Physiological profiles of Hong Kong elite soccer players

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Most physiological profiles of elite soccer players originate from Western Europe and North America. Unfortunately, there is a scarcity of descriptive data on the physical characteristics of Asian soccer players. Therefore, the purpose of this study was to evaluate the physiological profiles of elite soccer players in Hong Kong. It was conducted in conjunction with the selection of the Hong Kong team before the 1990 Beijing Asian Games. In all, 24 professional soccer players were selected from a pool of 180 players as subjects for the study. The following means(s.d.) were observed: height 173.4(4.6) cm; weight 67.7(5.0) kg; body fat 7.3(3.0)%; forced vital capacity (FVC) 5.1(0.6) l; maximum oxygen uptake ($\dot{V}O_{2\max}$) 59.1(4.9) ml kg⁻¹ min⁻¹; anaerobic threshold (AT 80.0(7.2)% of $\dot{V}O_{2\max}$; alactic power index 13.5(2.4) W kg⁻¹; lactic work index 298(27) J kg⁻¹; peak isokinetic dominant knee extensor and flexor strengths 2.72(0.36) Nm kg⁻¹ and 1.65(0.20) Nm kg⁻¹. On average the physique of Hong Kong soccer players appeared to be smaller and lighter than those found in Europe, which may be one of the key factors that contribute to the lack of success of Hong Kong soccer teams in international competition.

Keywords: Soccer, elite athletes, oxygen uptake, body composition, isokinetic strength, anaerobic power

Despite the large number of soccer players in Asia, research dealing with the performance capacity of elite Asian soccer players is lacking. Most physiological data on elite soccer players originate from Western Europe and North America¹⁻⁶. To the best of the authors' knowledge, there have been no comprehensive reports on the physiological characteristics of Asian soccer players. A comparison of such data with those of international soccer teams may shed light on factors contributing to the lack of success of Hong Kong soccer teams in international competition. Since this is the first study describing the physiological profiles of Hong Kong players, it provides baseline data against which future studies can be compared.

Method

In all, 24 top Hong Kong professional soccer players of ethnic Chinese origin volunteered to participate in the study before selection of the national team for the 1990 Beijing Asian Games. The subjects were nominated by the Hong Kong Football Association from a pool of 180 professional players of nine first division teams. Informed consent was obtained from all subjects before testing. The test battery included measures of body composition, pulmonary function, maximal aerobic power, anaerobic threshold, anaerobic power, flexibility and muscle strength. All tests with the exception of the field tests took place at the Human Performance Laboratory of the Hong Kong Sports Institute (HKSI).

Percentage body fat was estimated from skinfold measurements using a Harpenden skinfold caliper (Quinton Instrument, Seattle, Washington, USA) at three different sites on the body surface⁷. The Vitalograph-Compact spirometer (Vitalograph, Buckingham, UK) was used to evaluate pulmonary functions by calculating the forced vital capacity (FVC), forced expired volume in one second (FEV_{1.0}) and maximal voluntary ventilation (MVV).

Maximal oxygen uptake ($\dot{V}O_{2\max}$) was measured using a continuous running test performed on a Quinton 65 treadmill (Quinton Instrument, Seattle, Washington, USA). All subjects were familiarized with the testing procedures before data collection. After a 10-min warm-up at 8.05 km h⁻¹ (0% grade), the subject began running at a velocity of 12.1 km h⁻¹ (0% grade). Every 2 min thereafter, the grade was increased by 2.5% until volitional exhaustion. Metabolic and respiratory measurements were obtained using a Gould 2900 Energy Expenditure Unit (Sensormedics, Yorba Linda, California, USA) and included $\dot{V}E$, $\dot{V}O_2$, $\dot{V}CO_2$, RQ, FE_{CO₂} and FE_{O₂} which were computed and displayed every 20 s. Anaerobic threshold (AT) measurements were determined by observing the onset of the non-linear relationship between $\dot{V}O_2$ and $\dot{V}E - \dot{V}CO_2$; and were expressed relative to oxygen consumption (% $\dot{V}O_{2\max}$) and heart rate (% HR_{max}).

