Anthropometric and physiological predispositions for elite soccer

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This review is focused on anthropometric and physiological characteristics of soccer players with a view to establishing their roles within talent detection, identification and development programmes. Top-class soccer players have to adapt to the physical demands of the game, which are multifactorial. Players may not need to have an extraordinary capacity within any of the areas of physical performance but must possess a reasonably high level within all areas. This explains why there are marked individual differences in anthropometric and physiological characteristics among top players. Various measurements have been used to evaluate specific aspects of the physical performance of both youth and adult soccer players. The positional role of a player is related to his or her physiological capacity. Thus, midfield players and full-backs have the highest maximal oxygen intakes ($> 60 \ \mathrm{ml \cdot kg^{-1} \cdot min^{-1}}$) and perform best in intermittent exercise tests. On the other hand, midfield players tend to have the lowest muscle strength. Although these distinctions are evident in adult and elite youth players, their existence must be interpreted circumspectly in talent identification and development programmes. A range of relevant anthropometric and physiological factors can be considered which are subject to strong genetic influences (e.g. stature and maximal oxygen intake) or are largely environmentally determined and susceptible to training effects. Consequently, fitness profiling can generate a useful database against which talented groups may be compared. No single method allows for a representative assessment of a player's physical capabilities for soccer. We conclude that anthropometric and physiological criteria do have a role as part of a holistic monitoring of talented young players.

Keywords: association football, genetics, muscle characteristics, talent, $\dot{V}O_{2\max}$.

Introduction

Soccer (more formally known as association football) is unarguably the world's most popular sport. The FIFA World Cup finals of 1998 attracted an estimated 40 thousand million television spectators (Hillis, 1998). Recent burgeoning of the football industry has enhanced the attractiveness of the sport as a professional occupation for performers at the highest standard, where the financial rewards for success are considerable. Management of the top teams is continually on the look-out for emerging star players, either mature players on opposition teams or those developing in under-age and youth ranks. The economic benefits of being able to recruit talented players and develop them to full potential are obvious. Recognition of the financial gains associated with early development of footballing talent has led to the institution of 'academies' as 'centres of excellence' attached to the major professional soccer clubs worldwide. In conjunction with these schemes, there has been an increased systematization of physical training and greater emphasis on fitness.

Identification and selection of talented soccer players are not straightforward operations. Detection and identification of talent are more difficult in team games than in individual sports such as running, cycling or rowing, where predictors of performance are more easily scientifically prescribed (see Reilly *et al.*, 1990). Long-term success in soccer is dependent on a host of personal and circumstantial factors, not least of which is the coherence of the team as a whole and the availability of good coaching. These factors make it difficult to predict ultimate performance potential in soccer players at an early age with a high degree of probability.

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Soccer players have to adapt to the requirements of the game to compete at the highest standard. Thus, the physical capacity of top-class players may give an indication of the physiological demands of the game. These demands are usually quantified by measuring players' physiological responses during match-play and represent, in an indirect way, the overall pace at which the game is being played. It is possible, therefore, that success can be achieved despite rather moderate fitness if a player has a well-developed tactical sense and a high technical standard that help him or her make a major contribution to team play in intensely contested matches. This means that the individual physical capacity at elite standard may not in all cases reflect the physical demands in top league games. Similarly, the physiological demands of a given position in the team may not be linked directly to absolute fitness, since the tactical role assigned to a player in that position is probably dictated already by the physical capacity of that player. Nevertheless, if a large number of players are observed in each position, mean values yield important information about activity and fitness profiles of the various positional roles and how these might vary with different team configurations.

This review focuses on the anthropometric and physiological characteristics of elite soccer players. A starting point in the search for outstanding talent is the use of profiles established for those who have already been successful. These multifactorial profiles are sketched from observations on anthropometric, physiological and performance measures. Knowledge of these characteristics can give clues as to the existence of biological prerequisites for playing at the highest standard. The degree to which physiological indices of performance capability prevail through growth and into adulthood is open to discussion. Information is also presented on groups selected for specialized training in 'schools of excellence' or those representative of elite 'under-age' squads. Consequently, some consideration is given to the extent to which relevant physiological measures are influenced by genetic and by training or environmental factors, and to principles for their development. Since the scientific literature contains as yet few reports on female soccer players, this overview is restricted to considering males only.

Physiological demands of contemporary elite soccer

The physiological demands of elite soccer match-play have been reviewed by various authors (Bangsbo, 1994a; Reilly, 1997; Shephard, 1999). The energy expenditure associated with competition has been estimated to be about 5700 kJ for a male weighing 75 kg and a maximal oxygen intake ($\dot{V}O_{2max}$) of 60 ml·kg^{-1}·min^{-1}. The mean rate of energy expended approximates to a relative oxygen utilization of about 70% $\dot{V}O_{2max}$.

The predominant metabolic pathways during competitive soccer are aerobic (Bangsbo, 1994b) and metabolic responses are broadly analogous to those encountered in endurance exercise. Most activity is composed of movement 'off-the-ball', creating space for team-mates to play the ball or deceive opponents, or following runs by opposition players. Overall work-rates tend to be relatively consistent in the top leagues among the main European countries (Reilly, 1994a), although players in the English Premier League cover 1.5 km more during a game than South American international players (Drust *et al.*, 1998). Players who can sustain a high work-rate throughout a full game gain an advantage over equally skilled players whose energy, expressed as glycogen stores, can approach depletion towards the end of a game (Saltin, 1973).

Whereas exercise 'off-the-ball' comprises most activity during a game and is in the main aerobic, activity while directly involved in play is largely anaerobic. Typically, competitive match-play calls for an all-out sprint once every 90 s on average and high-intensity efforts every 30 s for each player. Indeed, anaerobic activity may constitute the more crucial moments of the game and contribute directly to winning possession of the ball and to the scoring or conceding of goals. The relative contribution of anaerobic activity is likely to be less in youth compared with adult players because of the delayed development of anaerobic metabolic pathways in adolescence (for reviews, see Reilly and Stratton, 1995; Boreham and Van Praagh, in press).

