	L/min	mL/kg/min	mL/kg$^{0.75}$/min	(% $\dot{V}O_{2max}$)[b]
Adhikari and Kumar Das[61]	National/India	2	G	180.1 ± 1.8	64.0 ± 3.0	3.60	56.3 ± 1.3	159.2	
		4	D	172.4 ± 2.9	65.1 ± 1.3	3.93	60.3 ± 5.0	171.3	
		5	M	173.2 ± 5.5	67.8 ± 5.4	3.91	57.7 ± 4.9	165.6	
		7	A	169.3 ± 2.3	60.1 ± 2.3	3.65	60.7 ± 4.9	169.0	
Al-Hazzaa et al.[62]	Elite/Saudia Arabia		CB	182.3 ± 6.1	82.1 ± 6.9	4.28 ± 0.66	52.3 ± 7.3	157.3 ± 21.8	
			FB	176.0 ± 3.9	72.4 ± 4.1	4.16 ± 0.19	57.7 ± 5.1	168.0 ± 12.8	
			M	174.7 ± 6.7	68.2 ± 4.4	4.13 ± 0.26	59.9 ± 0.93	172.2 ± 1.7	
			A	177.4 ± 5.8	72.7 ± 5.9	4.11 ± 0.29	56.9 ± 2.5	165.8 ± 5.4	
Apor[63]	Division 1–1st/Hungary						66.6		
	2nd						64.3		
	3rd						63.3		
	5th						58.1		
	National/Hungary	8			68.6 ± 8.7	5.07	73.9 ± 10.8	212.7	
Arnason et al.[27]	Division elite/Iceland	8[c]					63.2 ± 0.4		
	Division 1/Iceland	7[c]					61.9 ± 0.7		
	Division 1 elite/Iceland	15	G				57.3 ± 4.7		
	Division 1 elite/Iceland	87	D				62.8 ± 4.4		
	Division 1 elite/Iceland	76	M				63.0 ± 4.3		
	Division 1 elite/Iceland	47	A				62.9 ± 5.5		
Aziz et al.[64]	National/Singapore	23		175.0 ± 6.0	65.6 ± 6.1	3.82 ± 0.42	58.2 ± 3.7	165.7	
Bangsbo[65]	Elite/Denmark	5	G	190.0 ± 6.0	87.8 ± 8.0	4.48	51.0 ± 2.0	156.1	
		13	CB	189.0 ± 4.0	87.5 ± 2.5	4.90	56.0 ± 3.5	171.3	
		12	FB	179.0 ± 6.0	72.1 ± 10.0	4.43	61.5 ± 10.0	179.2	
		21	M	177.0 ± 6.0	74.0 ± 8.0	4.63	62.6 ± 4.0	183.6	
		14	A	178.0 ± 7.0	73.9 ± 3.1	4.43	60.0 ± 3.7	175.9	
Bunc and Psotta[66]	Elite/Czech	15		182.7 ± 5.5	78.7 ± 6.2	4.80 ± 0.41	61.0 ± 5.2	181.7	80.5 ± 2.5
	8 years/Czech	22		132.4 ± 4.3	28.2 ± 3.2	1.60 ± 0.14	56.7 ± 4.9	130.7	76.5 ± 1.3
Bunc et al.[67]	Elite/Czech	15		182.6 ± 5.5	78.7 ± 6.2	4.87	61.9 ± 4.1	184.4	80.5
Casajus[58]	Division 1/Spain	15		180.0 ± 8.0	78.5 ± 6.45	5.10 ± 0.40	65.5 ± 8.0	193.4	76.6
	Division 1/Spain	15		180.0 ± 8.0	78.5 ± 6.45	5.20 ± 0.76	66.4 ± 7.6	197.2	79.4
Chamari et al.[68]	U-19 elite Tunisia-Senegal	34		177.8 ± 6.7	70.5 ± 6.4	4.30 ± 0.40	61.1 ± 4.6	177.0 ± 13.0	90.1 ± 3.9
Chin et al.[69]	Elite/Hong Kong	24		173.4 ± 4.6	67.7 ± 5.0	4.00	59.1 ± 4.9	169.5	80.0

Continued next page

Table V. Contd

Study	Level/country	n	Position	Anthropometry[a]		$\dot{V}O_{2max}$[a,b]			AT
				height (cm)	weight (kg)	L/min	mL/kg/min	mL/kg$^{0.75}$/min	(% $\dot{V}O_{2max}$)[b]
Drust et al.[70]	University/England	7		178.0 ± 5.0	72.2 ± 5.0	4.17	57.8 ± 4.0	168.5	
Ekblom[3]	Top team/Sweden						~61.0		
Faina et al.[60]	Amateur/Italy	17		178.5 ± 5.9	72.1 ± 8.0	4.62	64.1 ± 7.2	186.8	
	Professional/Italy	27		177.2 ± 4.5	74.4 ± 5.8	4.38	58.9 ± 6.1	173.0	
	world class/Italy	1					63.2		
Helgerud et al.[10]	Juniors/Norway	9				4.25 ± 1.9	58.1 ± 4.5	169.9 ± 9.6	82.4
	After training period	9				4.59 ± 1.4	64.3 ± 3.9	188.3 ± 10.6	86.3
	Division 1/Norway	21		183.9 ± 5.4	78.4 ± 7.4	4.73 ± 0.48	60.5 ± 4.8	178.4 ± 14.8	
	After training period	21		183.9 ± 5.4	78.4 ± 7.4	5.21 ± 0.52	65.7 ± 5.22	192.9 ± 19.4	
Heller et al.[71]	League/Czech	12		183.0 ± 3.5	75.6 ± 3.4	4.54	60.1 ± 2.8	177.2	79.4
	After season	12				4.48	59.3 ± 3.1	174.9	81.1
Hoff et al.[72]	Division 2/Norway[d]	8				4.63 ± 0.51	60.3 ± 3.3	178.6 ± 13.3	85.5
Hollmann et al.[59]	Nationals-78/Germany	17					62.0 ± 4.5		
Impellizzeri et al.[73]	Young/Italy	19		178.5 ± 4.8	70.2 ± 4.7	4.03	57.4 ± 4.0	166.2	
Leatt et al.[74]	U-16 elite/Canada	8		171.1 ± 4.3	62.7 ± 2.8	3.68 ± 0.43	59.0 ± 3.2	165.2	
	U-18 elite	9		175.8 ± 4.4	69.1 ± 3.4	3.99 ± 0.59	57.7 ± 6.8	166.5	
MacMillan et al.[75]	Youth team/Scotland	11		177.0 ± 6.4	70.6 ± 8.1	4.45 ± 0.37	63.4 ± 5.6	183.3 ± 13.2	
	After training period	11			70.2 ± 8.2	4.87 ± 0.45	69.8 ± 6.6	201.5 ± 16.2	
Matkovic et al.[76]	Division 1/Croatia	44		179.1 ± 5.9	77.5 ± 7.19	4.12 ± 0.64	52.1 ± 10.7	157.7	
Nowacki et al.[77]	Division 3/Germany	10					69.2 ± 7.8		
Puga et al.[78]	Division 1/Portugal	2	G	186.0	84.4	4.45	52.7	159.7	
		3	CB	185.3	75.9	4.16	54.8	161.7	
		2	FB	175.0	67.5	4.19	62.1	178.0	
		8	M	176.8	74.0	4.58	61.9	181.6	
		6	A	174.6	71.1	4.31	60.6	176.0	
Rahkila and Luthanen[79]	Senior/Finland	31		180.4 ± 4.3	76.0 ± 7.6	4.20 ± 0.30	56.0 ± 3.0	163.2	83.9
	U-18 plus U-17/Finland	25		178.6 ± 6.3	71.3 ± 6.8	4.00 ± 0.50	56.0 ± 4.0	163.0	85.7
	U-16/Finland	21		177.1 ± 7.4	66.7 ± 6.8	3.80 ± 0.40	58.0 ± 5.0	162.8	84.5
	U-15/Finland	29		174.7 ± 5.1	62.5 ± 6.5	3.60 ± 0.40	57.0 ± 5.0	162.0	86.0
Rhodes et al.[80]	Olympic/Canada	16		177.3 ± 6.5	72.6 ± 6.2	4.20 ± 0.40	58.7 ± 4.1	168.9	
Strøyer et al.[37]	EbP/Danish	9		154.1 ± 8.2	42.5 ± 7.2	2.47 ± 0.28	58.6 ± 5.0	148.2	
	EeP/Danish	7		172.2 ± 6.1	57.5 ± 7.2	3.59 ± 0.44	63.7 ± 8.5	172.1	
Vanderford et al.[81]	U-14/US	20		163.9 ± 0.4	49.9 ± 0.4	2.64	52.9 ± 1.2	140.6	65.9 ± 1.4

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Table V. Contd

Study	Level/country	n	Position	Anthropometry[a]		$\dot{V}O_{2max}$[a,b]			AT
				height (cm)	weight (kg)	L/min	mL/kg/min	mL/kg$^{0.75}$/min	(% $\dot{V}O_{2max}$)[b]
	U-15/US	19		176.1 ± 0.3	62.8 ± 0.3	3.42	54.5 ± 1.3	153.3	63.5 ± 2.5
	U-16/US	20		177.1 ± 0.3	68.6 ± 0.4	3.86	56.2 ± 1.5	161.9	61.2 ± 1.3
Vanfraechem and Thomas[82]	Division 1/Belgium	18		181.0 ± 3.9	76.7 ± 6.4	4.30 ± 0.52	56.5 ± 7.0	165.9	90.3
Verstappen and Bovens[83]	Division 1/Holland	15			72.0 ± 3.7	4.90 ± 0.50	68.0 ± 5.0	198.2	
		15			77.7 ± 4.8	4.90 ± 0.60	63.0 ± 7.0	187.2	
Wisløff et al.[57]	Division 1/Norway (first)	14		181.1 ± 4.8	76.9 ± 6.3	5.20 ± 0.40	67.6 ± 4.0	200.2 ± 8.4	
	Division 1/Norway (last)	15		180.8 ± 4.9	76.8 ± 7.4	4.60 ± 0.50	59.9 ± 4.2	177.1 ± 13.5	

a Data presented without standard deviation are calculated from the average bodyweight measured in the respective studies.

b $\dot{V}O_{2max}$ and AT presented are from valid and reliable tests, not estimations.

c Number of teams.

d Including elite juniors.