Anaerobic power was measured according to the procedure developed to accompany the REPCO front access cycle ergometer (EX10, Repco Cycle, Huntingdale, Australia) and work monitor unit (EX50)⁸. The

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protocol is described in detail elsewhere⁹. Briefly, the subject was required to perform a maximal-effort standing cycle test over 10 s to assess work capacity and peak power. After another 2 min rest, the soccer player was required to perform 30 s of maximal standing cycle ergometry.

Maximal strength of extensor and flexor muscles of each knee was measured using an isokinetic dynamometer (Cybex II+, Lumex, New York, USA). After a warm-up, five consecutive maximal contractions were performed at 60° s⁻¹; peak torque was recorded as the highest value of the trials. The strength ratio between knee flexors and knee extensors of each leg (hamstring:quadriceps (H:Q) ratio) was also calculated.

The field test evaluation consisted of an endurance run, the Cooper 12-min run-walk test for distance¹⁰ and sit-and-reach test for flexibility. The endurance run was conducted outdoors on a tartan-surfaced, 400-m track. The sit-and-reach test was used to test lower back and hamstring flexibility.

The physiological profile of the Hong Kong players was compared with that of top soccer teams from other countries. Direct statistical comparisons could not be performed, since raw data were not available.

Results and discussion

Anthropometry

The physical characteristics of the subjects are presented in Table 1. As a group, the average age (26 years) was comparable with other studies of top soccer teams¹¹. Height (173.4 cm) and weight (67.7 kg) tended to be lower compared with first division English league soccer players (180.4 cm; 76.7 kg)¹² and Italian professional soccer players (177.2 cm; 74.4 kg)¹³. Body size represents ethnic, racial and possibly nutritional influences. Generally, the percentage of body fat of an adult male in his mid-20s is 15–16% of body weight. The subjects used in the study were lean, with a percentage of body fat of 7.3, which appears to be lower than that of Canadian Olympic soccer players (9.8%)⁴, Australian soccer players (9.7%)¹⁴, US professional soccer players (9.6%)¹, US national soccer players (9.5%)¹⁵, Kuwaiti world cup soccer players (8.9%)⁵ and Brazilian soccer players (10.7%)¹⁶.

Pulmonary functions

All pulmonary function variables (Table 2) measured in this study were above normal limits for the age group 19–34 years of the Hong Kong Chinese¹⁷. FVC (5.1 l) values appear to be higher than those of first division league Yugoslavian players (4.9 l)¹⁸, Indian national players (4.1 l)¹⁹, but comparatively lower than those of English league players (5.8 l)²⁰ and Dallas Tornado professionals (5.3 l)¹.

The mean FEV_{1.0} (4.2 l; % FVC = 82.4), and MVV (169.0 l) in this study demonstrated a high efficiency of the respiratory muscles at which air can be breathed in and out to supply the oxygen transport system. However, it is not surprising that the subjects exhibited lower pulmonary values compared

Table 1. Physical characteristics of Hong Kong elite soccer players (*n* = 24)

Variables	Mean(s.d.)	(range)
Age (years)	26.3(4.2)	(19–36)
Height (cm)	173.4(4.6)	(166.7–179.5)
Weight (kg)	67.7(5.0)	(67.3–76.4)
Lean body weight (kg)	62.2(4.2)	(52.1–70.3)
Body fat (%)	7.3(3.0)	(4.2–15.4)

Table 2. Selected pulmonary function measurements of Hong Kong elite soccer players (*n* = 24)

Variables	Mean(s.d.)
FVC (l)	5.1(0.6)
FEV _{1.0} (l)	4.2(0.6)
FEV _{1.0} (%)	82.4(5.0)
MVV (l min ⁻¹)	169.0(36.0)

FVC = forced vital capacity; FEV_{1.0} = forced expiratory volume at 1.0 s; MVV = maximum voluntary ventilation

with other endurance athletes such as cross-country runners (FVC = 5.7 l, Reference 21; MVV = 207.5 l, Reference 22) because of the intermittent bursts of intense action in which players frequently rely on anaerobic mechanisms.