In addition to the global aspects of locomotion during match-play, there are actions directly concerned with playing the ball. Muscle strength has been suggested to be relevant to kicking the ball (De Proft *et al.*, 1988; Reilly and Drust, 1997), to tackling and tolerating physical contact. Anaerobic power is important in accelerating the body during short movements, in leaping to win the ball or contest its possession in the air. Symmetrical inter-limb distribution of strength and an appropriate balance between flexors and extensors are important for injury prevention (Fowler and Reilly, 1993), as is flexibility in the hamstrings and hip adductors (Ekstrand, 1982; Reilly and Stirling, 1993). Upper body strength is also relevant for coping with the physical aspects of the game and for throwing-in (Togari and Asami, 1972; Shephard, 1999). These physical characteristics are important components in the timing and execution of games skills.

There is evidence that the physiological demands of soccer vary with the work-rates in different positional roles. Aerobic requirements are greatest in outfield

Table 1. Anthropometric and performance test characteristics of top-class Danish players according to positional roles

	Goalkeepers (*n* = 5)	Central defenders (*n* = 13)	Full-backs (*n* = 12)	Midfield players (*n* = 21)	Forwards (*n* = 14)
Height (m)	1.90 ± 0.06	1.89 ± 0.04	1.79 ± 0.06	1.77 ± 0.06	1.78 ± 0.07
Body mass (kg)	87.8 ± 8.0	87.5 ± 2.5	72.1 ± 10.0	74.0 ± 8.0	73.9 ± 3.1
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	51.0 ± 2.0	56.0 ± 3.5	61.5 ± 10.0	62.6 ± 4.0	60.0 ± 3.7
$\dot{V}O_2$ at 3 mmol·l^{-1} (ml·kg^{-1}·min^{-1})	40.6 ± 5.0	44.0 ± 2.5	49.0 ± 6.0	51.0 ± 5.0	47.5 ± 3.0
Intermittent field test (m)	1790 ± 120	1900 ± 140	1950 ± 150	1950 ± 130	1820 ± 150
Peak torque at 3.14 rad·s^{-1} (N)	162 ± 9	165 ± 9	131 ± 6	134 ± 3	161 ± 12
Peak torque at 0.5 rad·s^{-1} (N)	260 ± 23	275 ± 20	268 ± 18	225 ± 9	277 ± 22

Source: Bangsbo (1994c).

players and midfield players, and least in central defenders (Reilly and Thomas, 1976). These differences are reflected in the physiological measures of fitness among players (Reilly, 1994b). There are also likely to be anthropometric predispositions for positional roles, with taller players being the most suitable for central defensive positions and for the 'target' player among the strikers or forwards. This factor may be linked with preselection of early maturers for key positional roles, where body size rather than playing skills provides an advantage.

Physiological and anthropometric correlates of success

Anthropometry

Elite soccer teams are characterized by a relative heterogeneity in body size. The overall mean ($\pm s_{\bar{x}}$) values for stature and body mass of nine professional squads reported by Reilly (1990) were 1.77 ± 0.15 m and 74.0 ± 1.6 kg, respectively. Tall players tend to have an advantage in certain playing positions and, therefore, are oriented towards these roles, notably in goalkeeping, central defence and central attack. In a study of 65 elite Danish players, goalkeepers and central defenders were the tallest and heaviest, while the mean stature and body mass of full-backs, midfield players and forwards were similar (see Table 1). Similar observations have been obtained in other studies (Bell and Rhodes, 1975; Reilly, 1979). Within each group of Danish players, a large range was observed (e.g. the tallest forward was 1.90 m and the shortest was 1.67 m). This variability may influence the tactical role allocated to individual players. The tall forward might be used as a 'target' player for high balls, whereas the short forward may prefer to run for balls played deep into the opponents' defence.

A comprehensive anthropometric profile of 95 international players at the 1995 'Copa America'

Table 2. Anthropometric characteristics of elite mature football players in different codes

	Rugby Sevens (*n* = 30)	Gaelic Football (*n* = 33)	Soccer (*n* = 110)
Age (years)	-	-	26.1 ± 4.0
Body mass (kg)	84.7 ± 10.4	79.9 ± 8.2	76.4 ± 7.0
Height (m)	1.79 ± 0.06	1.79 ± 0.07	1.77 ± 0.06
Adipose mass (%)	11.7 ± 2.3	14.7 ± 3.0	10.6 ± 2.6
Muscle mass (%)	62.4 ± 4.1	60.7 ± 2.4	62.2 ± 2.9
Endomorphy	2.3 ± 0.6	2.7 ± 0.7	2.0 ± 0.5
Mesomorphy	5.9 ± 0.9	5.7 ± 1.0	5.3 ± 0.8
Ectomorphy	1.5 ± 0.6	1.9 ± 0.8	2.2 ± 0.6

Sources: Rugby Sevens (Rienzi *et al.*, 1999), Gaelic Football (Reilly and Doran, 1999), Soccer (Copa America) (Rienzi *et al.*, 1998).

Championships in Uruguay yielded mean estimated body fat values of 11% (determined from summed skinfolds) and muscle masses averaging 62% (Rienzi *et al.*, 1998). These figures are close to those observed in other football codes at elite standard, most notably Rugby Sevens internationals (Rienzi *et al.*, 1999) and top Gaelic Football players (see Table 2). The technical error of measurement of the sum of the eight skinfold thicknesses was < 2% and the average for the eight individual sites was < 5%. Both Rugby Sevens and Gaelic Football demonstrate work-rate patterns that are broadly similar to those of soccer and are sports in which a muscular physique can bestow an advantage (Reilly, in press). The South American international soccer players tended to congregate within a small area of the 'somatochart'. Although the proportional muscle mass determined using the equation of Martin *et al.* (1990) may represent an overestimate according to Cattrysse *et al.* (1999), the somatotypes do emphasize the muscular physique of players at elite standard, highlighted by the higher than normal average mesomorphy.

Aerobic performance

Aerobic performance is determined by aerobic power and aerobic capacity. The former component reflects the ability to produce aerobic energy at a high rate and is characterized by maximal oxygen intake ($\dot{V}O_{2max}$). Aerobic capacity expresses the ability to sustain exercise for a prolonged period and is synonymous with endurance.

