Summary

Field hockey is a sport with a long history that has undergone quite rapid and radical change within the past decade. The advent of the synthetic playing surface has changed the technical, tactical and physiological requirements of the game at all levels, but in particular at the elite level. In order to cope with the technical evolution within the game, the hockey player has also had to develop physiologically to meet the physical standards required at elite levels.

Analysis of the physiological cost and energy expenditure of playing hockey has placed it in the category of 'heavy exercise', with reported VO₂ values during a game of 2.26 L/min. Energy expenditure has been estimated to range from 36 to 50 kJ/min.

Physiological profiling of female hockey players has shown that somatotype tends towards 3.5/4.0/2.5. Figures for percentage body fat in female players range from 16 to 26%. Anaerobic power output has been shown to compare favourably with other groups of sportswomen and has also been shown to be a discriminating factor between elite and county level female players. Aerobic power amongst female players has been shown to range from 45 to 59 ml/kg/min.

The reported somatotypes of male hockey players have shown considerable variation but there seems to be a trend away from ectomorphy towards mesomorphy. Anaerobic power output in male players has been shown to be the same as that of soccer players and better than other sports,
e.g. basketball and also higher than reference norms. The range of aerobic power reported in the literature is 48 to 65 ml/kg/min and it would appear that an aerobic power in excess of 60 ml/kg/min is required for elite level play.

The physical strain of hockey play has been shown to be considerable, in particular with respect to spinal shrinkage. There is a greater injury risk inherent in playing on synthetic surfaces than on grass.

1. Historical Background

The game of field hockey has a long history. It is thought to have evolved from prehistoric humans’ delight in stick-and-ball games. Its origins as a semiorganised activity have been traced to Asia, about 2000BC. There is evidence to show that a form of the game was played by the Egyptians 4000 years ago and later in Ancient Greece. It is believed that the Romans developed the game from the Egyptians and Greeks and passed it on to the European nations they conquered. Thus, German (Kolbe), Dutch (het kolven – a forerunner of ice-hockey) and French (hocquet – meaning shepherd’s crook) versions of the historic game were developed (Ward 1989). The true ancestor of hockey is assumed by some sport historians to be Irish hurling, the original Gaelic term ‘iomáin’ meaning a ‘thrusting action’ or a vigorous forward drive (Brisch 1972): hurling is thought to be the oldest of the stick-and-ball games.

The game grew to such popularity in fourteenth century England that it was banned by King Edward III in 1365 due to its interference with men’s national service. Its appeal persisted and the ban was finally lifted, although hockey reappeared in a list of prohibited games in 1527. The lack of rules inevitably led to accidents and injuries in a rough, dangerous game played with sticks by easily roused and committed participants.

The formation of the Blackheath Club in the London area in 1840 led to the drafting of the first set of rules and codes for the game. Other clubs emerged in the metropolis and the game was finally standardised in 1883 by the Wimbledon Hockey Club. Its regulations were adopted in 1886 when the Hockey Association was formed. The adoption of the ball to replace the ‘bung’ (a cube of solid rubber) used by the Blackheath players helped to improve the game, encouraging passing and stickwork skills compared with the hacking techniques used to propel the ‘bung’. National Associations were founded soon after in Ireland (1893), Wales (1897) and Scotland (1901). At the same time national associations were formed overseas in France (1887), The Netherlands (1898), New Zealand (1902), Belgium (1907), Denmark (1908) and Austria (1910). The game was brought into the Olympics in 1908. The Calcutta Hockey Club, founded in 1895, formed the basis of Olympic Games successes of India whose team dominated the Olympic men’s competition from 1928 until defeated by Pakistan in 1960. Internationally the game is regulated by the International Hockey Federation (FIH) set up after hockey was omitted from the 1924 Olympics in Paris.

The Ladies’ Hockey Association was established at the same time as the Men’s; later, it became the All England Women’s Hockey Association in 1895. The first known ladies’ hockey club was Molesley formed in 1887 and the first women’s international match was played in 1896 at Dublin between Ireland and England. Soon after this the women’s international programme was widened to include Scotland, Wales, New Zealand, Belgium, South Africa, USA, Denmark, France, Holland and Germany. From early in this century the game has been adopted as the primary field game for girls in secondary schools in many European countries.

2. Technical Development

Hockey is described as a field-invasive game and is played on a pitch 90m long and 55m wide. Teams are composed of 11 players, including a goalkeeper.
Unlike other stick-and-ball games (hurling, lacrosse, bandy and shinty) the ball is played with the stick on the ground and use of the hand in catching is prohibited. A match is played over 2 halves, each of 35 minutes, with a 5 to 10-minute interval break. The game calls for a wide repertoire of skills, physical and psychomotor attributes.

In terms of technical development there are 2 areas of change that have affected the physiological requirements of the game. These are the hockey stick and the playing surface.

Advances in stick construction, over the past decade in particular, have allowed players to reach greater levels of ball control and have also increased their hitting power. The crook of the stick has become much tighter and smaller in the more recent years, giving rise to the improvements in ball control. The physical properties of the stick have also changed, from sticks constructed purely of wood to sticks that are amalgams of wood and man-made materials such as Kevlar and aluminium. These changes have increased the rigidity of sticks, thereby allowing greater pace to be imparted to the ball since less energy is lost at impact in the vibration of the stick. It is now possible to attain a greater velocity on shot and pass with the same level of muscular work.

The second significant factor in technical development has been the advent of the synthetic playing surface. The ramifications of this are discussed fully in the next section.

Hockey is similar to the majority of field-invasive games; however, it does have one unique feature. The rules governing the use of the stick and the type of design to be used preclude any left-handed sticks. They require the player to use only the flat side of the stick. Consequently the easiest position from which to exercise the majority of skills is with the ball out to the right of the body. The effectiveness of this body-ball position determines the pattern of play when 2 opposing players confront each other. An attacker will work to try to take the ball around the left side of the defender, the defender’s weakest tackling area; the defender will try to force an attacker to pass down his/her right side, the strongest tackling area.