Cardiorespiratory fitness

Data on selected aerobic capacity and cardiorespiratory fitness of the subjects are presented in Table 3. Mean $\dot{V}O_{2\max}$ (59.1 ml kg⁻¹ min⁻¹) for the subjects appears to be lower than the values reported for a group of top-level Australian players (62 ml kg⁻¹ min⁻¹)²³; the German national team (62 ml kg⁻¹ min⁻¹)²⁴; the national Swedish team (61 ml kg⁻¹ min⁻¹)²⁵; the national Canadian team (58.7 ml kg⁻¹ min⁻¹)⁴; and the Austrian national team (58.3 ml kg⁻¹ min⁻¹)²⁴. The Kuwaiti World Cup team appeared to have a lower $\dot{V}O_{2\max}$ than the Hong Kong players (51.9 ml kg⁻¹ min⁻¹) (Reference 5). The maximal aerobic power of elite soccer players seems to have values around 65–67 ml kg⁻¹ min⁻¹ (References 25–27), which reflect a fairly high aerobic demand, but less than that of other endurance events such as distance running, cycling, cross country skiing, etc. It is interesting to note the lower $\dot{V}O_{2\max}$

Table 3. Selected aerobic capacity and cardiorespiratory fitness of Hong Kong elite soccer players (*n* = 24)

Variables	Mean(s.d.)
$\dot{V}O_{2\max}$ (l min ⁻¹)	3.9(0.3)
$\dot{V}O_{2\max}$ (ml kg ⁻¹ min ⁻¹)	59.1(4.9)
HR _{max} (beats min ⁻¹)	179(7)
$\dot{V}E_{\max}$ (l min ⁻¹)	136(13.4)
O ₂ pulse (ml beat ⁻¹)	21.9(2.1)
Respiratory exchange ratio (RQ)	1.18(0.07)
$\dot{V}O_2$ at anaerobic threshold (ml kg ⁻¹ min ⁻¹)	47.2(5.4)
AT (% $\dot{V}O_{2\max}$)	80.0(7.2)
Heart rate at anaerobic threshold (beats min ⁻¹)	159(5)
AT (% HR _{max})	88.9(3.9)

values of the Kuwaiti soccer players, an Asian team which qualified in the top 24 teams in the world in 1982. This may suggest that a higher aerobic capacity may not be a critical factor in determining success.

The mean(s.d.) maximal heart rate (179(7)) of the subjects tended to be lower than that of the 1978 Argentina team (194(10))²⁸ and Austrian national team (194(6))²⁹, but similar to that of the 1984 West German national team (176(8))²⁴ and English league first division players (179(2))¹⁵. Reported mean(s.d.) values of $\dot{V}E_{\max}$ for soccer players varied from 108.3(16.9) l min⁻¹ (Reference 30) to 153.6(4.1) l min⁻¹. The values found in the current study (136.0(13.4) l min⁻¹) were within this range but are well below those achieved by elite cyclists (183 l min⁻¹)³¹ and professional basketball players (168 l min⁻¹)³². The mean(s.d.) oxygen pulse value of the subjects (21.9(2.1) l beat⁻¹) appeared to be lower in comparison with the highest average values reported for a German league team (29.1 l beat⁻¹), 1974 and 1981 national German teams (27.9 l beat⁻¹ and 28.2 l beat⁻¹) (Reference 24), and East German first division soccer players (24.0 l beat⁻¹) (Reference 33).

The measured anaerobic threshold as a percentage of $\dot{V}O_{2\max}$ (80.0%) for the Hong Kong team is similar to that for the Canadian national soccer team (80.5%)⁴, which is relatively high for trained athletes. The high ATs of the Hong Kong soccer players can be attributed, at least in part, to the specific inclusion of intermittent, high-intensity exercise in their training programme.