The maximum oxygen intake for elite male players has been determined in several studies, with mean values between 56 and 69 ml·kg^{-1}·min^{-1} having been reported (see Reilly, 1996). These values are similar to those obtained in other team sports, but are considerably lower than those for elite athletes within endurance sports, where $\dot{V}O_{2max}$ in excess of 80 ml·kg^{-1}·min^{-1} has been observed (Reilly and Secher, 1990). Studies of soccer players show a variation in $\dot{V}O_{2max}$ which is influenced by fitness at the time of testing and is also partly associated with the different positions of the players within the team. The coefficient of variation is relatively modest, amounting to 7.8% among the elite teams reviewed in Reilly (1996). Based on results obtained for elite Danish players, full-backs and midfield players had the highest values and goalkeepers and central defenders the lowest, but a broad range was found within each positional group (see Table 1). Players in a top Norwegian team (Rosenborg FC) had higher $\dot{V}O_{2max}$ values than players from a lower ranked team playing in the same league (67.6 *vs* 59.9 ml·kg^{-1}·min^{-1}; Wisløff *et al.*, 1998). On the other hand, in a study of top-class Danish players, no difference in $\dot{V}O_{2max}$ was observed between regular and non-regular first-team players (possibly because they were subject to the same training regimens), which suggests that this variable does not necessarily determine good performances in soccer (Bangsbo, 1994a). Thus, $\dot{V}O_{2max}$ appears not to be a truly sensitive measure of performance capability in soccer and cannot be used in isolation to identify talent. Nevertheless, the consistent observation of mean $\dot{V}O_{2max}$ values exceeding 60 ml·kg·min^{-1} in elite teams suggests the existence of a threshold below which an individual player is unlikely to perform successfully in top-class contemporary soccer.

As soccer is predominantly supported by aerobic metabolism with frequent anaerobic bouts of exercise superimposed on background submaximal activity, physiological responses to moderate or high exercise intensities can yield insights into the game's requirements. For example, endurance performance is associated with the relative exercise intensity than can be sustained, expressed as a percentage of $\dot{V}O_{2max}$ (Costill, 1979). It has also been linked with the blood lactate response during submaximal continuous exercise. Frequently, running velocity is related to a fixed reference concentration of blood lactate, usually 4 mmol·l^{-1}. The velocity–blood lactate curve shifts to the right as aerobic capacity improves. This renders blood lactate measurements useful for the evaluation of long-term exercise performance in groups of players that perform the same test (see Jacobs, 1981).

When elite Danish soccer players were tested using treadmill running, it was observed that the oxygen intake ($\dot{V}O_2$) corresponding to a given blood lactate concentration – in this instance, 3 mmol·l^{-1} – was higher for full-backs and midfield players than for central defenders and goalkeepers (Table 1). In accordance with the $\dot{V}O_{2max}$ determinations, the forwards had values in between the two groups for their blood lactate responses. When the $\dot{V}O_2$ for a given blood lactate concentration was expressed in relation to $\dot{V}O_{2max}$, slightly higher values were obtained for the full-backs and midfield players (Bangsbo, 1994a). As for $\dot{V}O_{2max}$, there was no difference between regular and non-regular first-team players in the relationships between submaximal treadmill speed and blood lactate concentration (Bangsbo, 1994b). These data may reflect that, once selected in a professional squad, maintenance of position in the first team is more likely to depend on competence in match skills during competition than in small differences in measures of aerobic power or aerobic capacity.

Anaerobic performance

When considering anaerobic performance, a distinction has to be made between anaerobic power and anaerobic capacity. Anaerobic power represents the highest rate of anaerobic energy release, whereas anaerobic capacity reflects the maximal anaerobic energy production an individual can obtain in any exercise bout performed to exhaustion. Although mean power output over 30 s on a cycle ergometer (Inbar *et al.*, 1996) has been used, as have 'supramaximal' protocols on a motor-driven running treadmill (for a review, see Reilly and Bangsbo, 1998), as yet no properly validated physiological measurement exists for determining anaerobic capacity (Bangsbo, 1997).

Several methods have been used to evaluate the maximal performance of soccer players during short-term exercise and thus, indirectly, their anaerobic power (see Reilly, 1990). Among these is a stair run test developed by Margaria *et al.* (1966). Using this test, di Prampero *et al.* (1970) found values for soccer players that were 5–15% lower than for middle-distance runners, sprinters and pentathletes. On the other hand, Withers *et al.* (1977) reported that soccer players had values about 20% higher than basketball players, walkers and runners. Similarly, Apor (1988) observed

that elite Hungarian soccer players had a 15–30% higher anaerobic power than an age-matched control group.

It would appear, therefore, that a high anaerobic power is desirable for success in top-class soccer. This capability is reflected in the higher values for anaerobic power among goalkeepers, central defenders and strikers observed in English League players (Reilly, 1979). Anaerobic power aids quickness 'off-the-mark', which can be decisive in critical match events for players in these positions. The high requirement for anaerobic power in soccer players is manifest in the typical mesomorphic somatotypes referred to earlier.

Intermittent exercise performance

The measurements discussed above express to a certain degree the physical capacity of a soccer player, and they can be used for comparisons with other sports. None of these determinations by itself accurately expresses the ability to perform prolonged intermittent exercise with alternating intensities, as in soccer match-play (Bangsbo and Lindquist, 1992). Various field tests of endurance performance which are highly valid for soccer have been used.

An intermittent field test was developed by Bangsbo and Lindquist (1992) to test soccer players. The players carry out many activities (e.g. accelerations, decelerations, stops, turns, backward and sideways runs) that are encountered in a competitive match. The players work intermittently switching between 15 s of running at high speed and 10 s of active rest. The test lasts 16.5 min and the test result is the performance (distance covered) during the 10 min of high-intensity running. Performance on this test was significantly related to the distance covered during a combined intermittent endurance field and treadmill test to exhaustion lasting 2–2.5 h.

In a study of elite Danish players (Bangsbo, 1994c), the mean distance covered during the field test by full-backs and midfield players was significantly greater than for goalkeepers and forwards (Table 1). In contrast to the results obtained during treadmill running, the central defenders performed better than forwards during this type of exercise. Thus, it would appear that the intermittent field test adds valuable information to that obtained by laboratory testing alone.