The right-sided playing position also determines the main characteristic of the game at competitive level. The right wing is the main channel of attack for all teams. Hughes (1988), in an analysis of women’s hockey, confirmed that the majority of attacking moves occurred on the right side of the pitch. This happens for 2 reasons:

1. It is easier to beat a defender when moving right; therefore, when players dribble forward there is a tendency to drift right.
2. It is easier to control a ball when moving at pace if the ball is arriving from left to right. It is, therefore, customary to mount attacks down the right side of the pitch where players can receive the ball whilst moving at speed since all passes out to the right wing are, by definition, moving from left to right.

Hockey is a game with an inbuilt assymetry (by virtue of the design of the hockey stick) in terms of individual and team play. This should serve to raise the physiological demand of the game since players are forced to pay greater attention to body position in relation to both ball and opponent. The maintenance of correct positioning will serve to increase the work-rate when playing and in particular defending.

The demands of the game are first described prior to reviewing fitness profiles of participants at a high level. Both men’s and women’s games are considered.

3. Work-Rate in Hockey

The exercise intensity in hockey can be gauged from a motion analysis of match-play. Such analysis can be used to highlight the frequency and level of activity cycles during games and the recovery periods punctuating the bouts of physical activity. From these work-rate profiles, the relative combinations of anaerobic and aerobic processes towards the total metabolism have been estimated.

Fox (1984) included hockey with lacrosse and soccer among sports with a 30% aerobic, 70% anaerobic contribution to energy expenditure. Later Sharkey (1986) classified the game as bordering on
the aerobic side (40% anaerobic, 60% aerobic) of the energy continuum, grouping it with sports of mixed demands including canoeing, kayaking, lacrosse, motocross and mountaineering. The contemporary game with its potential for continuous activity appears to be aerobically more demanding than heretofore and it is appropriate to view the game at top level as aerobically demanding with frequent though brief anaerobic efforts superimposed.

Wein (1981) provided data on distances covered by players during a match in the second World Cup in 1973. These indicated that on average players were in action for 20.6 minutes (30% of match time) and in that time covered 5.61 km, implying a work-to-rest ratio of 2:5 approximately. Defenders were reported to cover less ground (5.14 km) and midfield players more ground (6.36 km) than the average. The player covering the greatest distance was on the New Zealand team, and had a value of 8.82 km. Although the reliability of the data collection procedure was not reported, the work-rate per minute covers the range of observations noted among professional soccer players, the mean value being somewhat lower (Reilly 1990).

A task analysis of players’ actions also suggested differences among outfield players, at least with the conventional game. Overall, hockey players were reported to ‘make more light than strenuous movements’, 69% compared with 31%. Centre-forwards were noted to make the highest number of strenuous movements (36%) whilst defenders and ‘halves’ functioned with 70% of light movements. The ‘heavy’ movements would call for great muscular effort in hitting the ball strongly, whereas light movements would encompass push passing for precision and dribbling (Wein 1981). Of all the activity on the ball, 61% lasted between 0.5 and 2.0 seconds, only 5% lasting more than 7 seconds. Clearly much of the work-rate of players refers to motion ‘off-the-ball.’

Comparisons of energy expenditure in field hockey have placed the men’s game in the category of ‘heavy exercise’, with a range of 30 to 50 kJ/min (Reilly 1981). Included with it are sports such as wrestling and boxing, which are of a shorter duration, and handball. Analysis of the women’s game has indicated that the most strenuous position, centre midfield, has an energy expenditure of approximately 35 kJ/min (Skubic & Hodgkins 1967). The figures are based on estimates rather than direct measurements due to the difficulties of monitoring VO₂ during match-play. From direct measurements of Indian soldiers playing a game, a value of 36.4 kJ/min (8.7 kcal/min) was reported (Malhotra et al. 1962). In view of the likely recreational nature of the game, this figure would understate the energy expenditure of competitive match-play.

Dribbling also entails elevated physiological responses to moving at a given speed compared with normal running. Reilly and Seaton (1990) measured energy expenditure, heart rate and perceived exertion in hockey players dribbling a ball on a treadmill at speeds of 8 and 10 km/h. Dribbling was found to increase energy expenditure by 15 to 16 kJ/min above that observed in normal running. The mean elevation in heart rate was 23 beats/min whilst the rating of perceived effort increased from values corresponding to ‘very light’ and ‘light’ to ‘somewhat hard’ and ‘hard’ in the 2 speeds used in the experiment. The greater additional energy cost in field hockey compared to dribbling a soccer ball (Reilly & Ball 1984) may be accounted for partly by postural factors and also the arm and shoulder exercise in using the hockey stick. Additionally, the intermittent nature of activity during match-play, the physiological costs of accelerating, decelerating and changing the direction of motion, add to the energetic requirements. Therefore the physiological cost of hockey play will be underestimated if the prediction of oxygen consumption, and hence energy expenditure, is based on the speed of locomotion.

The playing surface may also have an influence on the severity of the physical and physiological strain on players. According to Wein (1981) the effective duration of a hockey match played on gras at the second World Cup in Amsterdam in 1973 was only 53% of the total game time. Interruptions lasted 8.7 seconds on average and about twice as many occurred compared with soccer at a com-
parable standard. There were 230 stoppages per match in the Pre-Olympic Tournament at Montreal in 1975, averaging 1 every 18 seconds. Adoption of synthetic surfaces at the 1976 Olympic Games and at all major international tournaments soon after helped to increase the playing times and decrease the number of interruptions. This was enhanced by the rule changes in 1981-2 which were designed primarily to speed up the game and keep the ball in play longer than before.

Hughes (1988) compared performances in international women’s matches between artificial and grass surfaces. On average there were significantly more touches per possession on the artificial surface. It was suggested that team skills are more easily executed on artificial than on natural pitches. As a proportion of the total number of touches, players ran with the ball more on the artificial pitch. It was concluded that tactics adopted on the synthetic turf do differ from tactics on grass.