A reported study¹⁸ on heart rate values during the game indicated that the heart rate was above 85% of maximum for two-thirds of the time and it is suggested that the average oxygen consumption during a normal game can be close to 80% of maximal oxygen uptake²⁵. Mean heart rates of 157 and 175 beats min⁻¹, respectively, were also recorded from English league players³⁴ and from a top player in the Swedish team during a match³⁵. It is interesting to note that the anaerobic threshold data collected during the present study (80.0% $\dot{V}O_{2\max}$, 88.9% HR_{max} and 159 beats min⁻¹) is similar to these previous reports. It is reasonable to suggest that a competitive football match may require Hong Kong soccer players to exercise close to their anaerobic thresholds for long periods of the game.

Flexibility and endurance capacity

Field test results for flexibility and 12-min run in Table 4 showed low values for Hong Kong team members compared with other studies^{1,4,36}. Soccer players in general have been found to be less flexible than non-athletes with the exception of goalkeepers³⁷, and

Table 4. Field test scores of elite Hong Kong soccer players (n = 24)

Variables	Mean(s.d.)	(range)
Sit and reach (cm)	31.0(7.0)	(15.0–44.0)
Distance in 12 min (m)	2892(226)	(2430–3283)

67% of all players in one study had one, or several, tight muscles in the lower extremities³⁸. The mean sit-and-reach value measured in the present study (31.0 cm) was even lower than that for the average untrained individual (range 35–40 cm)³⁷, the Canadian Olympic soccer team (40.5 cm)⁴ and Dallas soccer team (51.3 cm)¹. This poor flexibility indicated tight hamstrings which may be due to the design of soccer training and the need for specific stretching to increase the range of motion in order to reduce the incidence of soccer injuries.

The mean 12-min run for distance (2892 m) in the present study was similar to that reported for the Dallas Tornado professionals (2993 m), but comparatively lower than the Brazilian national soccer team (3540 m)¹.

Anaerobic power

The anaerobic power data of Hong Kong soccer players and a comparison with other Hong Kong and Australian elite athletes⁸ are presented in Table 5. The mean(s.d.) alactic power index (13.5(2.4) W kg⁻¹); alactic work index (103(20) J kg⁻¹); and lactic work index (298(27) J kg⁻¹) measured in this study were comparatively lower than for cyclists, badminton players, squash players and swimmers. A sprint test on a bicycle ergometer, used to evaluate maximal anaerobic alactacid power in national Swedish soccer players, found a similar value of 13.5 W kg⁻¹. This is only approximately 10% higher than in untrained controls³⁹. A stair-run test to measure the anaerobic power of Olympic soccer players in one study⁴⁰ found that anaerobic power was less than in pentathletes, sprinters and middle-distance runners. The soccer players in the present study were found to be only average in anaerobic power in comparison with other sportsmen in Hong Kong.

Isokinetic knee strength

The torque output in the joint actions of the knee were assessed because they are important in the skills of kicking and shooting. The mean peak torque

Table 5. Anaerobic power tests – comparative figures from Hong Kong and Australian team athletes⁸

Sport	n	Mean(s.d.)		
		Alactic power index (W kg ⁻¹)	Alactic work index (J kg ⁻¹)	Lactic work index (J kg ⁻¹)
Soccer (HK team, present study)	24	13.5(2.4)	103(20)	298(27)
Cycling, road (HK team)	6	17.0(2.0)	131(17)	315(23)
Badminton (HK team)	8	17.1(2.0)	138(13)	332(22)
Squash (HK team)	5	15.0(2.0)	127(13)	321(25)
Squash (Australian state team)	7	14.7(2.1)	118(15)	318(19)
Swimming (Australian national team)	63	14.3(1.5)	118(13)	299(26)
Volleyball (Australian national team)	16	16.3(1.6)	131(14)	291(32)

Table 6. Peak torque outputs of the knee – comparative figures from Hong Kong team athletes (measured in Nm kg^{-1} at 60°s^{-1}). Data are presented for the dominant knee