A = attacker; **AT** = anaerobic threshold; **CB** = central-back; **Czech** = Czech Republic; **D** = defender; **EbP** = elite players beginning of puberty; **EeP** = elite players end of puberty; **FB** = full-back; **G** = goalkeeper; **M** = midfield player; **U** = under; $\dot{V}O_{2max}$ = maximal oxygen uptake.

same sex, the female elite soccer players have improved as much as the male elite soccer players. Therefore, there is no reason to claim that female soccer has shortcomings compared with elite male soccer in terms of strength and endurance.[91]

2.1.4 Aerobic Capacity During Season and Inter- and Intra-Country Comparison

Casajus[58] noted a higher $\dot{V}O_{2max}$ at the end of the season, while Helgerud et al. (unpublished observation) and Heller et al.[71] reported the opposite. In this context, the initial level of $\dot{V}O_{2max}$ at the beginning of the season, as well as the training schedule during the season, surely have an impact on the time course of $\dot{V}O_{2max}$ during the season (table VII).

The lower ranked national teams seem to have a lower $\dot{V}O_{2max}$ (e.g. India, Singapore and Saudi Arabia) than the best national teams (e.g. Germany). Apor[63] reported that the winning team in the Hungarian elite league had higher average $\dot{V}O_{2max}$ than the teams at the second, third and fifth places. Wisløff et al.[57] showed that the winning team in the Norwegian elite league had superior aerobic capacity compared with the team that finished last. While some authorities claim $\dot{V}O_{2max}$ is not a truly sensitive measure of performance capability in soccer, it is positively related to work rate in a game.[10] Reilly et al.[101] previously suggested that the consistent observation of $\dot{V}O_{2max}$ >60 mL/kg/min in elite teams implied a threshold below which an individual player is unlikely to possess the physiological attributes for success in elite soccer. Furthermore, they also highlight the need for reference value to be adjusted upwards as training programmes in the elite game are optimised. Considering all advantages of a high level of $\dot{V}O_{2max}$ in soccer, it would be reasonable to expect about 70 mL/kg/min for a 75kg professional male soccer player, or about 200 mL/kg$^{0.75}$/min ‘independent’ of m_b.

2.1.5 Strength Capacity

As no standardised protocol for testing strength of soccer players exists, it is difficult to compare results among different studies. Results from previous studies are summarised in table VIII. In our view, the commonly used isokinetic tests do not reflect the movement of the limbs involved during soccer, as no natural muscle movement is isokinetic.

Table VI. Maximal oxygen uptake ($\dot{V}O_{2max}$) and running economy in two subjects differing in bodyweight (reproduced from Chamari et al.,[85] with permission)[a]

	Subject A (80kg)	Subject B (50kg)
Running economy,[b] **$\dot{V}O_{2submax}$**		
mL/lm_b/min	34.5	39.0
mL/$lm_b^{0.60}$/min	199	186
$\dot{V}O_{2max}$		
mL/lm_b/min	55	60
mL/$lm_b^{0.72}$/min	188	179

a Variables measured in a $\dot{V}O_{2max}$ treadmill test (treadmill slope: 5.5%).

b Running economy measured at the end of 4 min at 7 km/h.

lm_b = lean body mass; **$\dot{V}O_{2submax}$** = submaximal oxygen uptake.

Tests employing free barbells will reflect the functional strength of the soccer player more accurately.[57] Furthermore, free barbells are readily available to most teams and provide more teams the potential to develop a meaningful functional testing programme in conjunction with strength training. In strength-training studies, it has been observed that measured increases in strength are dependent on the similarities between training and testing exercise. This specificity in movement patterns in strength training probably reflects the role of learning and coordination.[102,103] The neuromuscular system also reacts sensitively, in terms of adaptation to slow or fast contraction stimuli.[25,104] Increased peak torque has been observed at, or near, the velocity of training[105,106] and at speeds below training velocity.[107-109] Nevertheless, in sports-specific training for high-velocity movements, a combination of maximum strength training in a basic nonspecific movement with emphasis on high velocity and high mobilisation of power, and training the fast movement in the same period of time, gave a substantially higher increase in movement velocity[102,110] than training the fast movement itself, even with supramaximal velocities.[111] These findings question some of the fundamentals of trying to establish both movement and velocity specificity as basics for strength development. Considering maximal strength from testing of other explosive events, it would be reasonable to expect, for a 75kg male soccer player, squat-values >200kg (90º in the knee joint) or about 11.0 kg/$m_b^{0.67}$.[26,57] The expected values for bench press would be 100kg or about 5.5 kg/$m_b^{0.67}$.[57] It would be reasonable to expect that the elite soccer player has vertical jump height values close to 60cm.[26,57] A higher level of all strength parameters would be preferable and would reduce the risk of injuries and allow for more powerful jumps, kicks, tackles and sprints, among other factors (table VIII).[28]

There exists little data for strength capacity in female soccer players. However, Helgerud et al.[91] compared one of the best female teams in the world (Trondheimsørn, Trondheim, Norway) with Rosenborg Football Club, Trondheim, Norway. To perform such comparisons, dimensional scaling must

Table VII. Physiological profile of female soccer players

Study	Level/country	n	Anthropometry (±SD)		$\dot{V}O_{2max}$ (±SD)		
			height (cm)	weight (kg)	L/min	mL/kg/min	mL/kg$^{0.75}$/min
Davis and Brewer[94]	National/England	14	166.0 ± 6.1	60.8 ± 5.2		48.4 ± 4.7	135.2
	After training period	14	166.0 ± 6.5	59.6 ± 5.2		52.2 ± 5.1[a]	145.0
Evangelista et al.[95]	Division 1/Italy	12				49.75 ± 8.3	138.5[b]
Helgerud et al.[91]	Elite/Norway	12	169.7 ± 7.1	62.5 ± 7.4	3.36 ± 0.37	54.0 ± 3.54	151.5 ± 9.3
Jensen and Larsson[96]	National/Denmark	10	169.0	63.2		53.3	150.3
	After training period	10				57.6	162.4
Polman et al.[97]	Elite/England	36	164.0	65.2		38.6[a]	109.7
	After training period	36	164.0	62.7		45.7[a]	128.6
Rhodes and Mosher[98]	University/Canada	12	164.8	59.5		47.1 ± 6.4	130.8
Tamer et al.[99]	Division 1/Turkey	22				43.15 ± 4.06[a]	120.1[b]
Tumilty and Darby[100]	National/Australia	20	164.0 ± 6.1	58.5 ± 5.7		48.5 ± 4.8[a]	134.1

a $\dot{V}O_{2max}$ is estimated.

b $\dot{V}O_{2max}$ calculated by using a bodyweight of 60kg, data presented without standard deviation is calculated from the average bodyweight measured in the respective studies.

$\dot{V}O_{2max}$ = maximal oxygen uptake.

Table VIII. Strength, power and jumping ability in male and female soccer players

Study	Level/country (sex)	n	Position	Absolute (N/m) peak isokinetic concentric knee extension torque at different velocities (rad/sec) ± SD					Half-squat		Jumping height (cm)	
				0.52	2.09	3.14	4.19	5.24	kg	kg/$m_b^{-0.67}$	CMJ	SJ
Adhikari et al.[61]	Nationals/India (M)	2	G								61.0[a]	
		4	D								54.0[a]	
		5	MF								57.2[a]	
		7	A								55.3[a]	
Arnason et al.[27]	Division elite/Iceland (M)	8[b]									39.4	37.8
	Division 1/Iceland (M)	7[b]									38.8	37.0
	Division elite-division 1/Iceland (M)	16	G								38.0	35.8
	Division elite-division 1/Iceland (M)	79	D								39.3	37.7
	Division elite-division 1/Iceland (M)	70	MF								39.3	37.6
	Division elite-division 1/Iceland (M)	49	A								39.4	37.8
Bangsbo[65]	Elite/Denmark (M)	5	G	260 ± 23		162 ± 9						
		13	CB	275 ± 20		165 ± 9						
		12	FB	268 ± 18		131 ± 6						
		21	MF	225 ± 6		134 ± 3						
		14	A	277 ± 22		161 ± 12						
Casajus et al.[58]	Division 1/Spain (M)	15									47.8[a]	39.0
	Mid-season	15									46.7[a]	39.2
Davis et al.[112]	Division 1 and 2/England (M)	13	G		239 ± 46							
		24	CB		243 ± 31							
		22	FB		219 ± 31							
		35	MF		211 ± 30							
		41	A		222 ± 26							
Diallo et al.[113]	12–13 years/France (M)	10									29.2	27.3
	After training period (M)	10									32.6	29.3
Ekblom[3]	Top team/Sweden (M)										59.0[a]	
Faina et al.[60]	Amateurs/Italy (M)	17									36.9[c]	34.2
	Professional/Italy (M)	27									43.5[c]	40.4