The main advantage of the synthetic surface over grass is that surface characteristics are more consistent over the whole playing area. The ball also travels over the surface with greater pace. Both of these factors have caused changes in the style of play at an individual and a team level that can be reasoned to have affected the physiological requirements of the game (Malhotra et al. 1983).

At an individual level it is far easier to exercise personal skills thereby facilitating the retention of possession even under pressure. As a consequence of this, defending players have to work much harder at maintaining correct positioning in relation to the attacking player, i.e. body in line with the attacker’s right shoulder, denying space on the attacker’s right and ‘inviting’ movement toward the defender’s right. An extension of the individual positional requirement is the greater emphasis being placed upon channeling skills, i.e. the player’s ability to guide an opponent into a well defended area of the pitch. At a team level the speed of ball movement combined with higher individual skill levels, has placed greater emphasis upon a team’s ability to play as a cohesive unit. The increased emphasis on the quality of tactical play has led to a rapid development and refinement in systems of play. Teams now adhere more closely to the concept of ‘total’ hockey, with players being able to comfortably interchange position during the course of a game without disrupting team balance. Players are therefore required to cover greater yardage within a game and as a consequence need to have the aerobic fitness to do so.

The playing changes that have been induced by the introduction of synthetic pitches all require of the modern player a greater level of all-round fitness. One study of the physiological demands of this sport used a Kofranyi-Michaelis meter for measurement of \( \dot{V}O_2 \) and \( \dot{V}E \) during a hockey game (Malhotra et al. 1983). The purpose of the study was to compare physiological responses to play on synthetic surfaces and on grass. Higher physiological responses were associated with the artificial pitch, mean \( \dot{V}E \) being 56.8 vs 46.6 L/min and mean \( \dot{V}O_2 \) being 2.26 vs 1.91 L/min. The \( \dot{V}O_2 \) values would correspond to energy expenditures of approximately 46.5 kJ/min (11.1 kcal/min) and 39.3 kJ/min (9.4 kcal/min) for the artificial and grass pitches, respectively. The higher physiological stress of playing on the synthetic pitch was due to the faster pace of play and higher running speeds. However, the game was 6-a-side played on half a normal-sized pitch and so was not definitive of true field hockey matches.

4. Positional Role

The evolution of playing formations within hockey initially followed the same pattern as in soccer. The classical 2:3:5 formation dominated tactical thinking for decades until the mid-1960s when a sweeper system was introduced into play in West Germany (Wein 1981). Since the mid-1960s the game has become more varied and dynamic in the formations that are used, the most popular systems being 1:3:3:3, 1:3:2:4 and 4:2:4 (Whitaker 1986). On top of the diversification in the playing formations used the advent of the synthetic playing surface has altered styles of play such that players are now expected to be capable of frequently interchanging position in the course of a game.
In the early investigations of female hockey players, physique and muscle function were shown to differ between playing positions. Johnston and Watson (1968) reported that forwards require a more muscular physique because of the greater speed, power and strength necessary in attacking play. A later study by Verma et al. (1979) partly supported this view in that forwards had a higher vertical velocity in a stair run test than backs and halfbacks; however, goalkeepers had a higher vertical velocity than the outfield players. The ranking of players on anaerobic power on the stair run showed that due to the low bodyweight of the forwards (mean 49.6kg), they were inferior to both goalkeepers and backs, although they had better performances than the halfbacks. The authors concluded that the speed and ability to accelerate as denoted in the vertical velocity findings along with the light bodyweight was a good combination of characteristics for forward players to perform their field duties.

Wilsmore (1987) concluded that somatotype is important in differentiating between players in various positional roles, particularly at higher levels of competition for women. There was a tendency for all players towards mesomorphy, but backs and halves tended to be more so inclined than forwards. Backs as a group had higher endomorphy ratings than halves or forwards and lower ectomorphy ratings. This somatotype profile would render them the less mobile but the more robust of the outfield players.

This picture of positional differences does not totally correspond to the findings of Ready and van der Merwe (1986) on the Canadian Olympic squad. The outfield players were classified as defenders, midfield and strikers, corresponding to the backs, halves and forwards of the Indian and Australian researchers. It was thought that the training programme and the system of play used by Canada would even out the fitness demands of outfield positions, but forwards were found to have the highest vertical velocity in a stair run and the highest $\dot{V}O_2$ max (fig. I); midfield players had the greatest anaerobic capacity measured in a treadmill run test. Defenders had the lowest anaerobic power, peak torque on an isokinetic dynamometer, peak lactates level and $\dot{V}O_2$ max among the outfield players. The authors expressed caution about generalising from the positional comparisons, in view of the small numbers in some of the outfield roles.

In a fitness evaluation of 24 English female hockey players Reilly and Bretherton (1986) failed to separate players according to positional roles on the basis of fitness test profiles. This applied to kinaesthetic measures, muscular strength and power, aerobic fitness and field tests. This conclusion did not apply to the goalkeepers who tended to be high in anaerobic power measures and poor to moderate in aerobic fitness indices.

Bhanot and Sidhu (1983) examined Indian male players for differences between playing positions. They recorded that goalkeepers were highest in vertical velocity in a stair run test and had the highest anaerobic power output. The poorer scores were for forwards, on both measures back and halfbacks being intermediate; this observation is at odds with the findings of Verma et al. (1979) for female players. Bhanot and Sidhu also recorded that speed and anaerobic power were better in left than right backs and that right wingers were faster than left. This is explained by the overall nature of the game.
in which the right side is the stronger attacking wing, resulting in asymmetry in play.

In examining the issue of positional requirements one must bear in mind that the increased introduction of synthetic surfaces, together with the natural evolution of the game, has significantly altered systems of play. These changes may have caused a blurring of the positional differences that were found in earlier studies. One must also consider that the construction of synthetic surfaces was more prolific in Western Europe and Australia than in India and Pakistan during the 1980s. It is possible that this may have led to differences between the playing populations of different countries within this period. Care must therefore be taken in comparing European, Australasian and Asian studies.