Recently, two other field tests of relevance to soccer have been developed: the 'Yo-Yo intermittent endurance test' and the 'Yo-Yo intermittent recovery test'. In the 'Yo-Yo' intermittent tests, the players perform repeated 20-m shuttle runs interspersed with a short recovery during which the players jog. The time allowed for a shuttle, which is progressively decreased, is dictated by audio bleeps from an audio tape. The objective in the tests is to complete as many shuttles as possible (Bangsbo, 1994c).
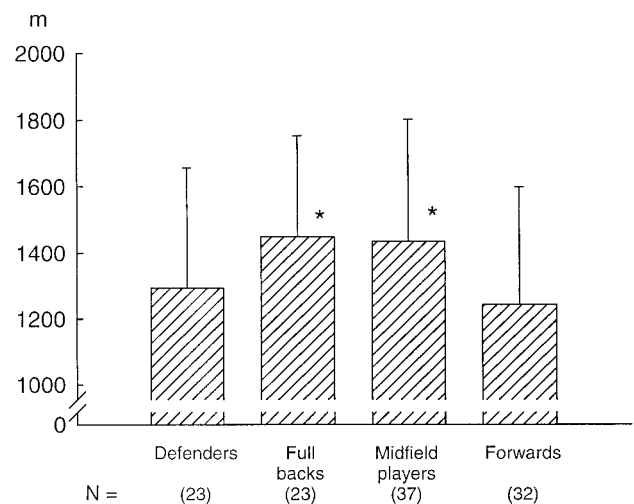

Fig. 1. Results for top-class Portuguese players on the 'Yo-Yo' intermittent endurance test based on playing positions (Oliveira *et al.*, 1998).

The Yo-Yo intermittent endurance test evaluates a player's ability to perform intense exercise repeatedly after prolonged intermittent exercise. In the test, players have a 5-s rest between each shuttle. The results of top-class Portuguese players performing the Yo–Yo intermittent endurance test are shown in Fig. 1. It is clear that the full-backs and midfield players performed significantly better than the other defenders and forwards. Similar differences were obtained when top-class Danish players were tested (Michalsik and Bangsbo, 1995).

The aim of the Yo-Yo intermittent recovery test is to determine a player's ability to recover from intense exercise. In this test, the running speeds are higher than during the endurance test and there is 10 s of jogging between shuttles. When comparing the performance of 44 professional players from two leading teams in the top Danish league, it was apparent that the midfield players performed better than players from other groups. This observation supports midfield players having the highest aerobic power and suggests that a well-trained oxygen transport system is beneficial in recovering from strenuous intermittent exercise. Furthermore, the test has relevance to the performance profiles that are characteristic of work-rates in competition.

Muscle strength

Many activities in soccer are forceful and explosive (e.g. tackling, jumping, kicking, turning and changing pace). The power output during such activities is related to the strength of the muscles involved in the movements. Thus, it might be beneficial for a soccer player to

have a high muscular strength, which also diminishes the risk of injury (Grace, 1985; Fleck and Falkel, 1986). In line with this suggestion is the finding that soccer players have higher muscular strength than untrained individuals (see Bangsbo, 1994b; Wisløff *et al.*, 1998).

The muscular strength of soccer players appears to be related to the position in the team. In a study of top-class Danish players, muscular strength was lowest for the midfield players at all angular velocities measured, while the full-backs generated lower forces than goalkeepers, forwards and central defenders at the high velocities. The peak torques generated at angular velocities of 3.14 and 0.15 rad·s^{-1} are shown in Table 1. The differences in muscular strength are probably due to selection of a specific type of player for a position, rather than to a more pronounced development of strength as a result of playing in that position.

In many activities in soccer, the generation of force occurs at angular velocities higher than 5.2 rad·s^{-1}, which is the upper limit for most isokinetic machines. For example, the angular velocity of the lower leg is about 17.5 rad·s^{-1} during a football kick (Miller and Nelson, 1976); that is one reason why a relationship has not always been observed between kick performance and knee extensor strength. From observations on top-class soccer players in various studies, it is clear that the strength of the knee extensors alone does not determine the final impact on the ball in a kick (see Bangsbo, 1994a). Technical skill is also a major factor in kicking a football, since the kick incorporates a complex series of synergistic muscle actions, involving the antagonistic muscles as well as agonists.

Quite apart from its relevance to games skills, muscle strength is relevant to more global aspects of competitive performance. For example, using factor analytic studies, Reilly and Thomas (1977) demonstrated that professional players with higher muscle strength in the lower limbs were the most consistent members of a first team representative squad over the entire season. Later, Fowler and Reilly (1993) reported that asymmetry in muscle strength, both between the left and right legs and between the leg flexors and leg extensor muscles, were factors in predisposing towards injury among professional players. Such observations would support a recommendation to screen for muscle strength imbalances among young players.

Muscle characteristics

In several studies with elite male soccer players, muscle morphological analysis has been performed on biopsies taken from the vastus lateralis or gastrocnemius muscle. The mean percentage of slow-twitch fibres ranged from 40 to 61% for vastus lateralis and from 49 to 60% for gastrocnemius. For both muscles, the individual variation in the percentage of slow-twitch fibres was large, indicating that a special distribution between slow- and fast-twitch (FT) fibres is not important for top-class players. On the other hand, soccer players have relatively few FTb fibres, most of whom also have a FTa myosin heavy chain expression (Anderson *et al.*, 1994). Thus, the muscles of elite soccer players can be characterized by having few FTb fibres, which has also been observed among endurance-trained athletes.

The soccer players studied by Anderson *et al.* (1994) had larger muscle fibres than untrained individuals, and the area of the fast-twitch fibres was greater than that of the slow-twitch fibres. However, both the slow- and fast-twitch fibre areas were significantly less than in muscle from athletes trained for sports in which high force development is essential for performance (Tesch *et al.*, 1984).

The mean number of muscle capillaries for elite players is higher than that observed for untrained individuals, but not as high as that found for athletes competing in endurance sports (Bangsbo, 1994b). In addition for professional soccer players, muscle citrate synthase activity and β-hydroxy-CoA-dehydrogenase (HAD) concentrations were only slightly lower than those found for endurance-trained elite Danish athletes. A cross-sectional comparison revealed that the muscle citrate synthase activity was lower in the vastus lateralis than in the gastrocnemius, while no difference was observed for the activity of HAD. The former difference might be attributed to the gastrocnemius being more involved in endurance exercise during training and match-play than the vastus lateralis.

In summary, the biological demands of competitive soccer have been studied by monitoring physiological responses during or after matches. Although aerobic metabolic pathways provide the dominant energy route, anaerobic activity is highlighted in direct involvement with the ball. Anthropometric characteristics and muscle performance vary with positional roles and such heterogeneity must be considered when shaping team configurations. While these phenomena are apparent in soccer players at the highest standard, it is not clear whether they are so obvious in young players.

Some consideration is now given to the biological maturation of these factors relevant to gross motor performance in soccer before observations on under-age players are discussed. In this context, the interactions of genetic and environmental influences are also addressed.