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Table VIII. Contd

Study	Level/country (sex)	n	Position	Absolute (N/m) peak isokinetic concentric knee extension torque at different velocities (rad/sec) ± SD					Half-squat		Jumping height (cm)	
				0.52	2.09	3.14	4.19	5.24	kg	kg/$m_b^{-0.67}$	CMJ	SJ
	World class/Italy (M)	1									48.0[c]	35.0
Garganta et al.[114]	Elite-young/Portugal (M)	23									34.7[c]	33.3
	Non-elite young (M)										31.6[c]	30.3
Gorostiaga et al.[115]	Young players/Spain (M)	21									37.0	
Helgerud et al. (unpublished observation)	Division 1/Norway (M)	21							115.7	6.3	57.2[a]	
	After training period (M)	21							176.4	9.4	60.2[a]	
	Division 1/Norway (F)	12							112.5	7.1	42.9	
Hoff and Helgerud[72]	Division 2/Norway	8							161.3	8.8	44.1[c]	38.6
	After training period	8							215.6	11.8	46.8[c]	39.8
Leatt et al.[74]	U-16,U-18/Canada	17		165		97	85	71			53.0[a]	
MacMillan et al.[75]	Youth team/Scotland (M)	11							129.1	7.49	53.4	40.3
Mathur and Igbokwe[116]	Top players/Nigeria	18									48.7[a]	
Polman et al.[97]	Elite/England (F)	36									39.3[a]	
	After training period (F)	36									44.8[a]	
Rahnama et al.[117]	Amateur premier/UK (M)	13			182 ± 34			129 ± 27				
	Amateur post-exercise/UK (M)	13			167 ± 35			118 ± 24				
Rhodes et al.[80]	Olympic/Canada (M)	16		246								
Siegler et al.[118]	High school teams/US (F)	17									37.7[d]	
	After training period	17									39.4[d]	
Tiryaki et al.[119]	Division 1/Turkey (M)	16									64.8[d]	
	Division 2/Turkey (M)	16									54.1[d]	
	Division 3/Turkey (M)	16									57.0[d]	
Togari et al.[120]	Nationals/Japan (M)	20			202 ± 37	157 ± 24	123 ± 17	101 ± 17				
	League players (M)	86			203 ± 34	162 ± 22	133 ± 21	102 ± 17				
	University national (M)	40			171 ± 26	149 ± 24	107 ± 21	95 ± 14				
	Youth national (M)	35			181 ± 42	146 ± 22	116 ± 24	97 ± 16				

Continued next page

Table VIII. Contd

Study	Level/country (sex)	n	Position	Absolute (N/m) peak isokinetic concentric knee extension torque at different velocities (rad/sec) ± SD					Half-squat		Jumping height (cm)	
				0.52	2.09	3.14	4.19	5.24	kg	$kg/m_b^{-0.67}$	CMJ	SJ
White et al.[121]	Division 1/England (M)	17									59.8[a]	
Wisløff et al.[26]	Division 1/Norway (M)	17							171.7	9.4	56.4[a]	
	Division 1/Norway (M)	14							164.6	9.0	56.7[a]	
	Division 1/Norway (M)	15							135.0	7.3	53.1[a]	

a With arms.

b Number of teams.

c No information whether arms were used or not.

d Sergeant test.

A = attacker; **CB** = central back; **CMJ** = counter movement jump; **D** = defender; **F** = female; **FB** = full-back; **G** = goalkeeper; **M** = male; **MF** = midfielder; $\mathbf{m_b}$ = body mass; **SJ** = squat jump; **U** = under.

be considered when evaluating strength measures.[57] In two geometrically similar and quantitatively identical individuals, one may expect all linear dimensions (L) to be proportional. The length of the arms, the legs, and the individual muscles will have a ratio L **:** 1, the cross-sectional area L^2 **:** 1 and the volume ratio L^3 **:** 1. Since muscular strength is related to muscle cross-sectional area, and m_b varies directly with body volume, whole body muscular strength measures will vary in proportion to $m_b^{0.67}$. In practical terms this means that strength training goals should not be given in relation to m_b. A training goal of 0.8 times bodyweight for bench press or 1.5 times bodyweight for half-squats is easy for a light individual, but very difficult for a big person. Relative strength should thus be compared between individuals in terms of $kg/m_b^{0.67}$.[38] Absolute strength is important when attempting to move an external object such as the ball or an opponent. Strength relative to m_b is the important factor when carrying bodyweight, especially for acceleration and deceleration in the soccer play. Relative strength comparisons are not functionally representative when values are divided by m_b. If maximum strength is divided by m_b for comparative purposes, the heavier individual's capacity will be underestimated and not representative of on-field work capacity. This information is important for coaches, and especially for evaluating physical fitness or work capacity in younger soccer players in different periods of growth where bodyweight and size differ significantly at the same age, as well as when comparing physical capacities of male and female soccer players.

Helgerud et al.[91] reported that Trondheimsørn lifted 112.5 ± 20.7kg in squats (corresponding to 1.8 ± 0.3 kg/m_b and 7.1 ± 1.3 $kg/m_b^{0.67}$) and 43.8 ± 5.1kg in bench press (corresponding to 0.7 ± 0.1 kg/m_b and 2.7 ± 0.3 $kg/m_b^{0.67}$). Furthermore, they had 42.9 ± 3.3cm in vertical jump height. In the study of Helgerud et al.,[91] the female maximal strength in squats was 68% of the result for the male team, in absolute terms. Corrected for size, the capacity to move oneself in jumps and sprints, i.e. the relative strength for the female players was 79% of the male players, which shows that a big part of strength differences is really size difference. Female vertical jumping height was 76% of the male results, which is in the lower part of differences reported. For bench press, the female players lifted 53% of the male performance, also indicating that part of the performance difference is a size difference. Corrected for size, the female relative bench-press values were 59% of the male values. Both results are in the range of what is normally reported as sex differences.[38] Part of the differences may also indeed be a result of differences in priority of strength training and type of strength training performed. New studies performing similar strength training in male and female soccer players will give new insight into sex differences in strength and power capacity in soccer.

3. Soccer Referees

A soccer match is controlled by a referee who has full authority to enforce the laws of the game and is free to move throughout the field using the most appropriate directional exercise modes in order to gain optimal positioning. The referee is assisted by two assistant referees, each moving on the touchline in one of the two halves of the field. Although, from the physiological point-of-view, the physical stress imposed on the elite soccer referee could resemble that found in soccer players playing in the midfield,[1,122] several aspects of a referees performance distinguishes him/her from that of a player's performance; for example, officials are not involved with the ball and cannot be substituted during the match. Furthermore, compared with the soccer players that they normally officiate, referees have only recently (and in limited numbers) become full-time professionals.

Another relevant aspect of soccer refereeing is the existing age difference between soccer players and soccer referees. For example, Bangsbo[1] reported that the average age of players competing in the highest Danish league during the 1991/92 season was 24 years. In contrast, the average age of referees currently officiating at elite level in European countries ranges from 38 to 40 years.[122-125] The difference in the average age of players and referees may exist because experience is considered, among the international refereeing governing bodies, as a fundamental prerequisite to officiate at the elite level.[126] Paradoxically, an elite soccer referee reaches his or her best performance level at an average age when most soccer players have retired from competition.[1] Usually elite-level soccer referees reach their 'gold-age' career level over 40 years of age.[124] Demonstration of that comes from the recent 2002 FIFA World Cup Finals in which the average age of the super elite-level soccer referees that officiated competitions from the quarter-finals, was 41 ± 4 years (n = 8).[127]

3.1 Physiological Aspects of Refereeing

3.1.1 Match Activity

Match-analysis studies reported that, during a competitive match, a referee can cover a mean distance of 11.5km, with ranges from 9 to 14km.[122,123,128,129] Of this distance, 16–17% is performed at high intensity or at speeds >15–18 km/hour.[122,123] Standing is reported to account for 14–22% of match duration.[122,123] Distances performed sprinting have been shown to range from 0.5% to 12% of total match distance covered by an elite-level soccer referee during actual match play.[122,123,128,129] Analysis of between-halves distance coverage is of great interest as it can reveal the occurrence of fatigue and/or refereeing strategies.[122] With respect to this interesting aspect of soccer refereeing performance, there exist conflicting results in the available literature.