5. Fitness Profiles: Women's Hockey

5.1 Anthropometry

The physique of female hockey players as indicated by somatotype tends towards a profile of 3.5/4.0/2.5 (Bale & McNaught-Davis 1983; Reilly & Bretherton 1986; Wilsmore 1987). A more defined somatotype of 3.2/4.4/2.4 was reported by Scott (1991) for African female players. A muscular physique is beneficial in many aspects of the game such as tackling and 2-handed hitting. Players tend to be low in ectomorphy; a specific disadvantage of a linear physique was demonstrated by Reilly and Bretherton (1986) who reported a negative correlation between ectomorphy and accuracy in a sustained hockey skills test. Female hockey players are generally more endomorphic than distance runners of a comparable competitive standard, an observation that is also reflected in estimates of body composition.

Percentage bodyweight as fat for national standard players was reported to be 25.1% (Johnston & Watson 1968) and 25.3% (Withers & Roberts 1981). These values are close to those reported for the general population of comparable age. Reilly et al. (1985) reported a figure of 25.8% for the Welsh national squad (table I), whilst values of 23.0 ± 1.9 and 22.9 ± 2.9 were found in English elite squad and county players, respectively (Reilly & Bretherton 1986). Withers et al. (1987a) found a mean of 20.2% for South Australian representative players; this was higher than the overall mean for games players (19.4%) within their study. The review of Reilly and Secher (1990) reported a spread of mean values in the literature for female hockey players ranging from 16 to 26%. The lower values may be found at the highest level of play as peak fitness for international tournaments is attained. Ready and van der Merwe (1986) in monitoring 18 members of the Canadian Olympic team in the year leading up to the Los Angeles Olympics found that mean percentage body fat dropped from 18.9 to 15.7% over the period of investigation.

Although height is not necessarily a predisposition for top-class hockey, mean values tend to be in the range 162 to 165cm. This is taller than mean values for cross-country skiers, alpine skiers and gymnasts, but smaller than mean values for weightthrowers, netball and softball players (Reilly & Secher 1980). Mean bodyweight values in the range 58.0 to 62.9kg show that female hockey players are on average heavier than orienteers and skiers, but lighter than pentathletes (now heptathletes), softball and netball players. It seems that female hockey players tend towards a moderate body size and a muscular physique to provide the robustness in body build suitable for rigorous competition. Exceptions to the trend are the Asian teams (notably Indian and Malaysian): the mean weight of the 23 Indian national players studied by Verma et al. (1979) was 51.0kg, goalkeepers and backs being the heaviest, forwards and halves being the lightest.

5.2 Muscle Performance

The figures reviewed by Reilly and Secher (1990) showed the high anaerobic power output of female hockey players in comparison with other games players. That mean performance on the stair run (955W) compared well with netball players (953W) and was superior to orienteers, cross-country skiers and softball players. When corrected for bodyweight the performance of the hockey players was 3.7 W.kg better than that of the netball players. The benefit of a high anaerobic power output is
Table I. Anthropometry of national women’s hockey teams. Values are mean ± SD

<table>
<thead>
<tr>
<th>Country</th>
<th>n</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>Body fat (%)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>16</td>
<td>165.8 ± 4.8</td>
<td>61.8 ± 7.4</td>
<td>25.8 ± 2.7</td>
<td>Tefford et al. (1988)</td>
</tr>
<tr>
<td>Wales</td>
<td>10</td>
<td>59.0 ± 3.2</td>
<td>25.8 ± 2.7</td>
<td></td>
<td>Reilly et al. (1985)</td>
</tr>
<tr>
<td>England</td>
<td>12</td>
<td>164.3 ± 5.6</td>
<td>60.6 ± 3.8</td>
<td>23.0 ± 1.9</td>
<td>Reilly &amp; Bretherton (1986)</td>
</tr>
<tr>
<td>England (county)</td>
<td>12</td>
<td>162.5 ± 5.7</td>
<td>61.0 ± 5.6</td>
<td>22.7</td>
<td>Cheetham &amp; Williams (1987)</td>
</tr>
<tr>
<td>England (provincial)</td>
<td>43</td>
<td>164.6 ± 5.0</td>
<td>60.2 ± 5.2</td>
<td></td>
<td>Bale &amp; McNaught-Davis (1983)</td>
</tr>
</tbody>
</table>

apparent when the frequent demands to change pace and direction in a game context are considered. Indeed Reilly and Bretherton (1986) reported that anaerobic power was successful in discriminating between elite and county level players, the higher performances being by the elite squad. In this study, the elite players were also superior to county players in standing broad jump (200 ± 18 vs 180 ± 17cm), vertical jump (40.3 ± 6.0 vs 36.6 ± 4.2cm) and vertical velocity in a stair run test (1.39 ± 0.13 vs 1.25 ± 0.10 m/sec). There were also differences in knee extension strength (98.0 ± 26.6 vs 89.8 ± 15.4kg), and left (35.1 ± 5.9 vs 33.0 ± 3.5kg) and right (38.2 ± 3.9 vs 35.2 ± 4.3kg) grip strength values.

Principal components analysis of fitness data on 24 female hockey players identified components related to anaerobic power and dribbling speed which were significantly correlated (r = 0.694). The ‘dribbling speed’ component incorporated a 50-yard (45.5m) sprint and a 60-yard (54.6m) run over a ‘T’ shaped course whilst dribbling a hockey ball around skittles (Reilly & Bretherton 1986). ‘Dribbling speed’ was found to discriminate between levels of play, indicating that dribbling the ball at speed is important in hockey. The relation with the run time suggests that sprinting ability is necessary to execute dribbling skills at speed.