Sport	n	Mean(s.d.)		
		Extension	Flexion	Flexion: extension ratio (%)
Soccer (present study)	24	2.72(0.36)	1.65(0.20)	60.0
Cycling, road	10	3.27(0.38)	1.88(0.29)	60.0
Badminton	11	3.42(0.43)	1.89(0.28)	55.5
Squash	5	2.97(0.32)	1.78(0.25)	60.0
Tennis	7	2.89(0.31)	2.02(0.44)	69.8
Water polo	12	2.80(0.28)	1.56(0.19)	55.7
Cricket	18	2.77(0.41)	1.57(0.21)	56.7

output of the knee flexion and extension and the comparative data from other Hong Kong team athletes are presented in Table 6. The mean(s.d.) knee extension (quadriceps) values $2.72(0.36) \text{ Nm kg}^{-1}$ at 60°s^{-1} were similar to those of the Singapore national soccer team ($2.66(0.57) \text{ Nm kg}^{-1}$ at 60°s^{-1})⁴¹, but somewhat lower than those of the Chinese national soccer team ($3.10(0.33) \text{ Nm kg}^{-1}$ at 60°s^{-1})⁴², and Hong Kong elite athletes in badminton, cricket, cycling, squash, tennis, waterpolo and cricket. Isokinetic measurements on the knee strength of elite soccer players were mostly conducted at an angular velocity of 30°s^{-1} (References 2, 3, 4, 43). Trial tests at 30°s^{-1} had been conducted previously at our laboratory using 70 other Hong Kong elite athletes and soccer players and the majority of subjects felt pain during the test and were not willing to continue. Since no previous literature had been reported for Asian athletes using an angular velocity of 30°s^{-1} , the question of whether a comparatively smaller body size and level of absolute strength contributes to muscle pain needs further investigation.

It has been known for some time that muscle strength imbalance can predispose an athlete to injury² and that isokinetic testing can serve as a tool for screening. The relationship of hamstring to quadriceps strength (H:Q ratio), an index for muscle strength balance, varies between 50% and 62% in healthy people⁴⁴. Sixty percent has been suggested as an ideal proportion^{45,46}. The H:Q ratio of the Hong Kong soccer players (60%) tended to be higher than that of the Chinese national soccer team (51.7%)⁴² and fell within the recommended range.

This is the first and most comprehensive physiological profile study of Hong Kong elite soccer players and, to the authors' knowledge, the most comprehensive investigation on Asian soccer players. The test data do provide a good baseline and reference for coaches, sports physiologists, physiotherapists and future investigators. Though soccer players are the only professional athletes in Hong Kong, physiological data show that the players tend to be smaller, comparable in cardiorespiratory fitness and anaerobic power, and appear to be lower in muscle knee strength, and poor in flexibility in comparison with data collected from other soccer teams and Hong

Kong elite sportsmen. All tests suggest strongly that if the team wants to achieve reasonable success in international competition, improvements in physical fitness need to be emphasized in addition to skill training. The selection of soccer players with height and weight comparable to those of the best teams of European origin may be one way to compensate for the ethnic disadvantages of being smaller in size.