D'Ottavio and Castagna[122] reported a significant 4% decrease in total distance across halves in Serie A (Italy) soccer referees. In contrast, Krustrup and Bangsbo[123] found no significant difference in total coverage between halves in Danish top-level referees. However, total distance should be considered as only a gross measure of match activity.[130] In this regard, analysis of those activities performed at high intensity during the match may reveal more relevant information in the attempt to assess the likelihood of possible fatiguing processes during the game. High-intensity performance analysis revealed the occurrence of a sort of 'sparing behaviour'[122] in referees who officiated at high competitive level (Italian Serie A championship). In fact, in the study by D'Ottavio and Castagna,[122] no between-half differences in high-intensity coverage were detected despite a significant decrease of total distance. This sort of 'sparing behaviour' has been confirmed in longitudinal studies in the same population of elite-level soccer referees.[131] In contrast, Krustrup and

Bangsbo[123] reported a second-half decrement in high-intensity activity, but no between-halves difference in total distance. These findings seem to show that referees officiating at elite level may use different refereeing strategies in order to conserve energy during the game. From a refereeing strategy point of view, it would be advisable to have referees with a well developed ability to perform at high intensity throughout the match. This ability is particularly important for soccer referees as it has been demonstrated that the most crucial outcome-related activities may be revealed at the end of each half,[130] where the likelihood of mental and physiological fatigue is higher. Similar to what was reported for elite-level soccer players,[1] elite-level soccer referees have been reported to change their motor behaviour every 4 seconds, performing approximately 1270[123] activity changes by the end of an average match. Recently, Helsen and Bultynck[124] found that international-level soccer referees, in the attempt to regulate the behaviour of players, undertake 137 (104–162) observable decisions per match. These results clearly show that elite-level soccer refereeing constitutes a demanding physical and cognitive task.

3.1.2 Heart Rate

Monitoring the HR of a referee compared with a soccer player is much more convenient as referees are not involved in physical contacts. The available scientific literature shows that soccer referees usually attain mean HRs between 85–95% of the estimated, or individual, HR_{max}.[123-125,128,129,132] Similar values in both halves have been reported in Italian and Danish elite-level referees.[123,132] In contrast, Weston and Brewer[125] found lower HRs during the second half in English premier league referees.

Direct metabolic assessment performed during friendly matches, has shown that referees officiate, on average, at 68% of their $\dot{V}O_{2max}$.[133] Using the HR–$\dot{V}O_2$ relationship Krustrup and Bangsbo[123] and Weston and Brewer[125] estimated an 81% $\dot{V}O_{2max}$ involvement during competitive games. In this regard, Weston and Brewer[125] estimated higher percentages of $\dot{V}O_{2max}$ during the first half compared with the second half (81.2 ± 5.6 vs 79.7 ± 6.1, $p < 0.05$).

3.1.3 Blood Lactate

Post-halves blood lactate concentration has been reported to be approximately 5 mmol/L with no significant differences across halves.[123] Blood lactate concentration analyses performed using during-competition blood sampling revealed blood lactate concentrations as high as 7 mmol/L.[133]

Similarly to what was reported in soccer players, these results support the notion that soccer referees experience substantial anaerobic exercise periods during the match. Further support to this observation comes from the analysis of the post-first-half and post-second-half blood lactate concentration ranges found in elite-level soccer referees during competitive matches. In fact, it has been reported[123] in Danish elite-level soccer referees, high inter-individual variation in blood lactate concentrations that ranged from 2–9.8 and 2.3–14.0 for the first- and the second-half, respectively. Those findings revealed that, as with soccer players, actual match-play blood sampling may have had a profound effect on blood lactate concentration results.[123,133] No difference in blood lactate concentration has been observed in referees of different competitive levels.[123] However, comparisons among competitive levels were performed using post-half sampling and this may have affected the actual differences in match activities that are usually observed in games at different competitive levels.

3.1.4 Physical Fitness and Match Performance

Although considered a crucial component of the physical match performance,[134,135] soccer referees do not seem to have high levels of aerobic fitness as far as $\dot{V}O_{2max}$ levels are concerned. The few papers that have addressed this issue reported $\dot{V}O_{2max}$ levels ranging from 40 to 56 mL/kg/min, with group averages around 46–51 mL/kg/min.[123,125,135] Lactate thresholds considered as speed attained at fixed blood lactate concentrations have been shown to be 10 and 13 km/hour at 2 and 4 mmol/L, respectively.[136] Similar results have been reported by Krustrup and Bangsbo[123] in top level Danish soccer referees during treadmill running. Similar to soccer players,[137,138] $\dot{V}O_{2max}$ has been reported to positively affect match physical performance in soccer referees.[136] Specifically, $\dot{V}O_{2max}$ has been shown to promote global space coverage and high-intensity running.[123,136]

Recent studies have revealed that field tests may be used to predict soccer referees physical match performance.[123,135] Castagna and D'Ottavio[135] showed that in elite-level Italian soccer, referee performance over a 12-minute run for distance[126] is related to match total distance and distance performed at high intensity (speed >18 km/hour). In Danish elite-level referees, high-intensity running (speed >15 km/hour) revealed to be related to Yo-Yo intermittent recovery test performance (distance covered).[123] These findings have a great impact on fitness assessments of soccer referees as these tests allow easy and low-cost mass testing.

3.1.5 Training Experiments in Soccer Referees

Soccer referees differ from soccer players in that they do not have to possess high levels of motor abilities in order to officiate; thus most of the training time can be devoted to the development of capacities that are important to endurance and speed[126] improvement. Researchers have reported the importance of space coverage for better positioning[139] in soccer refereeing. Additional evidence is available regarding the positive effect of soccer referees' aerobic fitness on match coverage.[123,134-136] As a logical consequence of this, aerobic training should be the main choice in soccer referee training. Training studies conducted on elite-level soccer referees have confirmed the effectiveness of structured and period-interval running for specific fitness.[123,140] Specifically, Krustrup and Bangsbo[123] showed significant improvement in Yo-Yo intermittent recovery test performance (31 ± 7%, $p < 0.05$) implementing 3–4 weekly training sessions during which referees completed long (4 × 4 or 8 × 2 minutes) or short (16 × 1 minutes or 24 × 30 seconds) running intervals. As exercise intensified, Krustrup and Bangsbo[123] used HRs >90% of soccer referees' individual HR_{max} during all interval-training bouts. This differs from what was reported for junior soccer players that exercised at similar intensities;[10] no significant $\dot{V}O_{2max}$ improvements were reported in this group (n = 8) of 38-year-old soccer referees. Significant improvements occurred in the peripherica-dependent aerobic fitness domain, such as lowering of HR and blood lactate concentration at selected treadmill speeds (12–16 and 14 km/hour, respectively). As a consequence of the training intervention, a significant 23% improvement was detected over the distance covered at high intensity (speed >15 km/hour during actual match play).

Interestingly, distance from infringements was lessened as a consequence of the training intervention. Although no structured studies have been carried out in order to validate this assumption, being as close as possible to the infringement is commonly considered a prerequisite of proper judgment in soccer refereeing.[126]

It could be argued that the training protocol used by the Danish referees[123] was not sufficient to induce the proper training stimulus to improve $\dot{V}O_{2max}$; even if the pre-$\dot{V}O_{2max}$ was as low as 46.5 mL/kg/min. It could be speculated that elite referees, or older active subjects, may adopt higher training intensities and possibly attain higher HR range (90–95% of HR_{max}) proven by Helgerud et al.[10] as effective in improving $\dot{V}O_{2max}$. Again, the use of short intervals (such as 16 × 1 minute or 24 × 30 seconds with 2 : 1 exercise vs recovery ratio) and/or the period of the season (mid-season break) used for the training intervention may have accounted for the absence of $\dot{V}O_{2max}$ improvements. In our view, soccer referees should use the same training principles as soccer players (described in section 5.1) to improve their strength and endurance capacity.

4. Exercise Training

It is beyond the scope of the present article to give a thorough review of the existing literature regarding different types of training and their effects, as well as detailed training plans. These topics are excellently covered elsewhere.[46,141-143] However, we will give a few examples of effective strength and endurance training regimens not highlighted in previous reviews.

5. Endurance Training

5.1 Training for Increased Aerobic Capacity

It has, for a long time, been known that cardiac output limits $\dot{V}O_{2max}$ in well trained individuals.[144] Furthermore, it is now known that there is no plateau in stroke volume in well trained athletes[145,146] as previously reported in untrained subjects.[38] As cardiac output consists of maximal heart frequency, which is intrinsic and unchangeable, and stroke volume, endurance training to enhance $\dot{V}O_{2max}$ should be designed to improve the stroke volume. Interval training at an exercise intensity corresponding to 90–95% of HR_{max}, lasting 3–8 minutes, separated by 2–3 minutes of active recovery at about 70% of HR_{max}, is an extremely effective training for increased stroke volume and $\dot{V}O_{2max}$ (unpublished observation). Recently, Helgerud et al.[10] showed in elite junior players that interval training of 4 × 4 minutes at 90–95% of HR_{max} (it normally takes 1–2 minutes to reach the required exercise intensity and this period is part of the 4-minute interval), separated by 3 minutes active recovery at 60–70% of HR_{max} (for increased lactate removal) increased the $\dot{V}O_{2max}$ about 0.5% each training session. A similar training programme, in which each training session lasted 35 minutes, was performed in a Norwegian, elite soccer club twice a week, increasing $\dot{V}O_{2max}$ from ~60 to ~66 mL/kg/min in 8 weeks (unpublished observation).