In view of the large muscle mass involved in hockey, strength testing should entail measurement of multiple muscle groups. Strauss et al. (1986) examined 17 members of the Australian Institute of Sport female hockey squad using an isokinetic dynamometer (‘Kin-Com’). Knee flexion and knee extension ratios were calculated for dominant and nondominant limbs, during concentric and eccentric actions at slow (60°/sec) speeds. Mean ratios varied between 0.55 and 0.61 and did not differ significantly between limbs, mode or speed of muscle contraction. Ratios for forearm supinator and pronator strength (calculated from average power values and also from torque at a constant joint angle) were much more variable, depending on the side of the body and the calculation procedure. Although flexor-extensor ratios may be useful in screening leg musculature for a balanced development of strength in hockey players, the same cannot be stated for forearm musculature.

5.3 Aerobic Factors

The maximal oxygen uptake (\(\dot{V}O_{2\text{max}}\)) is generally taken to be the best indicator of maximum aerobic power. The mean \(\dot{V}O_{2\text{max}}\) of elite female hockey squads reported in the literature (table II) ranges from 45 to 59 ml/kg/min (Reilly & Secher 1990). This is comparable to values reported for lacrosse players but below the range given for cross-country skiers and orienteers. Softball and netball internationals tend to have lower values than the hockey players.

The elite English squad players had mean values of 46 ± 9 ml/kg/min which distinguished them from county players who had mean values of 41 ± 6 ml/kg/min (Reilly & Bretherton 1986). These figures were predicted from heart rate responses to a submaximal cycle ergometer test. American (Zeldis et al. 1978) and Australian (Withers & Roberts 1981) international players demonstrated mean values of 50 ml/kg/min.
Although $\dot{V}O_{2\text{max}}$ is amenable to a training effect, the order of magnitude of the improvement is only about 25 to 30% (Åstrand & Rodahl 1986). Nevertheless this range could account for the spread of values reported for top players, reflecting the phase of the competitive season and the training status of players. The study of the Canadian Olympic team in the year leading up to the Los Angeles Olympics showed that the $\dot{V}O_{2\text{max}}$ improved in this time from 52.7 ± 6.0 to 55.7 ± 4.5 and finally to 59.3 ± 4.1 ml/kg/min just before the tournament. The higher values reported during peak training periods may be partly attributable to the loss of bodyweight as fat due to training and to expression of aerobic power relative to bodyweight. In the year’s build-up to the Los Angeles Games the average percentage bodyweight as fat fell from 18.9 to 15.7%. This factor alone would account for 25% of the change reported in $\dot{V}O_{2\text{max}}$.

Typically, intensification of the training programme of hockey players entails superimposition of specific drills on the normal regimen. The mean $\dot{V}O_{2\text{max}}$ of Welsh international players was 54 ml/kg/min in the early stages of planning for the Intercontinental tournament (Reilly et al. 1985). The squad had a good background of match-play and endurance, and general fitness training in the 2 months prior to measurement, which took place 3 months before the tournament. The training programme from then on was designed to maintain this level of aerobic fitness but introduced intense elements of sprint training into the programme. When remeasured in the month of the competition, the $\dot{V}O_{2\text{max}}$, $\dot{V}E_{\text{max}}$, % body fat, ventilatory threshold and anaerobic capacity were unaltered. Significant improvements were observed in flexibility and in sprinting speed. The conclusion was that flexibility and anaerobic power could be improved in preparation for major competition without detrimental effects on aerobic fitness.

Similar findings were noted in English county players by Cheetham and Williams (1987). The players completed 6 weeks of high intensity training which included 4 or 5 training sessions per week (2 fast runs between 5 and 9km approximately, 2 interval sessions which involved repeated runs of 30 to 300m and at least 1 circuit training session) in addition to their normal hockey commitments of 1 to 2 skill/tactical sessions and 1 to 2 matches per week. The improvement in $\dot{V}O_{2\text{max}}$ was small, from 50.1 ± 4.1 to 52.2 ± 3.7 ml/kg/min. These figures compared with values of 43.9 ± 2.5 and 44.9 ± 2.7 ml/kg/min for club players measured at the same times but who did not take part in the supplementary training. Aerobic rather than anaerobic factors were found to distinguish between the 2 levels of play. Peak blood lactate levels measured 5 minutes after a 30-second all-out treadmill sprint were similar, being 15.4 ± 2.2 and 14.9 ± 1.7 mmol/L for the county and club players, respectively.

The predominance of aerobic over anaerobic factors in the physiological make-up of female hockey players is further suggested by results of muscle biopsy studies. Prince et al. (1977) reported that female college players possessed a significantly higher proportion of FOG and SO skeletal muscle fibres than controls. The extent to which this trend was due to endowment or training could not be established.
Pulmonary and cardiac function data have also been reported for female hockey players. The vital capacity of players studied by Reilly and Bretherton (1986) was 17.6 and 16% better than normal values matched for age, gender and body size for the elite and county squads, respectively. Corresponding values for FEV₁ were 14 and 13% above expected. The highest maximum minute ventilation (VEmax) measured on the Canadian national squad (Ready & van der Merwe 1986) was just prior to the Olympic tournament when a mean figure of 96.4 ± 10.7 L/min was attained. The maximal heart rates were 195 ± 9 beats/min. The mean VEmax of the Wales team (Reilly et al. 1985) was 100.3 ± 19.2 L/min. The maximal heart rate for the whole sample of English players (elite and county) studied by Reilly and Bretherton (1986) was 192 ± 7 beats/min, a figure close to general population values.

The ventilatory threshold indicates the point at which in an incremental exercise test the ventilation (Ve) increases disproportionately to the increase in oxygen consumption (VO₂). This is assumed to represent the approximate upper limit at which aerobic exercise can be sustained. The ventilatory threshold was measured in the Welsh international players at 76.8 ± 6.6% of VO₂max (Reilly et al. 1985). This figure is thought to represent a good training status, comparing favourably with values expected of good distance runners.