Developmental considerations

Cardiorespiratory endurance

Maximal aerobic power ($\dot{V}O_{2max}$) increases with age, largely because of increased body size. When expressed

in $ml \cdot kg^{-1} \cdot min^{-1}$, values for adolescents are similar to those for young adults. Bangsbo *et al.* (1994b) reported that the $\dot{V}O_{2max}$ of young elite Danish players was as high as that of older professionals when expressed relative to body mass.

It is believed that $\dot{V}O_{2max}$ is more sensitive to aerobic training once peak height velocity – calculated from the rate of increase in stature with time – has been attained. The maximal attainable effect on this parameter in the young has been reported to be less than the 20–25% obtained in adults (Gilliam and Freedson, 1980). Trainability appears to be lower in children (approximate age 4–12 years) than in adolescents (approximate age 13–19 years), which in turn is lower than in youth athletes (Ekblom, 1969). Rowland (1985) concluded that prepubescents do increase their aerobic power at the same rate as other age groups when the training regimens conform to criteria set for adults. It would also seem that these youngsters are equally responsive to intermittent and continuous endurance training protocols (for a review, see Van Praagh, 1998). A particularly poor response to aerobic training in prepubertal soccer players might be attributable to low androgen concentrations for hypertrophy of cardiac muscle, stimulation of red blood cells and haemoglobin, and synthesis of metabolic enzymes.

Youngsters should not be viewed simply as miniature adults and training programmes used by adult professional teams should not be transferred to them without appropriate modifications. Furthermore, there are substantial ethical issues associated with the exploitation of young players for commercial gain by transferring them to the richer professional clubs for specialized training. The contemporary traffic of young African players by professional 'agents' to European nations without any guarantee of subsequent employment by any of the league clubs exemplifies a practice that contravenes normal sports ethics.

Anaerobic power and muscle strength

In children, anaerobic power and capacity are less well developed than aerobic power (see Bar-Or and Unnithan, 1994). This difference is reflected in the relative contribution of aerobic and anaerobic mechanisms in 'all-out' efforts. In children, a 6-min run is dependent almost entirely on aerobic metabolism. For a maximal effort of less than 60 s, children derive 60% of the total energy from anaerobic sources compared with 80% in adults (see Borms, 1986). The relatively poor anaerobic capacity in children is reflected in low lactate production during intense exercise bouts and suggests a low glycolytic rate. There is especially limited potential in the prepubescent child for developing the anaerobic system. Recent evidence

from magnetic resonance spectroscopy has confirmed that children are less able than adults to effect ATP rephosphorylation in aerobic pathways during high-intensity exercise (Zanconato *et al.*, 1993; Kuno *et al.*, 1995). Pre-adolescents accumulate lower lactate concentrations in their blood than adults during high-intensity exercise, but they recover much faster than men following short-term (30 s) intense exercise (Hebestreit *et al.*, 1993). Anaerobic capacity increases progressively during maturation until reaching that of adults after the teenage years. For further consideration of developmental aspects of anaerobic performance, readers are directed to Boreham and Van Praagh (in press).

Responses to strength training are also thought to be small in the prepubescent child, although there are few studies to substantiate this (see Bar-Or, 1988). Until testosterone increases in boys at the time of the adolescent growth spurt, muscle mass remains below the percentage of total body weight observed in adults. Strength gains pre-puberty are mainly due to improved neuromuscular coordination. The percentage muscle mass increases after sexual maturation as muscle development is stimulated by androgenic hormones. Increasing strength gains also accompany the rise in testosterone (Round *et al.*, 1999). Where weight-training is undertaken by young players, submaximal loads are advocated, in view of potential compressive loading on the growing skeleton. Emphasis should be placed more on the number of repetitions than on heavy resistances and maximal efforts.

Speed and coordination

The foundations for gross motor skills are laid down in the course of the child's habitual activity and early exposures to playing soccer. Development of running speed accelerates in two phases. The first is at about 8 years in both sexes; the second is at about the age of 12 for girls and between 12 and 15 years for boys. The former is related to the maturing of the nervous system and improved coordination of arm and leg muscles, and a broad range of physical activities has been recommended to stimulate whole-body coordination at this age (Borms, 1986). The latter improvement is related to the increase in body mass and muscle performance. The increase in muscle mass occurs slightly after peak height velocity is reached. There is a common perception of 'awkwardness' occurring at this period of adolescence, which is thought to be linked to disproportionate increases in leg length relative to trunk length. It appears that only 10–30% of adolescent boys are affected and the effects are transient (Beunen and Malina, 1988). Selective training for sport is probably not necessary before this

phase of development, although this recommendation does not apply to a formal organization of activities in the context of playing for fun to support motor skills acquisition. Nevertheless, some exposure to games skills is necessary at an early age, since Elliott *et al.* (1980) reported that movement and muscle activity patterns in young soccer players were evident by age 11 years.

The questions posed concerning the extent to which anthropometric and physiological criteria are appropriate markers of talent have remained largely unresolved for purposes of application to soccer. This gap in knowledge is partly because it is invalid to extrapolate from longitudinal studies in which biological and health-related characteristics have been 'tracked' from childhood through adolescence to adulthood in sub-elite samples. It is also due in part to the limited long-term studies of soccer players across the same stages. Nevertheless, the development process entails training interventions designed to maximize physiological adaptations. All of the anthropometric and physiological variables considered so far are determined by the interplay between genetic and environmental influences. A knowledge of the background of their influences should be useful in setting realistic projections for individual players during the processes of talent identification and development.

Genetics and environmental influences on performance

Within the human sciences there has been a long-standing debate about the relative contributions to performance of heredity and environment. The argument about nature versus nurture has spilled over into the sports sciences and raised questions with respect to the extent to which performance determinants are innate or prone to training influences. It is intuitively apparent to followers of the game that soccer skills are common to many fathers and sons, implying an influence of heredity. Methods used by sports scientists to partition genetic and environmental factors are known as 'quantitative genetics'. The theorem is that 'the degree of similarity exhibited by individuals in multifactorial traits (such as sports performance) is proportional to the number of genes they have in common' (Bouchard and Lortie, 1984). The convention has been to measure either the *distance* or the *similarity* between individuals of the same generation with known biological relationships. The 'distance approach' incorporates an overall variance which is partitioned according to the relative sources of variance; in contrast, the 'similarity approach' concentrates on the covariance between individuals and the analysis is primarily one of correlation and regression.