In two recent studies (one unpublished),[10] the interval training was performed as uphill running. The reason for this is that it is difficult to reach the desired exercise intensity close to $\dot{V}O_{2max}$ (90–95% of HR_{max}) when running flat.[38] However, training, purely by running, may raise motivational problems in soccer players. Hoff et al.,[39] therefore, designed a soccer-specific track as well as small-group playing sessions for specific interval training. Ball dribbling, changes of direction and backward running on the soccer-specific track are supposed to substitute 'up-hill' when purely running. Similarly, Reilly[147] showed that running with the ball increased the energy cost by approximately 8% compared with purely running.

Hoff et al.[39] showed that interval playing in small-sided games induced a steady-state exercise intensity of 91% of HR_{max}, corresponding to about 85% of $\dot{V}O_{2max}$, in Norwegian first-division players. Furthermore, the corresponding values for running on the specially designed dribbling track were 94% and 92%, respectively. Thus, both methods were able to perform interval training. However, the players with $\dot{V}O_{2max}$ >60 mL/kg/min had problems reaching high enough intensities in the small-group play. Thus, it appears that in small-group play there is a ceiling of $\dot{V}O_2$ above which one should prefer to perform interval training either as pure up-hill running or by means of the soccer-specific track. However, it is not known whether this is true for elite soccer players as the highest value for $\dot{V}O_{2max}$ ever reported for an elite soccer team, 67.6 mL/kg/min, was achieved through pure playing sessions.[57] Whether endurance training should be organised as a playing session, dribbling track or as purely running, it must be considered by each team. Monitoring the training intensity during a playing session, with the assistance of an HR monitor, will be helpful in this regard.

A similar method to that described by Hoff et al.[39] was proposed by Platt et al.[148] suggesting that groups of five or less may be more effective in younger players. For example, it seems that three-a-side is preferable to five-a-side in terms of: direct involvement in play; high-intensity activity; more overall distance; less jogging and walking; higher HRs; and more tackling, dribbling, goal attempts and passes in young players.[148] As mentioned earlier in this section, the described interval training (4 × 4 minutes, 90–95% of HR_{max}, active pauses) improves the $\dot{V}O_{2max}$ by about 0.5% per training session. Unpublished data show that players with $\dot{V}O_{2max}$ >60 mL/kg/min require one interval training per week to maintain the $\dot{V}O_2$, whilst players with $\dot{V}O_{2max}$ >70 mL/kg/min require two interval trainings per week for maintenance. Thus, those players will increase their $\dot{V}O_{2max}$ by about 0.5% per session beyond the required number to maintain the aerobic capacity. Furthermore, the beauty of this type of training is that it is possible to improve the aerobic capacity of the team in a short period of time.

Recently, we (unpublished data) tested the usefulness of a 10-day '$\dot{V}O_2$ cure' for a Norwegian second division team using the following receipt: half of the players (n = 10) performed interval training (4 × 4 minutes, using the dribbling track as described earlier in this section immediately after the regular soccer training; whilst the other half of the players (n = 10) performed continuous dribbling at 70–75% of HR_{max} (corresponding to about 65% of $\dot{V}O_{2max}$) for the same period of time (total of 28 minutes each training). The team alternated between one and two soccer training/interval sessions every second day, except at day 7, when no training was performed. A total of 13 interval sessions were performed during the 10-day period. After the tenth day the players rested for a day, and performed regular soccer training for the next 4 days before retesting $\dot{V}O_{2max}$. The interval group increased their $\dot{V}O_{2max}$ by 7.3% (from 62 to 66.5 mL/kg/min, $p < 0.001$), whilst the other group increased from 62 to 63.1 mL/kg/min (not significant). This illustrates how it is possible, in a short period of time, to increase the aerobic capacity of the team, which obviously may have an impact upon the on-field performance.[10,101] We suggest that soccer teams with high ambitions should perform one or two short periods of '$\dot{V}O_2$ cures' in the preparation for the season (depending on the length of the preparation phase), and one in between the two halves of the season. In addition, the capacity should be maintained by one interval bout per week throughout the season. Furthermore, it seems like non-starters do not improve their capacity throughout the season.[149] Thus, it may be necessary to differentiate the training plan between the regular non-starters and starters during the soccer season.

There exists a myriad of other training regimens to improve aerobic capacity, but in our view these are not as effective as those described in section 5.1. Although there exists attractive methods that try to simulate a soccer game,[18] it is our experience that these are not as effective as the described interval training because the exercise intensity is not high enough to challenge the limitation of soccer players' $\dot{V}O_{2max}$ – the stroke volume. However, such training protocols may be valuable to simulate and study the physiology of a soccer game. Low-intensity training should, according to our view, not gain priority in the planning of aerobic capacity of soccer players as they will naturally perform such efforts during technical and tactical drills in normal soccer training.

Training for improved anaerobic thresholds involves continuous running for ≥30 minutes at an exercise intensity corresponding to 85–90% of HR_{max}.[150,151] As stated in section 1.1, the players are exercising either above the threshold (accumulating lactate) or below (for lactate removal). However, the best exercise training regimen to improve anaerobic threshold is to improve $\dot{V}O_{2max}$; then anaerobic threshold improves substantially[10] in absolute terms, but not in a percentage of $\dot{V}O_{2max}$ (unpublished observation).[152] Also, running economy has been shown to improve substantially by interval training[10,152] and by high-intensity strength training.[72,153,154]

6. Strength Training, Sprinting and Jumping Ability

During a game, professional soccer players perform about 50 turns, comprising sustained forceful contractions, to maintain balance and control of the ball against defensive pressure.[5] Hence, strength and power share importance with endurance at top-level soccer play. Power is, in turn, heavily dependent on maximal strength[23] with an increase in the latter, being connected with an improvement in relative strength and therefore with improvement in power abilities.[155]

Maximal strength is defined as the result of force-producing muscles performing maximally, either in isometric or dynamic pattern during a single voluntary effort of a defined task. Typically, maximal strength is expressed as 1RM in a standardised movement (and speed if performed using isokinetic equipment), for example the squat exercise. Power is the ability to produce as much force as possible in the shortest possible time. The muscle's ability to develop force is dependent on many different factors of which the most common factors are: initial position; speed of lengthening; speed of shortening; eccentric initial phase; types of muscle fibres; number of motor units active at the same time; cross-sectional area of the muscle; impulse frequency; and substrate available for the exercising muscles.[105]

Two different mechanisms – muscular hypertrophy and neural adaptations – are central in the development of muscular strength. It is impossible to generalise which type of training to choose and this must be judged by the coach and/or the individual player. However, in general, we advise coaches and/or soccer players to perform strength training for neural adaptation if the player already carries 'enough muscle mass' as this type of training gives advantages over just getting stronger (see section 6.1). In most cases, a combination of the two is the optimal solution starting with some weeks of training for hypertrophy before only giving priority to neural adaptation, regardless of playing position.

6.1 Muscular Hypertrophy

There is a connection between the cross-sectional area of the muscle and its potential for force development.[25] The hypertrophy occurs as an increase in the myofibril content of the fibres.[156] For many soccer players, increased bodyweight as a result of hypertrophy is not desirable because the player will have to transport a higher m_b. In addition, increased muscle mass does not necessarily increase the high-velocity strength.[157] However, for players whose goal is to increase muscle mass, this type of training is effective.

Typically, bodybuilder training includes a great volume of high-resistance, slow-velocity movement to promote the hypertrophic effect.[157] Several methods for developing muscular hypertrophy are reported.[104] Eight to twelve RM in series is often used. The execution of the exercises changes from slow to fast, and particularly the eccentric phase is slow.[25] The goal of such training sessions is to exhaust the trained muscle groups. If the coach thinks more muscle mass is necessary for some players we suggest performing this type of strength training in the preparation phase (1–3 sessions per week) and switch to strength training for neural adaptation close to and in the season as described in section 6.2.

6.2 Neural Adaptations

During recent years, the focus of strength training has turned to neural adaptations.[105] The term 'neural adaptations' is a broad description involving a number of factors such as: selective activation of motor units; synchronisation; selective activation of muscles; ballistic contractions; increased firing frequency of nerve impulses; increased reflex potential; increased recruitment of motor units; and increased co-contractions of agonists.[158] A notable part of the improvement in the ability of lifting weights is a result of an increased ability to coordinate other muscle groups involved in the movement, such as those which stabilise the body.[159] To develop maximal force, a muscle is dependent on as many active motor units as possible. In a maximal voluntary contraction the small oxidative fibres are recruited first[160] and the fastest glycolytic fibres are recruited last in the hierarchy. In the early stages of a training period, an increase in activity of fast glycolytic fibres is seen with an increase in strength.[103] The central nervous system recruits motor units by sending nerve impulses to the motor neuron. The increased firing frequency contributes to increased potential for force development.[103] An increased activation of the muscle may be a result of a lower threshold of recruitment and an increased firing frequency of the nerve impulses. These changes are possible explanations for increased strength. Both maximal strength and rate of force development are important factors in successful soccer performance because of the demands apparent from game play.[9] Both should therefore be systematically worked on within a weekly schedule using few repetitions with high loads and high velocity of contraction.[24,25,102,103]

Behm and Sale[105] suggest two major principles for maximal neural adaptation. To train the fastest motor units, which develop the highest force, one has to work against high loads (85–95% of 1RM) that guarantee maximal voluntary contraction. Maximal advantage would be gained if the movements were trained with a rapid action in addition to the high resistance. As a method to increase the rate of force development, upon neural adaptations, Schmidtbleicher[25] suggests dynamic movements with a few repetitions (3–7). The resistance should range from submaximal to maximal (85–100% of 1RM) with explosive movements. This may give raise to neuromuscular adaptation with minimal hypertrophy.[102] Because of high resistance, the movement speed will be slow, but the muscular contraction will be fast if mobilised during the concentric phase of the movement, attempting to lift the weight as fast as possible. Mobilisation in the concentric phase of contraction is very important for achieving the described training adaptations (table IX).