The physical working capacity at a heart rate of 170 beats/min has conventionally been used as a measure of submaximal endurance. The PWC₁₇₀ of England elite squad members was found to be 2.3 W/kg compared to 2.0 W/kg for county players (Reilly & Bretherton 1986). Mean PWC₁₇₀ values were about 24% better in the elite squad than in sedentary females (Davies & Daggett 1977). The average for the Welsh internationals was 2.87 W/kg, recorded after they had a good background of match-play and fitness training. It seems that aerobic fitness does exert an influence on the standard of play in female hockey players and so aerobic training should form an essential part of the preparation for competitive match-play.

6. Fitness Profiles: Men’s Hockey
6.1 Anthropometry

In a review of competitors at the 1964 Olympic Games in Tokyo, Hirata (1966) concluded that the physique of male hockey players was almost the same as that of soccer players. He considered that the peak age for ball players was at 24 to 27 years, soccer success being accomplished earliest and hockey latest. Although training programmes for games players have improved considerably in the intervening quarter of a century, hockey is still a largely amateur game and social pressures rather than aging processes determine the duration of top players’ careers and the fitness levels they reach and maintain.

The mean height and weight of the Indian gold medal winning team at the Tokyo Olympics were 173cm and 69.2kg (Hirata 1966). The Pakistan and all the non-Asian teams were taller and heavier than this. The small size of Indian international (Bhanot & Sidhu 1981) and national police team (Sidhu et al. 1989) players reported in other studies (table III) reflects the smaller stature and body mass of the Asian population rather than elite hockey players. The elite South African players studied by Scott (1991) had a mean height of 176.3 ± 6.5cm and body mass 75.2 ± 8.1kg.

The data reported for 16 Argentinian players at the 1968 Olympics in Mexico provide a clue about how fitness requirements for that level of play might have changed since then. The anaerobic power (corrected for bodyweight) on a stair run test was no better than that observed in sedentary people aged 20 (di Prampero et al. 1970). All groups of athletes, except for swimmers, rowers and hockey players, were superior to the reference population. This led the authors, rather hastily, to the conclusion that hockey players do not have to rely on anaerobic sources of energy during their performance. A glance at the data for percentage body fat shows that only the rifle shooters had a higher figure for fat: this suggests that at this time hockey skills must have predominated in choosing squad members to the virtual neglect of fundamental fitness factors.
Sodhi and Sidhu (1984) compared Indian state-level hockey players with counterparts in soccer. The forwards, backs and halfbacks in hockey had larger anthropometric measures and had more lean tissue in their limbs compared with analogous positions among the footballers. For all outfield positions the hockey players had more fat and were heavier relative to stature than the Indian state soccer players. This finding is supported by Withers et al. (1977) who found that male South Australian state hockey players had marginally higher percentage body fat than a comparable group of state soccer players (16.7 vs 15.7). A later study by the same research group (Withers et al. 1987b) reported a mean of 10.3% body fat for state hockey players, a figure still higher than the 9.7% for a comparable sample of soccer players. The lower values in the latter study could reflect more intensive training over the intervening decade. It might be partly accounted for by a different methodology, skinfold thicknesses and underwater weighing in the first and second studies, respectively. The soccer goalkeeper in the first study (Withers et al. 1977) was bigger than the goaltender in hockey but lighter relative to stature: this would be beneficial in defending the larger goal area in soccer.

The mean percentage body fat of the 162 elite players from 12 South African club teams competing at the Senior Provincial tournament was 11.1 ± 3.3%. There was a relation between the mean percentage body fat for the team and its finishing position in the tournament.

The mean somatotype of the Indian state level players studied by Sodhi and Sidhu (1984) was 3.3: 3.8: 2.8. The average of 32 national probables for the Indian team was found to be 3.6: 4.1: 2.9 and that of 16 players on the Pakistan national team was 2.8: 4.3: 2.5. Olympic players of other leading countries were more mesomorphic than the Asian players, as were the South African top club players (2.2: 5.3: 2.3) studied by Scott (1991). The fullbacks of the Indian and Pakistan national players were described as endomorphic-mesomorphs (Chinnappa 1988). The goalkeeper of the Indian state-level players (Sodhi & Sidhu 1984) was the most endomorphic and the least mesomorphic. The rating for mesomorphy at this level was highest among the fullbacks but forwards and halves were close to them in this respect. There seems to be a trend in physique in top male hockey players towards mesomorphy and away from ectomorphy that is similar to observations in female hockey players.

Grip strength may have importance in handling the stick during practice and competition. Scott (1991) reported greater grip strength values in South African players (54 ± 8kg) than in male college students. Although most of the players were right-hand dominant, the difference between left and right grip strength was insignificant. This was thought to reflect the fact that players have to use both hands, or either hand unilaterally, in controlling the hockey stick during a game.

### 6.2 Aerobic Factors

Of the male hockey players reviewed by Reilly and Secher (1990) the range of the average values of \( \dot{V}O_{2\text{max}} \) for teams was from 48 to 65 ml/kg/min. The lowest value was obtained on the Argentinian team at the Olympic village in Mexico in 1968, but on a step test (di Prampero et al. 1970). The figure for top German players measured at the Köln Institute for Circulatory Research and Sports

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**Table III. Anthropometry of national men's hockey teams. (Values are mean ± SD. Body fat was not measured.**

<table>
<thead>
<tr>
<th>Country</th>
<th>n</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>17</td>
<td>180.7 ± 5.1</td>
<td>75.9 ± 4.6</td>
<td>Telford et al. (1988)</td>
</tr>
<tr>
<td>Spain (B and Junior)</td>
<td>24</td>
<td>176.0 ± 4.5</td>
<td>70.6 ± 7.2</td>
<td>Drobnic et al. (1989)</td>
</tr>
<tr>
<td>India (National Police team)</td>
<td>27</td>
<td>168.7 ± 5.9</td>
<td>61.0 ± 5.4</td>
<td>Sidhu et al. (1989)</td>
</tr>
<tr>
<td>India</td>
<td>27</td>
<td>62.7 ± 5.4</td>
<td></td>
<td>Bhanot &amp; Sidhu (1981)</td>
</tr>
</tbody>
</table>
Medicine by Rost (1987) was estimated from a graphical presentation of results (table IV). The results were comparable with observations on top German tennis players and middle-distance runners and were greater than values for handball players, ice-hockey specialists, decathletes and gymnasts. Withers et al. (1977) found a mean \( \dot{V}O_{2\text{max}} \) of 64.1 ml/kg/min amongst the South Australian state hockey team. It seems that values in excess of 60 ml/kg/min are required of top field hockey players and this respect they feature close to the aerobic power of professional soccer players (Reilly 1990).