A general model used first by Bouchard and Malina (1983) incorporated terms for the total phenotypic variance observed, the genetic source of variance, the environmental component (training, lifestyle), the interaction between genetic and environmental factors, and for the random source of variance. The interaction represents the view that the sensitivity of the organism to the environment is genotype-dependent. Early studies (e.g. Klissouras, 1971) ignored the interaction concept, which in sport indicates 'trainability'. Bouchard and Lortie (1984) claimed this interaction is important for determining sports potential, whereas Klissouras (1997) maintained that it can be largely ignored and that functions such as aerobic power ($\dot{V}O_{2max}$) are mainly determined by heredity but the biological responses to training are not. Bouchard and co-workers reported large individual differences in responses to the same exercise programme, concluding that the responsiveness to training was partly due to genetic factors. Their methods could be criticized for failing to consider the large test–retest error and its influence on 'apparent trainability'. The general model constituted a prototype from which refinements or alternatives have subsequently been developed (for a review, see Bouchard *et al.*, 1997).

Heritability estimates were derived over recent decades for a number of anthropometric, physiological, muscle and performance variables relevant to sports such as soccer. They include high values for height and segment length, high (Klissouras, 1971) to moderate (Sundet *et al.*, 1994) values for $\dot{V}O_{2max}$ and high values for muscle fibre type and flexibility. More recently, Seeman *et al.* (1996) reported that 80% of the individual variation in bone mineral density and lean muscle mass is genetically determined; according to Thomis *et al.* (1998), the corresponding value for cross-sectional area of the arm was 85%.

In contrast, heritability values reported for muscle enzymes and metabolic (lactate) responses to submaximal exercise are low, as these variables are highly sensitive to training (see Table 3). Although the data reflect the estimated mean contribution of genetic influence on the different factors, the variability is quite large and may in itself be meaningful. Heritability estimates are also influenced by the mode of analysis and whether the data are based on studies of twins or other family relationships (Maes *et al.*, 1993).

Height is strongly influenced by genetic factors, with a heritability coefficient of 0.85 (see Table 3). A coefficient of 1 indicates a total dependence on genetic factors, whereas a value of 0 indicates no genetic influence. It is clear from the range of heritability coefficients reported for each variable that the magnitude of genetic influences is difficult to quantify with precision. Based on a knowledge of inheritance and use

Table 3. Heritability coefficient estimates of variables related to talent in soccer (mean ± *s* or range)

Anthropometry	
Height	0.85 ± 0.07
Leg strength	0.80 ± 0.10
Height^3/weight	0.53 ± 0.19
Skinfolds	0.55 ± 0.26
Ectomorphy	0.35–0.50
Mesomorphy	0.42
Endomorphy	0.50
Physiology	
$\dot{V}O_{2max}$	0.30–0.93
Slow-twitch muscle fibres	0.55–0.92
Anaerobic power	0.44–0.97
Muscle endurance	0.22–0.80
Field and performance tests	
Sprinting	0.45–0.91
Jumping	0.33–0.86
Flexibility	0.69–0.91
Balance	0.24–0.86
Static strength	0.30–0.97

Sources: Bouchard and Malina (1983) and Maes *et al.* (1993).

of population data, tools are available to predict adult height of growing children. Such information could be very valuable to soccer coaches concerned about the long-term prospects of their young protègès.

Regression equations that can be applied to boys at the ages of 6 and 11 years, respectively, were described by Komadel (1988). The equations require information on stature (in centimetres) currently and 'mid-parents value' calculated from the heights of both parents, divided by two. An alternative approach exemplified by Tanner *et al.* (1983) incorporated stature (cm), chronological age (years) and skeletal age (years) into the regression equation to predict adult stature. Lack of ready access to methods of assessing skeletal maturity limits the use of this particular approach. More recently, Beunen *et al.* (1997) reported a non-invasive anthropometric method in which adult stature for a boy aged 12.5–13.5 years could be predicted according to an equation incorporating current stature, sitting height, triceps and subscapular skinfolds and chronological age.

The availability of regression formulae may give a misleading impression of their precision in predictions. The standard error of forecasting adult stature is equal to ± 4 cm. Furthermore, a limitation of the anthropometric formulae is that chronological age is not a perfect marker of biological maturity. Consequently, an early onset of maturation can bestow an advantage in selection due to the greater than average body size. Late maturers are not necessarily shorter as adults but they may have missed opportunities for training at a critical time. Young players who mature early biologically may be given specialist coaching which late maturers are denied at the same chronological age. The late developers may emerge as potential future players only when growth is completed. Nevertheless, Claessens (1999) considered the prediction of adult stature to be important within the talent detection and talent development processes in sport in general, without any particular reference to soccer.

There is a further confounding effect due to seasonal influences on eligibility for under-age competitions. A 12 months gap in age can make an enormous difference in performance capability in youth competitions. It is therefore not surprising that players with birth dates early in the eligibility season tend to be pre-selected for elite squads, in both England and Sweden (Brewer *et al.*, 1995). Evidence that this advantage persists into adult elite squads was reported by Richardson and Stratton (1999) when they analysed the birth-dates of the England World Cup squads for the 1982–98 campaigns. Their conclusions were as follows:

- there was an over-representation of England World Cup team players born early in the competition year (September to December);
- the discrimination effect was greatest for goalkeepers, forwards and defenders;
- talent identification and selection procedures should place more emphasis on talent and less reliance on physical attributes such as body size and strength.

It would appear, therefore, that if boys have a birth-date late in the competition year, they may be disadvantaged by procedures within soccer sports systems. The matching of children according to biological age is unrealistic (Borms, 1986), but there are opportunities to band players according to body size for training purposes.

Body composition is more amenable to environmental and training factors than are linear anthropometric variables. The mean heritability coefficient cited in Table 3 for skinfold thicknesses is 0.55, but there is a large standard deviation. Coefficients for somatotypes range from 0.35 to 0.50, the mean value for mesomorphy being 0.42 (Bouchard and Lortie, 1984).

Maes *et al.* (1996) provided evidence that genetic factors are more influential than environmental variables in a range of measures in 10-year-olds. Fitness components included nine motor tasks and six skinfold measures. The tests were divided into performance-related (stature, strength, 'explosive' strength, running speed, speed of limb movement and balance) and health-related (trunk strength, functional strength,

$\dot{V}O_{2max}$, flexibility) measures. The performance-related fitness characteristics were moderately to highly heritable, and heritability estimates were slightly higher for the health-related fitness characteristics. The heritability coefficients ranged from 0.56 for speed in a shuttle run to 0.97 for static strength in an arm pull.