A significant relationship has been observed between 1RM and acceleration and movement velocity.[23] This maximal strength/power performance relationship is supported by results from both jump and 30m sprint tests.[25,155] Thus, increasing the available force of muscular contractions in appropriate muscles or muscle groups, acceleration and speed in skills critical to soccer such as turning, sprinting and changing pace may improve.[7]

Table IX. Sprinting performance in male and female soccer players

Study	Level/country (sex)	n	Sprinting performance (sec) [± SD]					
			5m	10m	15m	20m	30m	40m
Brewer and Davis[161]	Professional/England (M)	15			2.35 ± 0.07			5.51 ± 0.13
	Semi-professional/England (M)	12			2.70 ± 0.09			5.80 ± 0.17
Chamari et al.[68]	Junior/Tunisia-Senegal (M)	34		1.87 ± 0.10			4.38 ± 0.18	
Cometti et al.[162]	Division 1/France (M)	29		1.80 ± 0.06			4.22 ± 0.19	
	Division 2/France (M)	34		1.82 ± 0.06			4.25 ± 0.15	
	Amateur/France (M)	32		1.90 ± 0.08			4.30 ± 0.14	
Diallo et al.[113]	12–13 years/France (M)	10				5.56 ± 0.10		
	After reduced training (M)	10				5.71 ± 0.20		
Dupont et al.[163]	International level/France (M)	22						5.55 ± 0.15
	After training period	22						5.35 ± 0.13
Gorostiaga et al.[115]	Young players/Spain (M)	21	0.95		1.09			
Helgerud et al.[10]	Juniors/Norway (M)	9		1.88 ± 0.06				5.58 ± 0.16
	Division 1/Norway (M)	21		1.87 ± 0.06		3.13 ± 0.10		
	After training period (M)	21		1.81 ± 0.07		3.08 ± 0.09		
Hoff and Helgerud[72]	Division 2/Norway (M)[a]	8		1.91 ± 0.07				5.68 ± 0.21
	After training period (M)	8		1.81 ± 0.09				5.55 ± 0.16
Kollath and Quade[164]	Professional/Germany (M)	20	1.03 ± 0.08	1.79 ± 0.09		3.03 ± 0.11	4.19 ± 0.14	
	Amateur/Germany (M)	19	1.07 ± 0.07	1.88 ± 0.10		3.15 ± 0.12	4.33 ± 0.16	
Little and Williams[165]	Division 1 and 2/England (M)	106		1.83 ± 0.08				
MacMillan et al.[75]	Youth team/Scotland (M)	11		1.96 ± 0.06				
Mohr et al.[34]	Division 4/Denmark (M)	8					4.45 ± 0.04	
Siegler et al.[118]	High school teams/US (F)	17				3.00 ± 0.15		
Tumilty and Darby[100]	National/Australia (F)	20				3.31 ± 0.11		
Wisløff et al.[26]	Division 1/Norway (M)	17		1.82 ± 0.30		3.00 ± 0.30	4.00 ± 0.20	

a Including elite juniors.

F = female; **M** = male.

The results from a recent study[26] confirm that a strong correlation exists between maximal strength, sprinting and jumping performance in elite soccer players, thus supporting the findings from earlier work.[23-25] There were also strong correlations between maximal strength and the 30m sprint test, including the recorded times between 10–30m where the acceleration is substantially smaller than between 0–10m, and with the 10m shuttle run test where breaking velocity is part of the performance.

It should be noted that in one of the Rosenborg Football Club studies,[26] strength training was performed on an individual basis without any supervised regimen from the coach. However, all players did perform half-squats as part of their normal strength-training programme. Nine of the players who participated in that study received additional advice from our research group and consequently integrated a strength-training programme twice a week into their normal schedule. This involved using few repetitions with high loads and high velocity of contraction as described in section 6.2. These nine players had considerably higher values of 1RM compared with the other eight players. We have recently demonstrated the effectiveness of such a training programme, increasing 1RM in half-squats by approximately 35% (from 160 to 215kg). The programme consists of three series of five repetitions performed twice a week over a period of 8 weeks with the load being increased by 5kg each time the athlete successfully completes the work load.[72] The high-strength group had undergone a training regime with emphasis on maximal mobilisation of force, which normally results in high training effects on rate-of-force development and might mean that the correlation between maximal strength and all sprint and jump parameters are not necessarily a global finding. Helgerud et al. (unpublished observation) showed that maximal strength training for neural adaptation (8 weeks) significantly increased: half-squat 1RM from 115 to 175kg; 10m sprints improved by 0.06 seconds (corresponding to an improvement of approximately 0.5m compared with pretest or an opponent running 0.06 seconds slower in 10m); vertical jump height by 3cm; and running economy by about 5%. These data are particularly interesting considering a study by Arnason et al.[27] reporting a positive relationship between jumping height and team success, and concludes that more attention should be paid to jump and power training in the training plan of soccer teams.

6.3 Strength Training Effects on Endurance Performance

Few studies have examined the impact of strength training on endurance performance. Hickson et al.[166] reported a 27% increase in parallel squat 1RM after 10 weeks of maximal strength training using squats and three supplementary exercises. $\dot{V}O_{2max}$ was unchanged during the same period while short-term endurance (4–8 minutes), measured as time to exhaustion during treadmill running and on a bicycle ergometer, increased by 13% and 11%, respectively. Several well controlled studies suggest that power enhancement might improve work economy in the order of 5–15%,[72,153,154] and that increased rate-of-force production was the main explanatory variable for improved work economy.[154]

6.4 Sprinting and Jumping Abilities

Recent studies report that 96% of sprint bouts during a soccer game are shorter than 30m,[167] with 49% being shorter than 10m. The 30m sprint times reported by Wisløff et al.[26] are in line with earlier studies undertaken with elite soccer players.[10] However, the data also show that there were substantial time differences evident within the 30m test. For example, 10m lap times could give important information indicated by substantial differences within the 30m test, some of the players having similar 30m time but notably different 10m performances. The implication of this is that it is possible to differentiate the focus of sprint training individually based on split-time recordings (results summarised in table IX).

In this context, it must be emphasised that the 10m performance is a relevant test variable in modern soccer. Indeed, Cometti et al.[162] have shown that the actual French professional and amateur soccer players had similar 30m sprint performances, but that the professionals had significantly lower 10m lap times. Sprinting time from 1.79 to 1.90 seconds over 10m are reported in the literature. This means that the fastest players are on average 1m ahead of the slowest ones after only 10m of sprint. This could be crucial in the critical duels influencing the results of a game. The professional players are faster over 10 or 15m[161,162,164] than the amateurs. Some also report a faster sprint time over 30 or 40m in the professionals.[161,164] A recent study by Mohr et al.[34] showed that the sprint capacity was reduced in the start of the second half compared with the first. This was related to a lowering of the muscle temperature in the 15-minute break. The reduction in sprint capacity was avoided when performing a low-intensity re-warm up before the second half of the game. This information should at least be considered by elite teams participating in important international games, but also by teams at lower levels that want to optimise their sprinting performances in the first minutes of the second half of soccer games.

Jumping heights (with freely moving arms) from 47.8 to 60.1cm are average values reported in the literature for adult players (table VIII). Goalkeepers have the highest scores,[61,168] while the midfielders jump lower than the other field players.[57,61,168] It also seems that non-professionals score lower on vertical jump tests in some studies[27,60,119] but not all.[169]

7. Anaerobic Power

Anaerobic power is difficult to measure and not a focus in this review. Here we present only results from the Wingate test and Cunningham and Falkner run test (table X). Mean power in the Wingate test ranges from 637 to 841W. The goalkeepers have the highest anaerobic power, while the midfielders present lower values.[112] The same tendency occurs when measuring peak power. The literature reports run times from 62 to 92.5 seconds in juniors for Cunningham and Falkner run test. Leatt et al.[74] noted 10 seconds' longer run times for under-18 players, compared with under-16 players (table X).