Heart size was also recorded in top Germany hockey players and compared with values in other sports specialists (Rost 1987). The heart size of the hockey players was close to that found in soccer players and greater than that noted in ice-hockey, handball and gymnastics specialists. Greater heart dimensions were observed in decathletes who might be expected to have the much more arduous training programmes.

The maximal minute ventilation of the Senior B and Junior Internationals of Spain measured by Drobnic et al. (1989) was 148.4 ± 10.9 L/min. These values compare favourably with those observed in professional soccer players (Reilly 1990).

6.3 Anaerobic Factors

Apart from a high aerobic power the game of hockey demands that the player has the capability to accelerate and decelerate quickly. It is acceleration that is critical to hockey performance rather than maximal speed. In an analysis of a variety of state level Australian sportsmen, Withers et al. (1977) found that hockey players had a mean absolute leg power of 1132W (115.54 kpm/sec), as measured on a stair test. The relative value was 15.2 W.kg (1.56 kpm/kg/sec). This compared favourably with state footballers (1233W, 16.1 W/kg), basketball players (1180W, 14.1 W/kg) and runners/walkers (965W, 14.0W/kg).

Scott (1991) used the standing broad jump in measuring top South African club players. The mean value of 2.3 ± 0.18m was considered ‘very good’ according to reference norms.

Both aerobic and anaerobic data suggest very strongly that the physiological profile of the hockey player is similar to that of the soccer player.

7. Training

Data on the most appropriate training regimens for hockey are sparse. Nevertheless, analysis of the literature presented in earlier sections indicates quite clearly that there is a significant aerobic contribution to energy expenditure in field hockey. This is evident in the levels of \( \dot{V}O_{2\text{max}} \) achieved by both male and female hockey players (Reilly 1990; Reilly & Bretherton 1986; Rost 1987; Withers et al. 1977). Training must, therefore, reflect the high aerobic demand of elite play with great emphasis being placed upon the development of aerobic capacity. The increased speed of movement demanded by synthetic surfaces would indicate that the majority of aerobic training needs to be done over shorter distances 5 to 9km) at high pace, or using interval sessions with high intensity 800 to 400m repetitions. Cheetham and Williams (1987) found an in-

<table>
<thead>
<tr>
<th>Level of play</th>
<th>n</th>
<th>( \dot{V}O_{2\text{max}} ) (ml/kg/min)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provincial (Australia)</td>
<td>9</td>
<td>64.1</td>
<td>Withers et al. (1977)</td>
</tr>
<tr>
<td>Provincial and national (Australia)</td>
<td>14</td>
<td>60.7</td>
<td>Roberts &amp; Morton (1981)</td>
</tr>
<tr>
<td>National (United Kingdom)</td>
<td>20</td>
<td>62.2</td>
<td>Hargreaves (1983)</td>
</tr>
<tr>
<td>National (West Germany)</td>
<td>5</td>
<td>63.5</td>
<td>Rost (1987)</td>
</tr>
<tr>
<td>National Senior B and Junior (Spain)</td>
<td>26</td>
<td>59.7</td>
<td>Drobnic et al. (1989)</td>
</tr>
</tbody>
</table>
crease of 2.1 ml/kg/min in $\text{VO}_2\text{max}$ following a 6-week programme of 2 fast runs (5 to 9 km) and 2 interval sessions (30 to 300 m) per week.

On top of the high aerobic power the elite hockey player must also possess significant anaerobic power. The game requirements are for frequent, high intensity bursts of activity involving acceleration, deceleration and turning movements. A high peak power output from the leg is, therefore, an important part of the physiological profile of the elite player. Unfortunately, no specific data are available on the effectiveness of sprint training regimens in improving sprint time and match performance in field hockey. However, male hockey players have been shown to have similar leg power profiles to male soccer players (Withers et al. 1977). It is, therefore, likely that sprint training regimens successfully utilised by soccer players will also be beneficial to hockey players. In this respect it has been shown that the use of short (30 m) sprints, with maximally explosive starts and a work : rest ratio of 1 : 5 improved sprinting speed in male soccer players (Apor 1988). It is probable that this style of training would also be beneficial to field hockey players.

8. Daily Energy Expenditure

The severity of the training programme of top level sports performers is reflected in extraordinarily high daily energy expenditure values. The energy intakes of cyclists, distance runners and weight-throwers may approach 30 MJ/day (7000 kcal/day) to furnish fuel for their high energy outputs. Grafe (1971) considered that an intake of 23 MJ (5600 kcal) daily was a satisfactory provision for field hockey players. This referred to male players and a similar intake was advised for basketball and handball specialists. In view of the relatively moderate training regimens of players at the time these figures may have overestimated the real requirements.

More recent figures give an actual energy intake of 181 kJ/kg/day for elite male hockey players. For a 75 kg individual this amounts only to 13.6 MJ (3250 kcal). The figure was below that for soccer players (192 kJ/kg/day) and water-polo players (194 kJ/kg/day). Values for female players were 145 kJ/kg/day or 8.7 MJ (2080 kcal) for a 60 kg individual (Erp-Baart et al. 1989). This figure was marginally above that for volleyball (140 kJ/kg/day) and handball (142 kJ/kg/day) players. These values were derived from recordings in food diaries over 4 to 7 days. It has been acknowledged that such recordings often underestimate the energy requirements (Westerterp & Saris 1991).