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References

- 1 Raven PB, Gettman LR, Pollock ML. A physiological evaluation of professional soccer players. *Br J Sports Med* 1976; 10: 209–16.
- 2 Oberg B, Moller M, Gillquist J, Ekstrand J. Isokinetic torque levels for knee extensors and knee flexors in soccer players. *Int J Sports Med* 1986; 7: 50–3.
- 3 Oberg B, Ekstrand J, Moller M, Gillquist J. Muscle strength and flexibility in different positions of soccer players. *Int J Sports Med* 1984; 5: 213–16.
- 4 Rhodes EC, Mosher RE, McKenzie DC, Franks IM, Potts JE, Wenger HA. Physiological profiles of the Canadian Olympic soccer team. *Can J Appl Sports Sci* 1986; 11: 31–6.
- 5 Ramadan J, Byrd R. Physical characteristics of elite soccer players. *J Sports Med Phys Fitness* 1987; 27: 424–8.
- 6 Mangine RE, Noyes FR, Mullen MP, Barber S. A physiological profile of the elite soccer athlete. *J Orthop Sports Phys Ther* 1990; 12: 147–52.
- 7 Jackson AS, Pollock ML. Generalized equations for predicting body density of men. *Br J Nutr* 1978; 40: 497–504.
- 8 Telford RD, Minikin BR, Hahn AG, Hooper LA. A simple method for the assessment of general fitness: the tri-level profile. *Aust J Sci Med Sport* 1989; 21: 6–9.
- 9 Telford RD, Minikin BR, Hooper LA, Hahn AG, Tumility DMCA. The tri-level fitness profile. *Excel* 1987; 4: 11–13.
- 10 Cooper KH. A means of assessing maximal oxygen intake: correlation between field and treadmill testing. *JAMA* 1968; 203: 201–4.
- 11 Reilly T, Thomas V. Estimated energy expenditures of professional association footballers. *Ergonomics* 1979; 22: 541–8.
- 12 White JE, Emery TM, Kane JL, Groves R, Risman AB. Preseason fitness profiles of professional soccer players. In: Reilly T, Lees A, Davids K, Murphy WJ, eds. *Science and Football*. London, UK: E and FN Spon, 1988: 164–71.
- 13 Faina M, Gallozzi C, Lupo S, Colli R, Sassi R, Marini C. Definition of the physiological profile of the soccer player. In: Reilly T, Lees A, Davids K, Murphy WJ, eds. *Science and Football*. London, UK: E and FN Spon, 1988: 158–63.
- 14 Withers RT, Craig NP, Bourdon PC, Norton KI. Relative body fat and anthropometric prediction of body density of male athletes. *Eur J Appl Physiol* 1987; 56: 191–200.
- 15 Mangine RE, Noyes FR, Mullen MP, Barber SD. A physiological profile of the elite soccer athlete. *J Orthop Sports Phys Ther* 1990; 12: 147–52.
- 16 De Rose EH. Determination of the ideal body weight and corporal composition of 16 professional soccer players. In: *Questions of Athletes Nutrition: Abstracts of the Reports of the International Symposium*. Leningrad, Russia: Leningrad Institute of Physical Culture, 1975.
- 17 Lam KK, Pang SC, Allan WG et al. A survey of ventilatory capacity in Chinese subjects in Hong Kong. *Ann Human Biol* 1982; 9: 459–72.
- 18 Smokdlaka VN. Cardiovascular aspects of soccer. *Phys Sportsmed* 1978; 6: 66–70.