The partitioning of genetic and environmental determinants of biological and performance-related functions is an informative descriptive exercise. In contemporary genetics research, a major effect is being devoted to completing the tracing of human gene sequences in their entirety. The most prominent programme is known as the Human Genome Project, which has accelerated the international effort to trace genes responsible for many biological phenomena and functions, including the location of genes that are important in determining variation in human performance and in its physiological correlates. The panel of genes responsible for variability in human performance is the subject of a collaborative programme (GENATHLETE project) between North American and European research centres. As the research so far has focused primarily on cardiorespiratory endurance and $\dot{V}O_{2max}$ (factors that are linked with performance in top-class soccer), it is relevant to a discussion of potential for soccer.

A muscle creatine kinase (CK) variant has been identified in the muscle samples of individuals who were the more effective in aerobic performance over a 90-min test and in the response to aerobic training (Bouchard *et al.*, 1989). The suggestion was that the variant CK individuals could be at a disadvantage in training anaerobic performance while benefiting most from aerobic training. Later, Rivera *et al.* (1997) reported that the muscle-specific CK genotype accounted for 9% of the increase in $\dot{V}O_{2max}$ associated with endurance training. Associations have also been described between $\dot{V}O_{2max}$ and mitochondrial DNA sequence variations (Dionne *et al.*, 1991), which also contributed to variation in the response to training. Relationships have also been reported between the angiotensin-converting enzyme (ACE) and performance-related phenotypes (Montgomery *et al.*, 1998), although a physiological explanation for the connection is lacking. It is possible that the reported relation is attributable to linkage disequilibrium with other genes in close proximity to the ACE locus (Jeunemaitre *et al.*, 1992).

Any application to sport of findings arising from research stimulated by the Human Genome Project probably lies well into the future and is likely to be restricted to health-related exercise. Indeed, Montgomery and Wood (1999) considered that the number of candidate genes that may influence vari-

ability in human performance is enormous. While encouraging the progress of genetics research into exercise performance for health and humanistic reasons, these authors cautioned against the misuse of the new discoveries, 'for instance in attempts to select athletes for training'. It is unrealistic to expect that gene sequencing will yield a formula for identifying potential talent in actions such as those skills engaged in soccer.

It is clear, therefore, that based on genetic principles there is no parsimonious solution to the selection of young soccer players according to anthropometric, physiological or biomolecular criteria. Nevertheless, profiling of young players according to anthropometric, physiological and performance characteristics is potentially highly useful in monitoring their progress through the age groups. Various approaches to evaluating the fitness of young players have been adopted throughout the world. These approaches have been augmented by periodic reports by researchers working with soccer teams. Together they have potential to generate a database that would provide reference material for different age-bands (Leatt *et al.*, 1987; Matsudo *et al.*, 1987; Hugg, 1994). The influence of biological age and the possible confounding influences of ethnic factors should be considered when these databases are inspected.

Performance profiles

A pyramid model representing six different levels of sports involvement was described for assessment of Brazilian children and youths aged 7–18 years. The tiers ranged from participants in physical education classes at the foot of the pyramid (Level 1) to those engaged in international competition at Level VI. Cross-sectional norms were used to assess developmental status and monitor change. These profiles incorporated anthropometric (height, weight, skinfolds), physiological ($\dot{V}O_{2max}$) and performance (50-m sprint, 40-s run, vertical jumps with and without arm assists, long jump, shuttle run) measures. In a review of their approach, Matsudo *et al.* (1987) concluded that differences in physique and performance at various standards of competition compared to non-athletic prototypes may be used to infer selective and training factors.

The relevance of $\dot{V}O_{2max}$ in establishing physiological characteristics of young Croatian soccer players was examined by Jankovic *et al.* (1997). Their participants were 47 members of the national team aged 15–17 years who were assessed for heart volume, $\dot{V}O_{2max}$, ventilatory responses to a graded treadmill test, a range of muscular strength tests, as well as limb speed in the dominant hand and leg. Although height and weight accorded with norms for the age range, the cardiorespiratory measures were well above normal population values.

Table 4. Anthropometric and physiological measurements in under-age players

Source	n	Players	Age (years)	Height (m)	Body mass (kg)	HR_{max} (beats· min^{-1})	$\dot{V}O_{2max}$ (ml· kg^{-1}· min^{-1})
Leatt *et al.* (1987)	8	Canada under-16	15.4 ± 0.5	1.71 ± 0.04	62.7 ± 2.8	-	59.0 ± 3.2
	9	Canada under-18	16.7 ± 0.5	1.76 ± 0.04	69.1 ± 3.4	-	57.7 ± 6.8
Jankovic *et al.* (1993)		Croatia national	16.0 ± 0.5	1.76 ± 0.05	66.2 ± 5.6	197 ± 9	59.9 ± 6.3
Jones and Helms (1993)		English League	14.9 ± 1.2	1.70 ± 0.08	55.4 ± 8.3	-	62.0 ± 2.0
		English League	15.8 ± 1.1	1.75 ± 0.06	66.3 ± 7.3	-	60.2 ± 6.0
Tumilty (1993)	16	AIS Squad	16.1 ± 0.7	1.78 ± 0.07	71.3 ± 6.7	181 ± 6	61.4 ± 4.0
Hugg (1994)	30	Australian under-17 (at World Championships)	-	1.72 ± 0.06	65.5 ± 6.0	-	N.A.
	23	Australian under-17 (at 1993 World Championships)	-	1.74 ± 0.07	65.1 ± 6.0	-	55.7 ± 4.2
Franks *et al.* (1999)	64	English National under-16	-	1.76 ± 0.06	69.9 ± 6.3	N.A.	59.3 ± 3.8

N.A. = not available.

Table 5. Anthropometric and performance profiles of 66 international under-16 England players (mean ± *s*)

	Goalkeeper ($n = 8$)	Defender ($n = 24$)	Midfield ($n = 22$)	Forward ($n = 10$)	Significance
Height (m)	1.84 ± 0.02	1.77 ± 0.01	1.73 ± 0.01	1.72 ± 0.02	$P < 0.001$
Body mass (kg)	79.4 ± 1.8	69.9 ± 1.1	67.6 ± 1.1	67.7 ± 1.7	$P < 0.001$
Body fat (%)	14.1 ± 0.7	11.0 ± 1.4	10.5 ± 0.4	11.0 ± 0.7	$P < 0.001$
Sprints					
15 m (s)	2.62 ± 0.07	2.48 ± 0.04	2.51 ± 0.04	2.43 ± 0.07	N.S.
40 m (s)	5.83 ± 0.11	5.53 ± 0.06	5.59 ± 0.06	5.43 ± 0.11	N.S.
$\dot{V}O_2$ (ml· kg^{-1}· min)	55.7 ± 1.5	59.6 ± 1.0	60.4 ± 0.9	60.0 ± 1.5	N.S.