8. Evaluation of Physical Performance

Tests are used to determine accurate values of $\dot{V}O_{2max}$, anaerobic threshold, work economy, maximal aerobic performance, strength and power, and anaerobic energy production, as well as talent identification.[101,169] For the anaerobic tests, the goal is

Table X. Anaerobic power in male soccer players

Study	Level/country	n	Position	Anthropometry (±SD)		Wingate (±SD)			AST
				height (cm)	weight (kg)	peak power (W)	mean power (W)	fatigue (% decrease)	(sec) [±SD]
Brewer and Davis[161]	Professional/England	15			75.0 ± 8.5	930	638		
	Semi-professional/England	12			82.7 ± 8.2	868	637		
Davis et al.[112]	Division 1-2/England	13	G		86.1 ± 5.5	1273	841	38.5 ± 3.2	
		24	CD		83.3 ± 6.3	1189	833	35.1 ± 7.8	
		22	FB		75.4 ± 4.6	1119	723	40.7 ± 8.0	
		35	M		73.2 ± 4.8	1037	684	39.8 ± 7.8	
		41	A		76.4 ± 7.2	1144	754	37.6 ± 9.3	
Leatt et al.[74]	U-16/Canada	8		171.1 ± 4.3	62.7 ± 2.8				62 ± 8.0
	U-18/Canada	9		175.8 ± 4.4	69.1 ± 3.4				72 ± 10.0
Rhodes et al.[80]	Olympic team/Canada	16		177.3 ± 6.5	72.6 ± 6.2				92.5 ± 9.5

A = attacker; **AST** = anaerobic speed test; **CB** = central-back; **CD** = central-defender; **FB** = full-back; **G** = goalkeeper; **M** = midfield player; **U** = under.

to estimate maximal anaerobic energy production. It is often argued that field tests do not require the advanced equipment not available to most soccer teams. However, the usefulness of most of the tests could be questioned, other than just being a test, as very few studies have tried to establish links between a test performance and on-field performance.[10,138] It is the authors' view that one should prefer to use those tests (field or laboratory) from which changes in test results have been shown to be translated into changes in on-field performance. There exists several studies examining whether there exists physiological predictors of talent in soccer.[101,170-172] Despite the case that such tests might be indicative of a player's talent, most studies conclude that physiological tests may be useful, alongside subjective judgments of playing skills, for initial talent detection. A physical test *per se* is not sensitive enough to predict on-field performance and cannot be used reliably on its own for talent identification and selection purposes.[101,169] This aspect will, therefore, not be covered in more detail in the present review.

9. Endurance Tests

Most soccer-specific endurance tests have an intermittent exercise pattern simulating match play. The unit of measurement varies from time to cover a specified distance, distance covered in a limited amount of time and time to fatigue. Some selected endurance tests are described in the following sections, but only a few are recommended for use in a test battery based on the scientific knowledge at present.

9.1 Continuous Multistage Fitness Test

Players run back and forth between two lines, 20m apart, with an increasing running speed. The exercise intensity is controlled by a series of 'bleeps', which are played by a tape recorder. By each 'bleep' the players must have passed a certain point in the circuit, if not, he/she is required to stop. Every minute, time between the 'bleeps' becomes shorter. The starting speed is about 8 km/hour.[173] This test is correlated (r = 0.92) to $\dot{V}O_{2max}$.[174] As changes in $\dot{V}O_{2max}$ have been shown to influence on-field performance, and the fact that this test correlates well with $\dot{V}O_{2max}$, this test may be used throughout the season to monitor each players' endurance performance. However, one should be aware that indirect measurement of $\dot{V}O_{2max}$ should be viewed with caution as the accuracy is about ±15%.[38] For example, a player may actually have 60 mL/kg/min in $\dot{V}O_{2max}$ whilst the test result may estimate it somewhere in the range of 51–69 mL/kg/min (±15%). So the test result should be expressed as distance covered (endurance performance) not as estimated $\dot{V}O_{2max}$. Furthermore, we do not know whether improvements in these tests lead to improved on-field performance.

9.2 Yo-Yo Intermittent Recovery Test

The Yo-Yo intermittent recovery test consists of repeated 2 × 20m runs back and forth between the starting, turning and finishing line at a progressively increased speed controlled by audio bleeps from a tape recorder.[142] Between each running bout, the subjects have a 10-second active rest period, consisting of 2 × 5m of jogging. When the subjects twice have failed to reach the finishing line in time, the distance covered is recorded and represents the test result. The test may be performed at two different levels with differing speed profiles (level 1 and 2). We suggest using level 1 as this has been documented to be reliable and valid and the test results reflect on-field physical performance. [138] Level 1 consists of four running bouts of 10–13 km/hour (0–160m) and another seven runs of 13.5–14 km/hour (160–440m), before it continues with stepwise 0.5 km/hour speed increments after every eight running bouts (i.e. after 760, 1080, 1400, 1720m etc.) until exhaustion. The test lanes, marked by cones, should have a width of 2m and a length of 20m, and similar environment (i.e. inside, outdoor, sun/rain, same type of shoes, clothes, etc.) to compare separate tests. Another cone placed 5m behind the finishing line marks the running distance during the active recovery period. Before the test, all subjects should carry out a warm-up period consisting of the first four running bouts in the test. The total duration of the test is 6–20 minutes. All subjects should be familiarised with the test with at least one pre-test. The reproducibility of the test is 0.98 and the performance is positively correlated to $\dot{V}O_{2max}$ and time to fatigue in an incremental treadmill running test. The performance is also significantly correlated to the amount of high-intensity running (>15 km/hour, r = 0.71), sum of high-speed running and sprinting during a game, and the total distance covered during a soccer match.[138]

During a pre-competition period, moderately trained elite soccer players (55 mL/kg/min) improved Yo-Yo test performance and $\dot{V}O_{2max}$ by 25% (from 1760 to 2211m) and 7% (from 55 to 59 mL/kg/min), respectively. High-intensity running covered by the players during games was correlated to Yo-Yo test performance, but not to $\dot{V}O_{2max}$. This indicates that this particular test may be more sensitive than $\dot{V}O_{2max}$ in evaluating soccer players' on-field physical performance. However, this correlation is highly dependent upon the type of endurance exercise performed before and during the preparation period as well as the homogeneity of the group of players. It should also be mentioned that others have found close correlation between $\dot{V}O_{2max}$ and high-intensity running[10] and more studies have to be performed to confirm these results at different levels of play, especially in players with higher $\dot{V}O_{2max}$ than those players reported in the study by Krustrup et al.[138] However, at present we recommend this particular test for teams not having access to laboratory tests of $\dot{V}O_{2max}$. The data of Krustrup et al.[138] showed that those players with a $\dot{V}O_{2max}$ >60 mL/kg/min ran more than 2250m in the Yo-Yo test.

9.3 Soccer-Specific Testing of Maximal Oxygen Uptake ($\dot{V}O_{2max}$)

The test circuit includes dribbling, repetitive jumping, accelerations, decelerations, turning and backwards running with the ball through a 55m long and 30m wide circuit first described by Hoff et al.[39] The players are instructed to gradually increase running intensity to about 95% of HR_{max}, which is maintained for 3 minutes. Thereafter, the players increase the running speed to a level that leads to exhaustion after about 6 minutes. While tested, the player is equipped with a portable metabolic test system. For the ten soccer players that took part in this study, the maximal cardio-respiratory variables, of which $\dot{V}O_{2max}$ was similar to that measured at the laboratory on a treadmill. The coefficient of variation in this test was 4.8%.[175] This is not only the most advanced, but also the most useful test to monitor soccer players' aerobic capacity on the field. As we know that $\dot{V}O_{2max}$ influences on-field performance,[10] the results from this test, as for $\dot{V}O_{2max}$ measured in the laboratory, are very reliable and user friendly in the training plan for further improvement in $\dot{V}O_{2max}$.

9.4 Hoff Test: Aerobic Testing with the Ball

The Hoff test (figure 2) is performed on an adapted circuit (290m per lap), previously presented by Hoff et al.[39] and used by Kemi et al.[175] It consists of dribbling the ball through the circuit with the identical moves described by Hoff et al.[39] and Kemi et al.[175] The test duration is for 10 minutes during which time the player is asked to perform the maximum number of circuit laps. The test performance (m) is reproducible (0.96) and significantly correlated to $\dot{V}O_{2max}$.[152] Furthermore, improvement in $\dot{V}O_{2max}$ was translated into improved test performance in the Hoff test.[152] Although, presently, few teams have the test (table V), we suggest that it should be an achievable goal for elite soccer players to cover >2100m in the Hoff test. This is because the test requires a $\dot{V}O_{2max}$ of >200 mL/$kg^{0.75}$/min that according to our view, due to all the positive adverse effects (easily trained and based upon trends),[26,57] will serve as a minimum in elite soccer players participating in international tournaments in the years to come.