The activity profiles during match-play over 70 minutes do not suggest that muscle glycogen stores in limb muscles would be depleted at the end of a game. Consequently, glycogen-loading protocols as used in endurance events do not seem necessary. An exception might be made in the case of frequent competitions during hockey tournaments or after prolonged training sessions in training camps. In these instances a high carbohydrate diet for replenishment of muscle glycogen stores would safeguard against starting subsequent competitive engagements with inadequate energy reserves.

9. Physical Strain

In field-invasive games such as hockey, the skill requirements and postural stress are superimposed on the work-rate demanded by the game and its pattern of play. This is accentuated in players as they dribble the ball or move in a semicrouched posture. This position of spinal flexion has been described by Fox (1981) as an ergonomically unsound position for fast locomotion. It may be implicated in risk of back injury. Indeed, Cannon and James (1984) reported that over a 4-year period, 8% of patients referred to a clinic for athletes suffering from back pain were hockey players. A survey of local male hockey clubs in the Merseyside region showed that 53% of respondents reported experience of low back pain (Reilly & Seaton 1990).

A biological effect of the postural stress during hockey play and practices is at the level of the intervertebral disc. Compressive loading of the discs causes them to lose height, water being extruded from the disc when the compressive load on it exceeds the interstitial osmotic pressure. The result
is a change in total body length, known as shrinkage, which can be measured using high resolution stadiometry (Troup et al. 1985). Shrinkage induced during an experimental 7 minutes whilst dribbling a hockey ball on a motor-driven treadmill at a speed of 8.5 km/h was investigated by Reilly and Seaton (1990). Loss of height was found to occur at a rate of 0.4mm/min which was greater than previously reported for other physical activities. The rate of shrinkage was about 4 times that observed in running and almost twice that found in circuit-weight training (Leatt et al. 1986). Although the comparison does not make allowance for the longer period of exercise in the running and weight-training experiments, nor the discontinuity of the spinal flexion posture in match-play and training practices, the indication is that spinal loading while dribbling is greater than in normal locomotion. There are indications also that attention to training of back strength (Wilby et al. 1987) and flexibility (Garbutt et al. 1990) may have a protective role to play in attenuating the risk of back injury to hockey players. Recovery procedures for unloading the spine, notably gravity inversion and Fowler’s posture, adopted before and after exercise or during intermissions, may also be helpful in this respect (Leatt et al. 1985). Such inferences may be made both for male and female players.

Games players have been shown to run faster on synthetic surfaces than on grass, partly because of the evenness of the surface (Stanitski et al. 1984). However, the grass surface absorbs 10% more energy, contributing a greater cushioning effect on each impact with the ground. Additionally, turning is more difficult on a synthetic pitch (Malhotra et al. 1983). Thus, the synthetic surface might have a greater risk of injury during hockey play. Jamison and Lee (1989) compared injury statistics for the 1984 Australian National Women’s Championships played on grass with those for the year following when the competition was on Astroturf. Soft-tissue injuries were found to be more frequent on Astroturf and joint injuries more frequent on grass. Overall injuries were higher on Astroturf and this led authors to recommend that players should be made aware of how the different surfaces affect their style of play with consequent injury risk.

Fig. 2. Field tests for assessment of fitness of female hockey players incorporating dribbling (from Reilly & Bretherton 1986).
10. Field Tests

Although hockey has been a part of the physical education curriculum in Europe and North America since the beginning of the century, there has been little attention given to the design of field tests for the game. Some tests designed for US College Women incorporated a dribble, dodge, circular tackle and drive (Wessel & Koenig 1971).

Other nonstandardised tests were built around 2 or more of the fundamental games skills, but failed to produce the physiological stress under which skills are executed in match-play.

Reilly and Bretherton (1986) used 2 field tests in their evaluation of English elite female players. The first was a ‘T’ run over a 60 yards (54.5m) course, dribbling a leather ball around skittles (fig. 2). The test involved as many circuits of the ‘T’ shaped course as possible in 2 minutes. According to Astrand and Rodahl (1986) sports which engage large muscle groups for 1 minute or more may tax \( VO_{2\max} \) and so this test implies a high aerobic loading. The use of reversed sticks is excluded and the best of 3 trials is recorded. Performance on the test was found to correlate significantly both with aerobic \( r = 0.48 \) and anaerobic \( r = 0.6 \) power and to differentiate between elite and county level players.

The second field test was a distance and accuracy test (Reilly & Bretherton 1986). This entailed a combination of dribbling a ball and hitting it at a target, a set sequence being repeated as often as possible within 2 minutes. Distance travelled was measured to the nearest 2.5 yards (2.27m) and relative accuracy was calculated by the number of accurate shots as a percentage of the number of hits (fig. 3). Accuracy on this test was significantly related to somatotype of subjects, the correlation between ectomorphy and accuracy being \(-0.63\).

Many hockey practitioners may find it convenient to eliminate hockey skills from field tests in evaluating fitness of players. In such instances sprint times over 50 yards or 50m (Reilly and Bretherton 1986) and the 20m shuttle run test to predict \( VO_{2\max} \) are examples of feasible tests. It should be recognised that these are dependent on motiva-

Fig. 3. Field tests for assessment of fitness of female hockey players incorporating speed and accuracy (from Reilly & Bretherton 1986).

11. Overview

It appears that a considerable amount of data has been generated in an attempt to describe anthropometric and physiological characteristics of hockey players. This applies both to female and male competitors, and reflects the counselling services available to sports associations at sports science laboratories and the attractions of squads towards fitness assessment. Such profiles need to be interpreted with caution, as competitive level, stage of the season, player position and other factors need to be considered.

In contrast there have been relatively few attempts to measure directly the physiological demands of match-play in field hockey. Nevertheless


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