- 19 Ghosh AK, Ahuja A, Khanna GL. Pulmonary capacities of different groups of sportsmen in India. *Br J Sports Med* 1985; 19: 232–4.
- 20 Reilly T. 'What research tells the coach about soccer'. American Alliance for Health, Physical Education, Recreation and Dance, Washington, 1970.
- 21 Arstila M, Koirikko A. Electrocardiographic and vectorcardiographic signs of left and right ventricular hypertrophy in endurance runners. *J Sports Med Phys Fitness* 1966; 6: 166–74.
- 22 Bowers RW, Costill DL. Some physiological characteristics of distance runners. Presentation at American College of Sports Medicine Meeting, 1967.
- 23 Withers RT, Roberts RG, Davies GT. The maximum aerobic power, anaerobic power and body composition of South Australian male representatives in athletics, basketball, field hockey and soccer. *J Sports Med Phys Fitness* 1977; 17: 391–400.
- 24 Nowacki PE, Cal DY, Buhi C, Krummelbein U. Biological performance of German soccer players (professionals and juniors) tested by special ergometry and treadmill methods. In: Reilly T, Lees A, Davids K, Murphy WJ, eds. *Science and Football*. London, UK: E and FN Spon, 1988: 145–57.
- 25 Ekblom B. Applied physiology of soccer. *Sports Med* 1986; 3: 50–60.
- 26 Hollmann W, Venrath H, Bouchard C, Budinger H. Beanspruchung von Herz und Kreislauf bei verschiedenen Sportarten. *Fortschr Med* 1964; 82: 289–92.
- 27 Rost R, Hollmann W. Athlete's heart – a review of its historical assessment and new aspects. *Int J Sports Med* 1983; 4: 147–65.
- 28 Hollmann W, Liesen H, Mader A et al. Zur Höchst- und Dauerleistungsfähigkeit der deutschen Fussballspitzenspieler. *Dtsch Sportsmed* 1981; 32: 113–20.
- 29 Bachl N, Prokop L. Wie gut trainiert sind österreichische Fussballer? Leistungsdiagnostische Standortbestimmung aus der Sicht des Sportphysiologen. *Osterr J Sportmed* 1977; 7: 3–10.
- 30 Williams G, Reid RM, Coutts R. Observations on the aerobic power of university rugby players. *Br J Sports Med* 1973; 7: 390–1.
- 31 Folinsbec LJ, Wallace ES, Bedi JF, Horvath SM. Exercise respiratory pattern in elite cyclists and sedentary subjects. *Med Sci Sports Exerc* 1983; 15: 503–9.
- 32 Parr RB, Hooper R, Wilmore JH, Bachmann D, Kerlan RK. Professional basketball players: athletic profiles. *Phys Sports-med* 1978; 6: 77–84.
- 33 Israel G, Israel S. Der Einfluss der Spielposition auf organische und funktionelle Anpassungserscheinungen bei Fussballspielern. *Med Sport*, Berlin 1964; 4: 176.
- 34 Reilly, T. Fundamental studies on soccer. In: Andresen, R. ed. *Sportwissenschaft und Sportpraxis*, Hamburg, Germany: Verlag Ingrid Czwalina, 1986: 114–21.
- 35 Agnevik G. *Fotboll Idrottsfysiologia Rapport No. 7*, Stockholm: Trygg-Hansa, 1970.
- 36 Jette M. The standardized test of fitness in occupational health: a pilot project. *Can J Public Health* 1978; 69: 431–7.
- 37 Ekstrand J. Soccer injuries and their prevention (thesis). Linköping University Medical Dissertation, 1982: 130.
- 38 Ekstrand J, Gillquist J. The frequency of muscle tightness and injuries in soccer players. *Am J Sports Med* 1982; 10: 15–18.
- 39 Bergh U, Ekblom B. Influence of muscle temperature on maximal strength and power output in human skeletal muscles. *Acta Physiol Scand* 1979; 107: 33–7.
- 40 Prampero Di, Pinera Limas PE, Sassi G. Maximal muscular power, aerobic and anaerobic, in the athletes performing at the XIXth Olympic Games in Mexico. *Ergonomics* 1970; 13: 665–74.
- 41 Chook KK, Teh KC, Giam CK. The isokinetic strength of dominant quadriceps and hamstring muscles of 47 Singapore National sportsmen. In: *Proceedings of 2nd International Sports Science Conference: towards Sports Excellence* (11–13 September 1986), Singapore: Singapore Sports Council 1986: 127–33.
- 42 Li G, Chen X, Zhang W. Isokinetic strength and endurance of quadriceps and hamstring muscles in elite Chinese athletes. *Chin J Sports Med* 1988; 7: 143–8.
- 43 Poulmedis P. Isokinetic maximal torque power of Greek elite soccer players. *J Orthop Sports Phys Ther* 1985; 6: 293–5.
- 44 Knapik J, Ramos M. Isokinetic and isometric torque relationships in the human body. *Arch Phys Med Rehabil* 1980; 61: 64–7.
- 45 Bender JA, Pierson JK, Kaplan HD, Johnsson AJ. Factors affecting the occurrence of knee injuries. *J Assoc Phys Ment Rehabil* 1964; 18: 130–4.
- 46 Burkett LS. Causative factors in hamstring strains. *Med Sci Sports* 1970; 2: 39–42.