9.5 Laboratory Tests

9.5.1 $\dot{V}O_{2max}$

$\dot{V}O_{2max}$ is the largest amount of oxygen the body can use during exhaustive exercise. In the laboratory, direct measurements are used to determine an accurate $\dot{V}O_2$. The standardised tests are performed on motor-driven treadmills (by running) or on cycle ergometers (by cycling). The coefficient of variation of these types of tests are normally in the order of 1–3%.[38] Soccer players should use the treadmill as this mode of exercise is close to their specific activity. Furthermore, it is well known that the $\dot{V}O_{2max}$ values obtained with cycle ergometer protocols are lower than those obtained with treadmill testing.[38] Previous studies have shown that the players' $\dot{V}O_{2max}$ correlated to the total distance covered in

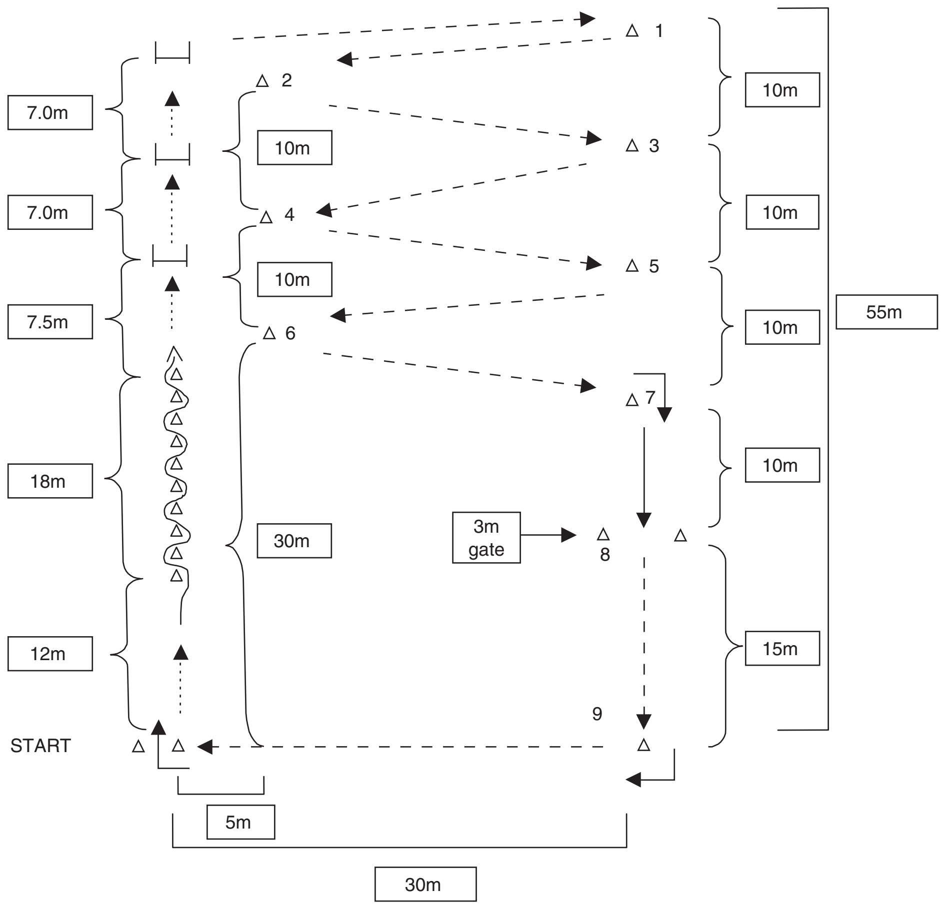

Fig. 2. The player dribbles the ball in a forward run through the track. The track width is 30m while its length is 55m on the right and 51.5m on the left side. The distance from cone 7 to gate 8 is performed as backwards running with the ball. Equipment: three hurdles (30–35cm height); 22 cones (two cones for the backward run gate and two for the starting line). Distances: total distance = 290m; hurdle 3 to cone 1 = 30.5m; distance separating cones 1, 2, 3, 4, 5, 6 and 7 = 25.5m each.

soccer games.[1,17] Helgerud et al.[10] showed that a period of 8 weeks of endurance training improved $\dot{V}O_{2max}$ in elite junior players resulting in an increase of on-field performance assessed during games. Improvements in match performance (i.e. a 3-point increase in average match HR [expressed as percentage HR_{max}]; 20% increase in distance covered; 24% increase in the number of involvements with the ball; and 100% increase in sprints performed) were not only accompanied by increases in $\dot{V}O_{2max}$ (10.8%), but also in the two other variables characterising aerobic capacity, i.e. anaerobic threshold and running economy.

9.5.2 Anaerobic Threshold

The anaerobic threshold is defined as the highest exercise intensity, HR or $\dot{V}O_2$ where the production and clearance of lactate is equal. There exist several methods to determine anaerobic threshold, including measurement of blood lactate and ventilatory measurements. The usefulness of different methods is discussed elsewhere[176] and will not be covered in this article. To our knowledge, no attempt has been made to study the particular relationship that could exist between anaerobic threshold and on-field performance.

9.5.3 Running Economy

The energetic cost of a run (running economy), is usually expressed as oxygen cost per metre, or minute at a defined intensity. The work economy is measured on a sub-maximal work rate. The importance of improved running economy is described in section 1.1.

9.5.4 Anaerobic Capacity Tests

Although a player's maximal anaerobic capacity may influence the score in a game, little is known about changed anaerobic capacity and on-field performance. Furthermore, it is very hard to determine maximal anaerobic capacity in an accurate and reproducible way. Two frequently used tests are described in sections 9.5.5 and 9.5.6.

9.5.5 The Wingate Test

The Wingate test is performed on a cycle ergometer with an usual resistance of 7.5% of the subject's bodyweight or a braking load calculated from the subject's m_b.[177] The subject has to pedal as fast as possible from a flying start for 30 seconds. The result can be calculated as peak 5-second power output, mean 30-second power output and the difference between peak 5-second power output, and the lowest 5-second power output divided by the peak 5-second power output, calculating a fatigue index. The test–retest reliability is between 0.90 and 0.98.[93] Even if this test has been considered as a test assessing anaerobic capacity, it has further been shown that aerobic contribution to energy production is high,[178] and that it is also dependent on the sport-specific activity of the tested athlete. Indeed, the aerobic contribution to energy production during the Wingate test can be as high as 28% for sprinters and 45% for endurance athletes.[177]

9.5.6 Maximal Anaerobic Oxygen Deficit

Medbø et al.[179] described a test protocol that allows the calculation of maximal anaerobic oxygen deficit after an all-out effort to exhaustion lasting 2–3 minutes at ~130% $\dot{V}O_{2max}$ on a treadmill. Nevertheless, to be able to make such calculations, the subject has to perform four pre-tests, one $\dot{V}O_{2max}$ test and three 10-minute sub-maximal continuous efforts in order to accurately determine the $\dot{V}O_2$-intensity curve. The $\dot{V}O_2$-intensity curve allows the determination of the theoretical $\dot{V}O_2$ at a supra-maximal exercise intensity (e.g. 130%). When the subject performs the all-out supra-maximal effort, gas exchanges are measured and the anaerobic capacity of the subject is considered as the difference between the actual amount of oxygen consumed and the theoretical presumed consumption from the $\dot{V}O_2$-intensity curve. This difference represents the energy provided by anaerobic pathways. Some authors raised criticisms about this method, questioning the linearity of the $\dot{V}O_2$-intensity curve above $\dot{V}O_{2max}$. However, Medbø[180] found a 4% deviation from anaerobic estimation from muscle biopsy and this finding should be considered valid.

To the best of our knowledge, there has been no attempt made to study the relationship between on-field soccer performance and anaerobic capacity.

9.6 Strength and Power Tests

Different tests have been used for the evaluation of strength parameters in elite soccer players. Most studies[74,112,120] have used isokinetic equipment with different speeds and joint angles, making direct comparisons difficult. However, there exist studies using more functional tests (using free barbells) that we prefer, such as 1RM in bench press and half-squats to test upper- and lower-body muscle strength of professional soccer players, respectively.[26,57]

9.7 Field Tests

9.7.1 Vertical Jump Test

For measurement accuracy this test has to be assessed by a portable force-plate. This way of evaluation makes it very close to the classical laboratory vertical jump test that assesses the jumping ability of the player and thus, his or her muscular power. The main jumps generally assessed are the squat jump, with hands at the hips, and the free-counter movement jump.[77] Arnason et al.[27] reported a close relationship between vertical jump height and performance in the league.

9.7.2 5-JumpTest

This consists of five consecutive strides performed from an initial standing position with joined feet.[153] Rohr[181] has shown that in soccer players this test was correlated with vertical jumping. If coordination interferes in the 5-JumpTest performance, this is an easy test to perform to assess the soccer player's power. Personal data in Tunisian under-23 elite soccer players showed that the performance in this test was significantly correlated to anaerobic performance measured during vertical jumping on a force-plate.

9.7.3 30m Sprint (10m Lap Time)

Results of this test have been discussed in section 6.4. This test is widely used in soccer as it represents a distance representative of soccer play, especially for the 10m lap-time distance.[26,68,162] For timing accuracy, photoelectric timing has to be used and this test is generally performed on the soccer field with soccer sportswear.

9.7.4 Repeated Sprinting Ability (Bangsbo Soccer Sprint Test)

This test is composed of seven successive sprints of 34.2m (30m with a direction change of 5m to the side between 10m and 20m) with a 25-second walk back in between.[142] The performance is represented by: (i) the best sprinting time; (ii) the mean sprinting time for the seven sprints; and (iii) a fatigue index (difference between best and worst times). This test is supposed to asses the soccer player's 'speed endurance', an important physical capacity in modern soccer.

9.7.5 10m Shuttle Test

This test consists of one 10m shuttle,[26] with its performance being a combination of speed, power and coordination. Wisløff et al.[26] has shown that the performance on this test was significantly correlated to 1RM in half-squats as well as vertical jump height.

10. Conclusion

It is obvious that the physical capacity of soccer players and referees influence their technical performance and tactical choices as well as the frequency of injuries. Acting upon the presented information may give soccer players, teams, coaches and referees a big advantage in the search for a successful career. Considering all the advantages of a high level of physical capacity, it is the authors' view that more focus should be attended on how to effectively train the different physical capacities.

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Correspondence and offprints: *Ulrik Wisløff*, Department of Circulation and Medical Imaging, Norwegian University of Science and Technology, Olav Kyrres gt. 3, Trondheim, 7489, Norway.
E-mail: ulrik.wisloff@ntnu.no