Source: Franks *et al.* (1999).

The sample was subdivided into those who became top-class professionals in Croatia, Germany, Italy or England and those who did not progress beyond competing in regional leagues (deemed unsuccessful). Those who were successful were taller and had a greater heart volume, respiratory measures, $\dot{V}O_{2max}$ and leg speed. The authors concluded that aerobic power can be a useful test in the selection of soccer players aged 15–17 years. This research represents one of the few longitudinal studies of elite players, even though physiological measures were not followed through into the participants' professional years. Observations on a selection of cross-sectional studies of national representative under-age teams are given in Table 4.

Both $\dot{V}O_{2max}$ and performance in an intermittent endurance test have demonstrated a correlation with work-rate in a game in both junior and senior players. In adult professional soccer players, the aerobic power, as indicated by $\dot{V}O_{2max}$ (Reilly, 1994a,b) and an intermittent endurance test (Bangsbo, 1994b), was correlated with distance covered in a competitive game. Tumilty (1993) demonstrated the same relationship in 16 members (age 16.1 ± 0.7 years; mean ± *s*) of the Australian Institute of Sport Association soccer squad for 1990. Work-rate was not significantly related to anaerobic capacity as determined in a treadmill run lasting 73.5 ± 8.4 s.

Players already highly selected and exposed to systematized training for national teams may not be so easily separated. Franks *et al.* (1999) studied a sample of 66 elite England International under-16 players exposed to 2 years of specialist training. Altogether, a 12-year intake of players was analysed, divided into those that succeeded in signing a contract as a full-time professional and those who did not acquire a professional contract on graduation (see Table 5). The groups could not be discriminated on the basis of anthropometry (height, weight, skinfolds), $\dot{V}O_{2max}$ or sprinting performance (15 m, 40 m). The authors concluded that, in a highly selected group of under-18 players, other more complex factors determined the players' employability as professionals. Nevertheless, the players overall had high anaerobic and aerobic performance, with $\dot{V}O_{2max}$ approaching 60 ml· kg^{-1}· min^{-1} among the outfield players irrespective of positional role. When positional roles were examined (confirmed by coaches'

assessments), significant differences were evident, mainly among the anthropometric measures (see Table 4). Goalkeepers were the tallest and heaviest and had more body fat than the other players, whereas the forwards were the smallest with the midfield players having the lowest body mass and body fat.

There are limited data with respect to the anaerobic power of young soccer players. Caru *et al.* (1970) tested 95 soccer players aged 14–18 years. They found that these players had higher values than non-athletes of similar ages. Nevertheless, in recent years emphasis has been placed on sprint performance tests for talented young players and these procedures have yielded useful reference data for performance.

Anaerobic performance profiles have also incorporated short all-out runs. Ribeiro and Sena (1997) used five 30-m sprints with 90 s rest between repetitions when assessing young players at Porto FC. Their participants included 33 boys aged 12–14 years, 23 aged 15–16 years and 26 aged 17–19 years. Speed improved with age; for each group the forwards were the fastest players and the goalkeepers the slowest.

The intermittent field test designed by Lindquist and Bangsbo (1993) was administered to 122 players aged 10–19 years to determine the intermittent exercise performance of young soccer players. Their results provide a useful database for reference purposes against which fitness test measures of age-matched young players could be compared. Except for an apparent plateau in the group aged 15, there was a systematic improvement between years in the total distance covered in the test. There was a significant linear correlation ($r = 0.65$; $P < 0.05$) between chronological age and the distance covered. The authors concluded that, in view of the variation between individuals, specific physical training should be given a lower priority than technical aspects until late puberty.

Twenty-three national team members (age 16.1 ± 0.4 years, height 1.71 ± 0.05 m, body mass 65.8 ± 5.1 kg; mean $\pm s$) in Portugal were studied by Garganta *et al.* (1993). The performance tests used were a 4×5.5 m shuttle run, a standing vertical jump and a counter-movement jump. The elite players were better in all tests compared with a group of regional players. The somato-type of the elite players ($2.3 \pm 0.5–4.9 \pm 0.7–2.5 \pm 0.5$) demonstrated their better muscular make-up even at age 16 years.

A broadly similar pattern was noted by Leatt *et al.* (1987) in young Canadian players. They concluded that elite young football players have a somewhat above average height and mass, strong leg extensor muscles (particularly at high speeds of movement), a good vertical jump and flexible hip joints. There was some evidence of selection by lean body mass in the under-16s and the additional muscle mass observed in the under-18s was attributed to prolonged training, possibly with specific development of the fast-twitch muscle fibres.

Overview

There are many factors that predispose towards a successful career in professional soccer. Foremost among these is excellence in games skills and the cognitive abilities to make correct decisions within the game. In view of heterogeneity in anthropometric and physiological characteristics among top teams, it is not possible to isolate individual prerequisites for success with great confidence. Nevertheless, players must possess moderate to high aerobic and anaerobic power, have good agility, joint flexibility and muscular development, and be capable of generating high torques during fast movements. Although no genetic factors can be identified for markers of potential in soccer, the ability to tolerate systematic training is clearly important. It is likely that even a multivariate formula for predicting future success will remain elusive. This is hardly surprising in view of the multitude of factors that have to coalesce in the realization of an elite player.

It is probable that talent detection, identification and development are not amenable to a reductionist process that can permit ultimate potential to be defined with much degree of certainty. The cross-sectional nature of research on talented athletes restricts performance prediction and there have been few attempts to validate predictive models in longitudinal approaches. The problem is especially complex in sports such as soccer where performance itself is multifactorial. The use of information on biological inheritance in identifying talent in soccer is highly unlikely, although knowledge generated by human genetics research in the future has possible applications in health-related fitness. At present, anthropometric and physiological profiling is best viewed as an objective means of monitoring young players, while emphasis should be placed on technical skills and engagement in teamwork.

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